Collapsible Coffee Maker
Team #2

Final Report
ME 450
Section 002
Professor Yoram Koren
Sponsor: April Bryan
12-11-2007

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ABSTRACT

Seventy-five percent of Americans drink coffee daily, making coffee makers some of the most used appliances in everyday life. However, due to their bulky and rigid structures, existing coffee makers are not easily transportable. The National Science Foundation Engineering Resource Center for Reconfigurable Manufacturing Systems has presented the task to develop a collapsible coffee maker design, manufacture a prototype of said design and present the results at the College of Engineering Design Expo on December 4th, 2007. Using market research, qualitative modeling and quantitative engineering analysis, our team developed a product which meets all the requirements of the proposed project.

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1. Introduction

The purpose of our project is to design a portable coffee maker and manufacture a prototype of this design. The motivation for this project came from April Bryan, of the National Science Foundation‘s (NSF) Engineering Research Center (ERC) for Reconfigurable Manufacturing Systems (RMS). After noting the rigidity and bulkiness of present coffee makers, Ms. Bryan presented us with the task of creating a new design that would allow the user to easily carry it with them. This was seen to have a potential market among college students who would like coffee but lack access to it while studying in places such as a library.

1.1 Basic Requirements

April Bryan established several requirements for our design during our first meeting. The first requirement was that our coffee maker needed to be travelable, meaning that it would be lightweight, completely sealable, and small enough to fit in a backpack. It was also established that our design must be capable of brewing two cups, or 16 fl oz. of coffee. Our final design and the resulting prototype are to be presented to April Bryan and the public at the University of Michigan-College of Engineering Design Expo on December 4th, 2007.

2. Information Search

In order to successfully design a coffee maker, we began the design process with an information search on coffee brewing methods and a search for similar products and patents. We then performed some physical testing on similar products and dissected them. Finally, we began doing some initial research on the possibilities for conceptual designs.

2.1 Methods of Brewing Coffee

The methods of brewing coffee vary according to how the water and coffee grounds come into contact. Most methods involve running near-boiling water through the coffee grounds and then through a filter. The strength and taste of the brew can depend on the method used, due to the amount and type of components in the coffee maker. Because personal preferences for brew style can vary greatly, we have decided to focus on the three most popular brewing methods.

Drip-brew. The drip-brew coffee method typically starts by rapidly heating water through a tubular heating element. The water is then boiled and the resulting water vapor passes through a one-way valve. The vapor then cools back to liquid, and is eventually forced up and dispersed over the coffee grounds. The water passes through the grounds, and then a filter typically made of paper or metal, before finally entering a pot. This pot is usually kept warm by a hotplate utilizing the same heating element used to boil the water.

Percolator. Percolating coffee makers share some of the same principles as the drip-brew, however the major difference is that the water passes through the coffee grounds multiple times. After boiling, the water is again forced up a tube, typically made of metal and placed in the center of the pot. The vapor then cools to water, passes over the coffee grounds and through a metal filter before returning back into the original reservoir of water. This process is repeated until sufficient time has passed, or until the user stops the process when the desired color of coffee has been reached.

French Press. The French press method is perhaps the simplest. Coffee grounds are added to a pot with a plunger device. Boiling water is then added to the pot, so the coffee grounds and water are in direct contact with each other without the use of a filter. After sufficient time has passed, the grinds are then separated from the brew using the plunger device.

2.2 Patent and Products Search

In order to get a better idea of the types of products on the market similar to the one we are trying to design, we performed a patent search. Although we could not find any patents for products exactly like ours, we did find some similar ones. Patent # 4,382,402 titled "Portable Coffee Maker", issued on May 10th, 1983, is a coffee maker designed for use in cars and uneven surfaces (Figure 1 below). It is powered by the vehicle battery through the cigarette lighter. It uses the drip-brew method with prepackaged water and coffee ground pods. The only other patent we found pertaining to portable coffee makers is merely an ornamental design issued on March 28th, 2000, with the patent # D 421,871 (Figure 2 below).

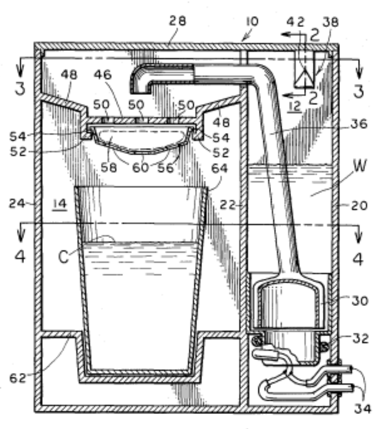


Figure 1 – # 4,382,402 [1]

Figure 2 - # D 421,871 [1]

We also performed a simple search on www.amazon.com and at local retailers for similar products. The only results we found were the Zelco Brisk Brew Travel Coffeemaker and "Brew and Go" devices like the Black & Decker DCM182 Brew 'n Go Personal Coffeemaker. The Zelco model came closest to the type of product we had in mind, although it produces less coffee and is not completely sealable for transporting purposes (Figure 3, page 3). The “Brew and Go” style coffee makers are typically simple drip-brew makers that brew into a travel mug as opposed to a coffee pot (Figure 4 below). Only the travel mugs in these products are “portable”, not the entire coffee brewing machine.

Figure 3 – Zelco Brisk Brew [2]

Figure 4 – Brew and Go [2]

2.3 Benchmarking and Product Dissection

We tested 4 drip-brew coffee makers to get an idea of some of the engineering parameters of current products on the market. We tested Mr. Coffee TF4, Sanyo SAC-MSTF6, Braun Type 3075/KF12, and Cuisinart Grind & Brew. Table 1 below summarizes our results. The errors were determined by simply taking twice the standard deviation of the measurements. Appendix A contains the results of our tests in more detail.

Table 1 - Benchmark Results

Parameter	**Average**
Output Temperature	132 ± 6 ºF (56 ± 4 ºC)
Reheat Temperature	140 ± 7 ºF (60 ± 4 ºC)
Brew Time	4 min 1 ± 28 sec
Liquid Absorbed in grounds	0.25 ± 0.12 cups (59 ± 29 mL)

We then dissected both the Mr. Coffee TF4 and the Sanyo SAC-MSTF6 coffee makers to get a hands-on view of not only how they operate, but also to better understand some of their design features.

2.4 Design Research

Our final information search dealt with our particular design. We wanted to get an idea of the types of design features that were plausible for our conceptual designs. We performed a basic internet search for things like optimal brewing temperature and plausible power supplies and heating elements. We found the optimal brewing temperature to be 91 – 96 ºC (approximately 195-205 ºF).[3]

Our initial thought for a portable coffee maker was to make it battery or USB (Universal Serial Bus) powered. After some preliminary calculations (see Appendix B), however, we realized that this would require a heating element requiring approximately 400-600 W. These levels of power are simply unreasonable from sources such as batteries or USB power which range only from about 2.5 to 13 W. [4]

We further performed research on heating elements. The most plausible elements heat by simply running current through high resistances. These can either have the water run through them or they can be submerged in water, depending on the design.

3. Customer Requirements and Engineering Specifications

Table 2 below shows our customer requirements with their corresponding engineering specifications. These customer requirements are the result of a survey of 52 University of Michigan students along with our sponsor requirements. Translations of customer requirements to engineering specifications using our Quality Functional Deployment (QFD) diagram can be seen below. Our QFD Diagram can be seen in Figure 5 page 7.

Table 2 - Customer Requirements and Engineering Specifications

Customer Requirement	Engineering Specification	Target Value
Safe	Number of exposed hazards	0
Sealable for transport	Liquid volume leaked during transport	0 mL
Minimal transport volume	Machine volume during transport	2300 cm^3
Sufficient brew volume	Volume of coffee made with 1 brew	473 mL
Brew quality coffee	Brew temperature	93 °C
Brew coffee quickly	Brew time	5 minutes
Easy to clean/maintain	Number of removable parts	6
Affordable	Retail price	$35
Sufficient coffee ground volume	Volume of coffee grounds	40 cm^3 (2 2/3 tbsp.)
Lightweight	Machine weight	1.8 kg
Reheat Option Available	Reheat temperature	60 °C
Minimal noise when brewing coffee	Decibel level when brewing	50 dB
Visibly pleasing	Number of colors available	4

3.1 Translating Customer Requirements to Engineering Specifications and Target Values

Safe. To ensure that the coffee maker is safe for use, we decided to minimize the number of exposed hazards. Furthermore, because this requirement ranked highest on our survey and is also a requirement of our sponsor, we decided that there must be zero exposed hazards.

Sealable for transport. We assumed that the coffee maker will be transported in a backpack and do not want any of the other objects inside the pack to be damaged by the coffee maker. Thus, we decided that the volume of liquid leaked when transporting the coffee maker should be 0 mL to ensure no damage to the customer's belongings.

Minimal transport volume. To transport the coffee maker, it will be in a compact or collapsible form and presumably stored in a backpack. Thus, we want to minimize the volume of the compact form of the coffee maker, and decided to have the total travel volume around the size of an average book. After investigating and recording several book volumes, we found an average book volume of approximately 2300 cm^3.

Sufficient brew volume. The coffee maker must be able to brew 473 mL (2 volumetric cups) of coffee. This specification is a requirement of our sponsor as the minimum amount of coffee made from one brew.

Brew quality coffee. To achieve maximum flavor from coffee grounds, the water must be heated to a specific temperature before it passes through the grounds. After benchmarking current coffee makers and some initial research, we found an adequate brew temperature of 93 °C.

Brew coffee quickly. The coffee maker must be able to brew 473 mL of coffee in 5 minutes or less. This specification is a requirement of our sponsor as the minimum time to brew 473 mL of coffee.

Easy to clean/maintain. The coffee maker must be able to be cleaned easily. Thus, we decided to minimize the number of parts that will have to potentially be cleaned. Possible parts that may need cleaning are the filter, water tank, coffee pot, and machine stand. Because our coffee maker may be collapsible, it is probable that our machine stand will require more than 1 piece. Thus, we hope to have a maximum of 6 removable parts.

Affordable. From our survey, we found that an average college student spends $12 on coffee a week. To achieve a competitive price with current non-portable coffee makers and also be able to produce a quality coffee maker, we arrived at a price of $35. At this price, the coffee maker will pay for itself in approximately 3 weeks.

Sufficient coffee ground volume. The coffee maker must be able to brew a sufficient volume of coffee which requires a minimum volume of coffee grounds. To brew the minimum amount of coffee, 473 mL, 2 2/3 tbsp. (approximately 40 cm^3) of coffee grounds are required, according to coffee ground producers.

Lightweight. From our survey results, we found that college students have little preference about the weight of the portable coffee maker in comparison to a current coffee maker. Thus, to determine our engineering specification of weight, we took an average weight of several competitive coffee makers on the market today. We then set our maximum weight allowed to this value of 1.8 kg.

Reheat Option Available. According to our survey results, customers prefer coffee makers with a reheat option. We simply translated this customer requirement into a desired reheat temperature. We determined our target reheat temperature value by taking the average reheat temperature of the products we tested, resulting in 60 °C.

Minimal noise when brewing coffee. The environments that the coffee maker will be used in are quiet areas, so the decibel level emitted from brewing coffee should be kept to a minimum. We chose a maximum of 50 dB during brewing in order to ensure that the coffee maker will not cause any noise disturbances. This decibel level was chosen because it is the average noise level of an office setting.[5] We plan to test the decibel level using a decibel meter.

Visibly pleasing. From our survey results, we found that aesthetics are the least important factor to our customer base. Furthermore, because the intent of the coffee maker is to be able to travel and brew coffee, we decided that to be visibly pleasing, we should offer a moderate variety of colors. Current coffee makers generally come in 4 colors: black, white, red, and silver. To be competitive, we decided to also offer our coffee maker in these colors. Our survey results also showed that a cylindrically-shaped coffee maker was the most desirable (See Appendix F).

3.2 Quality Function Deployment (QFD)

Our QFD (Figure 5 below) summarizes our translation of customer requirements into engineering specifications.

Quality Function Development (QFD)

Key:

9 => Strong Relationship

3 => Medium Relationship

1 => Small Relationship

(blank) => Not Related

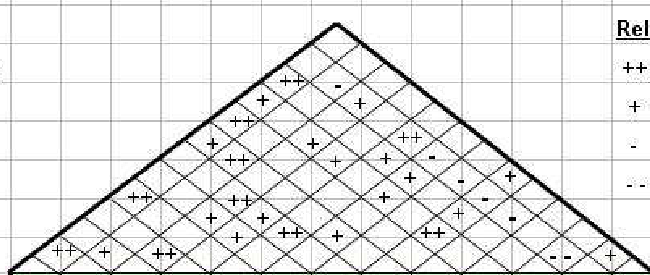
Relationships

++ Strong Positive

\+ Medium Positive

\- Medium Negative

\- - Strong Negative



***Weights are figured on a scale of 1 to 10** (ten being most important)

	Weight*	No. of Hazards (-)	Volume Leakage (-)	Volume of Coffee (+)	Volume of Grounds (+)	Brew Temperature (+)	Travel Volume (-)	Brew Time (-)	No. of Parts (-)	Decibel Level (-)	Weight (-)	Reheat Temperature (+)	Price (-)	No. of Colors (+)	*Mr. Coffee*	*Zelco Brisk Brew*	*Sanyo SAC-MST6*
Safe	10	9	3	3		9		1	3	3	3	9	3		3	2	3
Sealable for Transport	10	3	9	3	1		3		9		1	3	3		1	5	1
Transport Volume	10	1	3	9	3	3	9		3		9	1	3		1	5	1
Quality of Coffee	8			3	9	9		1				1	3		5	2	5
Sufficient Brew Volume	8	1	9	9	3	1	9	3			3	1			5	1	5
Quick Brew Time	8	1		9	1	9	3	9					3		4	3	5
Affordable	7	1	3	1		3	3	3	9	3	3	1	9	1	5	2	3
Easy Maintenance	7	1	3	1	3	1	3		9		1	3	3	1	4	5	4
Sufficient Coffee Ground Volume	5			9	9	1	3	3			1				5	1	5
Light Weight	5	3		3	1		9		3		9	3	9		4	5	2
Reheat Option	5	3		1		3	1		3		3	9	3		5	1	5
Low Noise	4	1				1		3		9		1			2	3	2
Visibly Pleasing	3	1	1	1		1	3		3			1	3	9	3	1	4
Measurement Unit		#	mL	mL	cm^3	°C	cm^3	s	#	dB	kg	°C	$	#			
Target Value		0	0	473	40	93	2300	300	6	50	1.8	60	35	4			
Importance Rating		**10**	**6**	**1**	**9**	**3**	**2**	**11**	**4**	**12**	**7**	**8**	**5**	**13**			
Total		197	267	400	215	327	332	162	315	87	247	241	291	41			
Normalized		0.06	0.09	0.13	0.07	0.10	0.11	0.05	0.10	0.03	0.08	0.08	0.09	0.01			
Mr. Coffee		2	N/A	710		-	N/A	231	3		1.7	61	25	1			
Zelco Brisk Brew		2	0	237			1229		6		0.9		50	1			
Sanyo SAC-MST6		2	N/A	1065		-	N/A	202	6		3.2	59	60	1			

Figure 5 - Quality Functional Deployment (QFD) Diagram

Correlations. After defining our customer requirements, their respective weights, and translating them into engineering specifications, we correlated the customer requirements and engineering specifications. The QFD illustrates the correlations in the middle box using the following value definitions: 9 = strongly related, 3 = somewhat related, 1 = weakly related, and blank = totally unrelated.

Cross-Correlations. Because changing an engineering specification can affect others, we cross-correlated each pair of engineering specifications. The QFD illustrates these correlations in the triangle at the top, using the following notation: ++ = strong positive, + = medium positive, - = medium negative, -- = strong negative, and blanks = totally unrelated. For example, as the volume of coffee increases, the brew time undoubtedly also increases, exhibiting a strong positive relationship. These cross-correlations were done to reveal indirect dependencies of customer requirements on engineering specifications.

Benchmarks and Competitor Values. In order to determine how well similar products currently on the market satisfy our customer requirements, we benchmarked 3 of these products. Each customer requirement for each product was ranked on a scale of 1 to 5, where 1 is "does not satisfy" and 5 is "satisfies perfectly". These rankings were based upon our personal experience and knowledge of the product, along with customer reviews from www.amazon.com. The QFD shows the results of these benchmarks down the right side. This benchmarking was done to reveal possible areas for improvements of our product.

Furthermore, from both our testing of these products and the specifications provided by the manufacturer, we provided their respective values for our engineering specifications at the bottom of the QFD.

Importance Ratings. The total weights of each engineering specification were found by summing the products of every correlation for a given specification with the weight of the corresponding customer requirement. These total weights were then normalized by dividing the total weight for a given engineering specification by the sum of all total weights across all specifications. Finally, these normalized weights were then translated into an importance rating, with the highest normalized weight being the most important and equal to 1.

3.3 Results of QFD

The most important customer requirements include safety, transport sealing ability, and transport volume. Safety of the user is always of the utmost importance when producing a potentially dangerous product. Furthermore, the purpose of our project is to produce a transportable coffee maker, so transport volume and sealing ability are the next important requirements. Transport volume is strongly correlated to both the travel volume and volume of coffee produced. Safety is also strongly correlated to brew temperature. Therefore, the top three engineering specifications include volume of coffee produced, travel volume, and brew temperature.

Engineering specifications related to manufacturing were also of high importance. These included specifications such as number of parts, price, and volume of leakage. Other important customer requirements include sufficient brew volume, quality of coffee, quick brew time, affordability, and ease of maintenance. Because these customer requirements and engineering specifications are most important, we concentrated on satisfying them during the conceptual design process.

4. Concept Generation

Figure 6 below shows a brief flow chart of our concept evaluation and selection process.

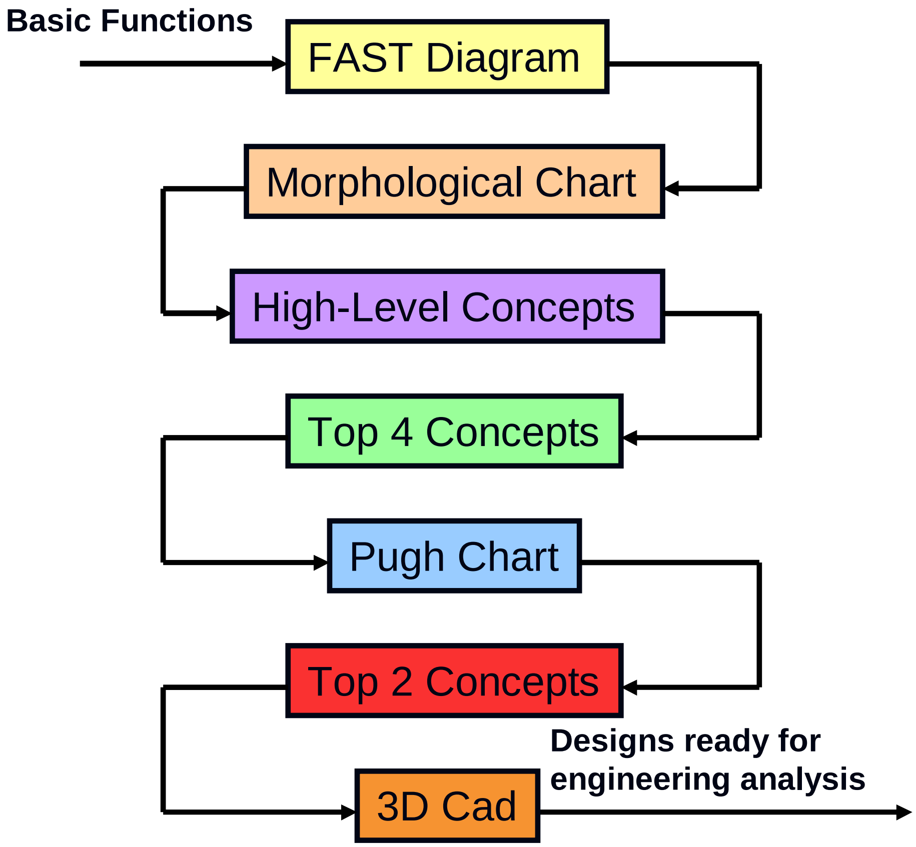


Figure 6 – Flow chart of concept evaluation and selection process

4.1 FAST Diagram

In order to begin the concept generation stage, we first needed to understand the basic functions of a coffee maker. We began by listing all of the functions performed by a coffee maker. We then selected one of these functions, "Brew coffee", as the task function because that is the overall function of the product. Next we categorized the basic functions, those required to accomplish the task of brewing coffee. These include boiling water, filtering and storing coffee. The primary supporting functions include assuring dependability by protecting the user, assuring convenience, enhancing the product, and pleasing the senses. We then expanded on these basic and primary supporting functions with other functions, until the function was fulfilled by the mere existence of an object or physical part. For example, the "Add heat" function can not be broken down further, because it is accomplished by the heating element of the coffee maker. The function "Simplify housing" is adequate because it is accomplished by collapsible parts and/or simply-shaped housing. The FAST Diagram (Figure 7 page 10) summarizes the results of this process.

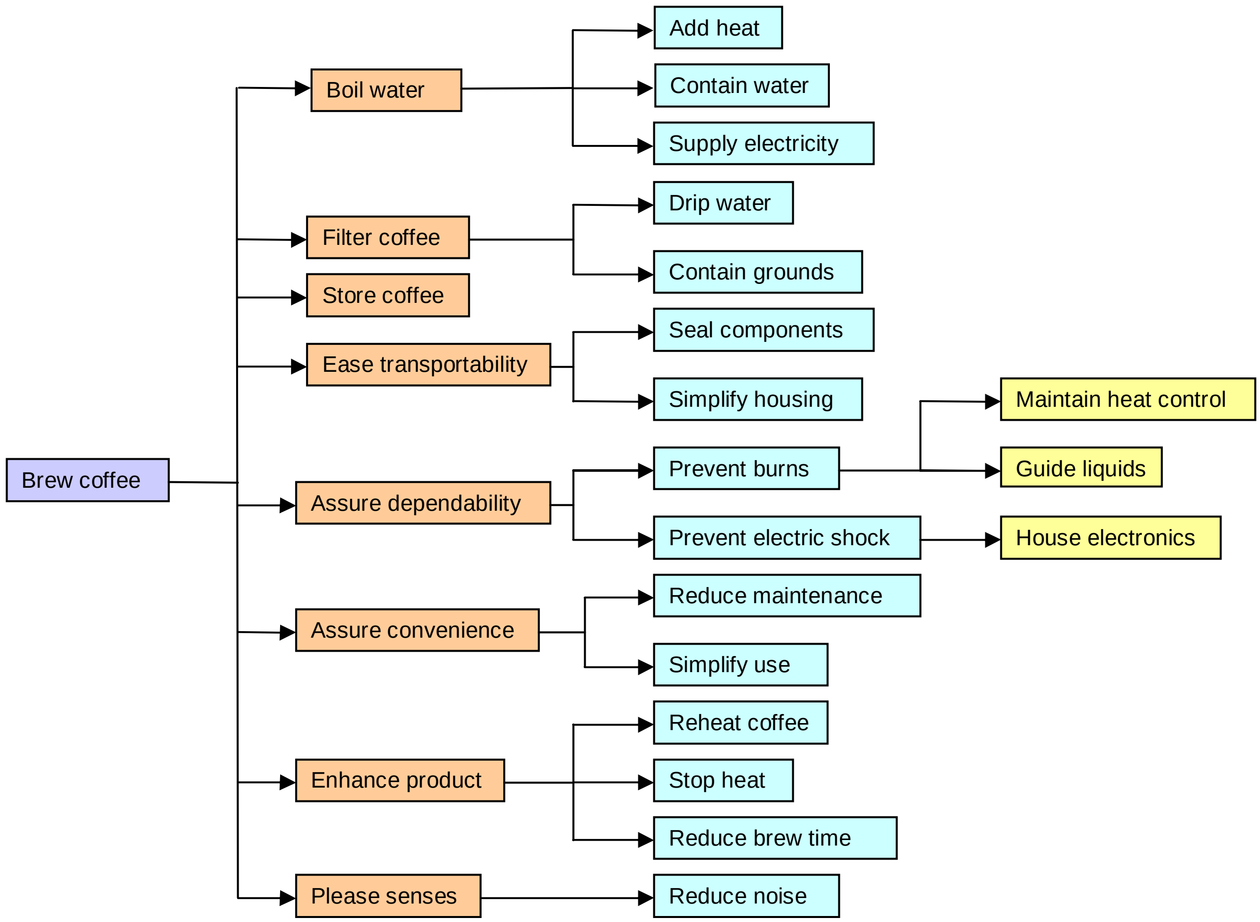


Figure 7 - FAST Diagram

4.2 Morphological Chart

Using the FAST diagram, we generated several options to accomplish each of the sub functions required of the final designs. These sub functions included the following:

- Add heat to water
- Disperse water to grounds
- Contain coffee grounds
- Maintain heat control
- House electronics
- Seal components
- Reduce noise
- Direct hot water
- Hold water/brewed coffee
- Reheat coffee
- Reduce maintenance
- Simplify housing
- Simplify use
- Reduce brew time

We organized the top two to three options for each function into a morphological chart (Table 3 below).

Because some of these concepts can be difficult to understand or differentiate, a more detailed morphological chart was generated. This morphological chart includes drawings of several of the functions (Table 4, page 12).

Table 3 - Morphological chart containing sub function options

Function	Option 1	Option 2	Option 3
Add Heat	Tubular Calrod	Submersible	Hot plate
Direct Water	Tubing	Gravity feed	Pump
Contain Water/Coffee	Single reservoir	Separate reservoirs	Funnel
Disperse Water	Drip-brew mechanism	Percolating mechanism	French press
Contain Grounds	Paper filters	Metal filter	Mesh filter
Reheat	Detachable/Separate	Internal/Shared	
Reduce Maintenance	Disposable filter	Removable permanent filter	Removable Cup
House Electronics	With heat source	Separate from heat source	
Maintain Heat Control	On/Off switch	Automated controls	Manual controls
Simplify Housing	Collapsible	Simple shapes	
Seal Components	Storage container	Threaded components	Latched components
Simplify Use	Automated controls	Prepackaged supplies	Non-collapsible
Reduce Noise	Noise damping material	Internal brew mechanism	
Reduce Brew Time	Larger heating element	Minimized tubing length	Larger tube diameter

Table 4 - Detailed morphological chart including drawings

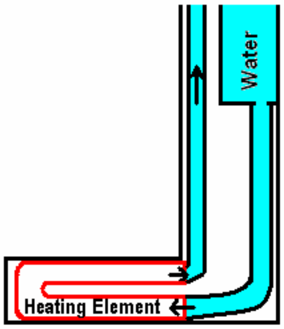
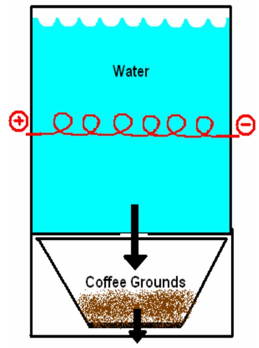
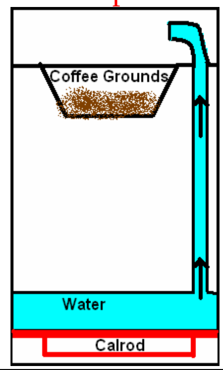
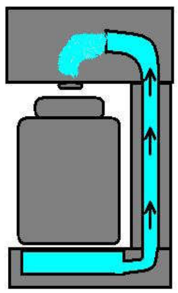
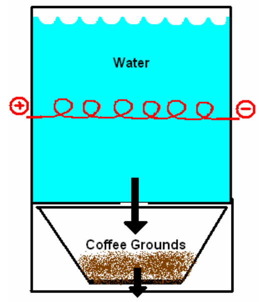
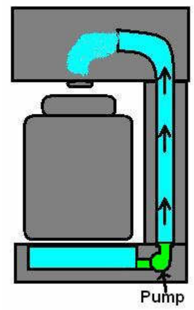
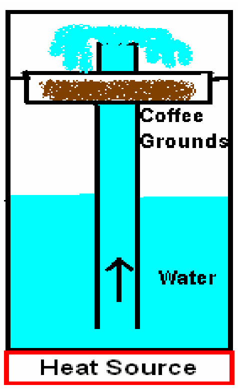
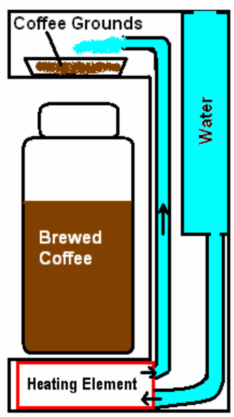
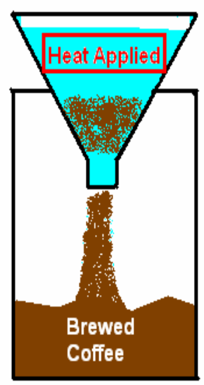
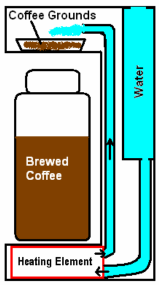
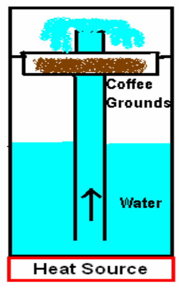
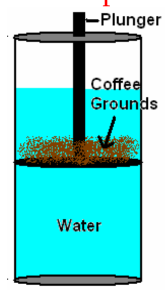
Function	Option 1	Option 2	Option 3
Add Heat	Tubular Calrod 	Submersible 	Hot plate 
Direct Water	Tubing 	Gravity feed 	Pump 
Contain Water/Coffee	Single reservoir 	Separate reservoirs 	Funnel 
Disperse Water	Drip-brew mechanism 	Percolating mechanism 	French press 

Table 4 cont. - Detailed morphological chart

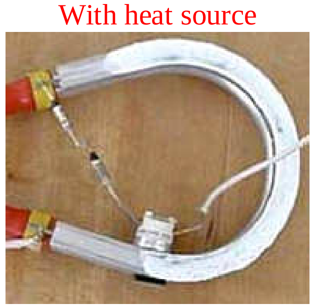
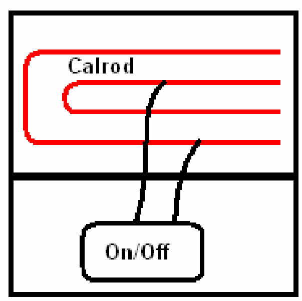
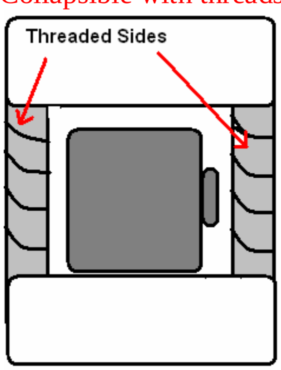
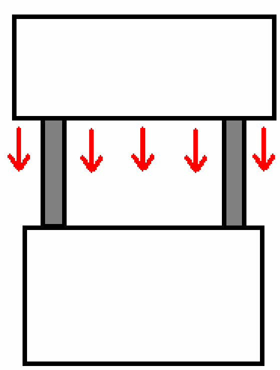
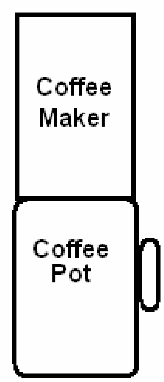
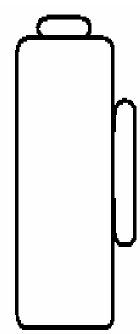
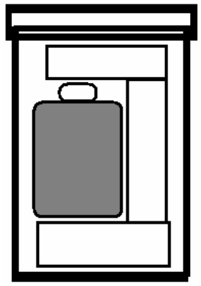
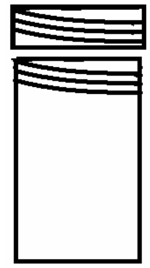
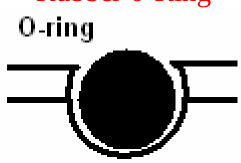
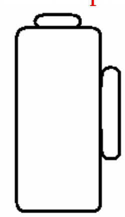
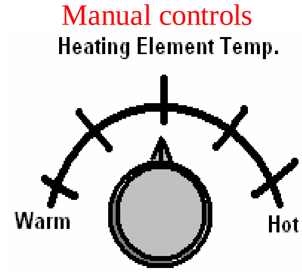
Function	Option 1	Option 2	Option 3	
Contain Grounds	Paper filters 	Metal filter 	Mesh filter 	
Reduce Maintenance	Disposable filter 	Removable permanent filter 	Removable Cup 	
House Electronics	With heat source 	Separate from heat source 		
Simplify Housing	Collapsible with threads 	Collapsible with posts 	Overhead brew 	Single reservoir 

Table 4 cont. - Detailed morphological chart

Seal Components	Storage container 	Threaded components 	Latched components 
Sealing Cont'd	Rubber 0-Ring 	Grommets 	
Simplify Use	Automated controls 	Prepackaged supplies 	Non-collapsible 
Maintain Heat Control	On/Off switch 	Automated controls 	Manual controls 
Reduce Noise	Noise damping material 	Internal brew mechanism 	
Reduce Brew Time	Larger heating element Increase Wattage	Minimized tubing length Efficient plumbing of lines	

4.2.1 Morphological Function Descriptions

Add Heat. To heat the coffee we have three options. We could use a Calrod heating element where the water is gravity fed into a tubular heating element, external to the water reservoir, and boiled out. Secondly, we could use a submersible heating element placed inside of the water reservoir to heat all of the water at once. Thirdly we could use an external hot plate to heat one or multiple walls of the water reservoir and thus heat the water through surface convection.

Direct Water. The fluids could be directed from the water reservoir to their final destination via tubing, gravity feed, and/or a pump. With tubing, the design would be similar to today's coffee makers with silicon tubing and possibly a one way valve directing the flow of the fluids. The gravity feed option would stack the coffee maker components vertically so as the water fell it was brewed into coffee. The pump option would replace the one way valve and direct the water without necessarily boiling the water.

Contain Water/Coffee. To contain the water and coffee we could use one reservoir, two reservoirs or a funnel. If one reservoir was used for both the water and coffee container, our design would be a percolating or French press coffee maker. The brewed coffee would mix with the remaining water unless some form of separator was used. With two reservoirs you have one reservoir initially empty and pour the brewed coffee into it. As a drip-brew coffee maker would. The final option is a funnel container where the water would be poured into a funnel and the funnel would be designed so the coffee was in it long enough to brew and then fall through as coffee.

Disperse Water. The three water dispersion options are drip-brew, percolating, and French press. These are discussed in greater detail in *2.1 Methods of Brewing Coffee*, on page 1.
Reduce Maintenance: Three ways we came up with to reduce the maintenance of our designs were to have a disposable filter, a removable permanent filter, and/or a removable cup. A removable filter would allow for quick and easy disposal of grounds and would eliminate any cleaning of the coffee maker. A removable permanent filter would be slightly less convenient as it would need to be cleaned but would be easily removed for cleaning so it would reduce maintenance compared to a permanent filter design. A removable cup would reduce maintenance because it would be easier to clean than a mug design where brewing components were combined and could be placed in a dishwasher or sink of water where as the latter could not.

House Electronics. In our designs we could either keep the electronics in the same section of the coffee maker as the heating element or in a separate place. In the coffee makers we tore down, the electronics were generally sitting within the U-shape of the calrod heating element. However, we think that having the electronics housed separate from the heating element with a single wire or wires running between should be considered as an option because of safety issues that would arise if the tubing to the heating element were to leak with electronic components around it.

Maintain Heat Control. To control heating element for our coffee maker we could use an On/Off switch, automated controls, or manual controls. With an off switch, the heating element would be turned on or off by the user when they chose. With automated controls, the heating element would be turned off by sensors that either sensed the temperature of the coffee, the time of the brew cycle, or the amount of water left to brew. With manual controls, the user would push a button or turn a knob to reach their desired heat control.

Simplify Housing. To simplify the coffee maker housing, we considered using several collapsible concepts. To collapse using threads, the user would simply screw and unscrew elements of the coffee maker to move them vertically. To collapse using posts, the user would elevate elements of the coffee with telescoping poles in collaboration with spring push-pins that would fall into place when the coffee makers reaches the desired height. These push-pins would allow the elements to remain elevated until manually deactivated. We also considered overhead brewing, which is simply a unique way of orienting the storage tanks of the coffee maker where all of the brewing of the coffee takes place in a tank above the coffee mug. The tank is then removed from the mug and the coffee is then ready for drinking. The concept of using a single reservoir requires a unique and clever way to manipulate the water and coffee flow that the same tank can be used to house both of these fluids without allowing them to mix with each other.

Seal Components. To seal components, we considered a storage container, which is simply a container that you would place the coffee maker in after use to prevent any leaks. We considered threading components together to reduce leaks (similar to how a bottle has a cap thread on to prevent it from leaking). We also considered latching components together (like latching a tool box together) to help with the sealing of components while still granting easy access to important parts of the coffee maker (such as the water tank, coffee mug, coffee filter).

Simplify Use. To simplify the use of the coffee maker for the user we could incorporate automated controls, prepackaged supplies, and/or make the design non-collapsible. Incorporating automated controls would mean the heating element would be on a timed cycle or sense when all of the coffee was brewed and give the user an indication that is was complete as well as turn of unnecessary components such as internal heating elements without any user input. Prepackaged supplies would eliminate any measuring of grounds or water volume for the user. Making the design non-collapsible would eliminate any confusion in how the design expanded/collapsed.

Reduce Noise. To reduce the overall noise we considered two options: noise dampening material and internal brew mechanism. To lessen the noise produced by our designs we could fill or cover the outer shell of with a noise dampening material. We could also keep the brew mechanism, whether it is drip or a spout, internal so its noise is damped by the outer casing.

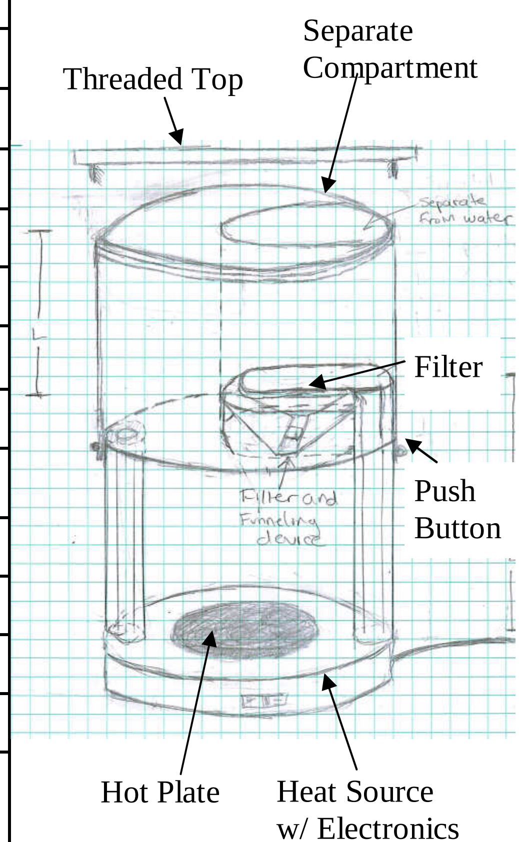
Reduce Brew Time. To reduce the brew time we could do any combination of enlarging the heating element, minimizing the tubing length, and/or enlarging the tube diameter. Enlarging the heating element would mean more water is heated at once and/or the same amount of water is heated more quickly, both resulting in decreased brew time. Minimizing the tubing length would decrease brew time because there is less travel distance from the heating element to the final destination.

4.3 Initial Conceptual Designs

Keeping all of the function options of the morphological chart in mind, each member of the team developed at least two conceptual coffee maker designs. The morphological chart was then used to determine which options, for a given sub function, would best fit each concept. Four of these concepts are detailed below, and are classified into two main categories: collapsible and non-collapsible.

4.3.1 Collapsible Concepts

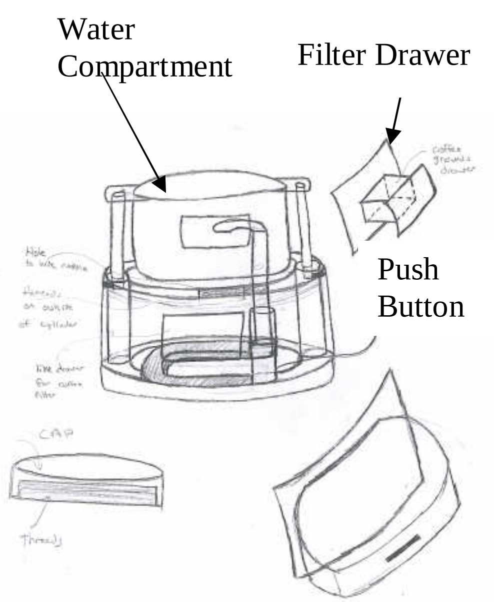
Concept #1	
Add Heat	*Tubular Calrod*
Direct Water	*Tubing*
Contain Water/Coffee	*Separate reservoirs*
Disperse Water	*Drip-brew mechanism*
Contain Grounds	*Paper filter*
Reheat	*Internal/Shared*
Reduce Maintenance	*Disposable filter*
House Electronics	*With heat source*
Maintain Heat Control	*On/Off Switch*
Simplify Housing	*Collapsible*
Seal Components	*Latched components*
Simplify Use	*Automated controls*
Reduce Noise	*Internal drip mechanism*
Reduce Brew Time	*Larger heating element*



Our first collapsible concept consists of a large cylindrical water compartment held up by two supports. These supports contain tubing which run into the bottom compartment, which contains the heating element. The placement of this heating element also allows for a hotplate, providing a reheat option. The water compartment contains a separate cylindrical compartment that contains the coffee filter. The coffee filter contains a funnel-like device to allow for the brewed coffee to drip into a cup or carafe. The top water compartment would collapse via spring-loaded push buttons on the supports. One support would collapse into the water compartment, and the other would collapse, along with the coffee filter, into the separate compartment. Finally, there would be a threaded cover for the top of the water compartment to ensure sealing ability.

The strengths of this design include the collapsibility, allowing for a smaller traveling volume. It also contains a reheat options and brews coffee via the drip method. With this reheat option however, comes the weakness of having an exposed hotplate. Space inefficiency is another problem with this design. Because of the separate compartment required for the filter and corresponding support to collapse into, this results in a large amount of unused space.

Concept #2	
Add Heat	*Tubular Calrod*
Direct Water	*Tubing*
Contain Water/Coffee	*Separate reservoirs*
Disperse Water	*Drip-brew mechanism*
Contain Grounds	*Mesh Filter*
Reheat	*Internal/Shared*
Reduce Maintenance	*Removable cup*
House Electronics	*With heat source*
Maintain Heat Control	*On/Off Switch*
Simplify Housing	*Collapsible*
Seal Components	*Latched components*
Simplify Use	*Automated controls*
Reduce Noise	*Internal drip mechanism*
Reduce Brew Time	*Larger heating element*

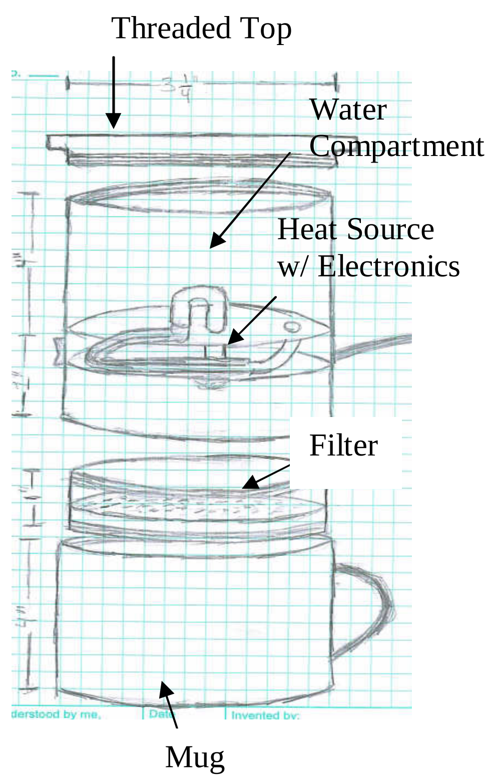


Our second collapsible design was a cylindrical concept with elevating water tank, reheat option and filter drawer for coffee ground storage. The water tank moves vertically from its collapsed position by activating spring push-pins on the telescoping poles located on the side of the coffee maker. Coffee grounds are added by pulling out the filter drawer from the water tank. The hot water spout is then placed inside this filter drawer to prevent hot water from splashing on the user and to eliminate mess. The coffee is brewed into a regular coffee cup which sits inside the coffee maker casing. To gain access to the cup, you simply unlatch the casing door on the side of the casing, open the casing door, and remove the cup. To collapse the design, you replace the filter drawer into the water tank and then slide the water tank into the coffee cup using the telescoping poles located on the side of the casing. The hot water spout slides down via a telescoping pole. Secure the casing door with the latch on the side of the casing and screw on the lid provided to ensure that the coffee maker is completely sealable.

The strengths of this design are similar to that of the first collapsible concept, in that it collapses to minimize travel volume, has a reheat option, and uses the drip-brew method. It has the further advantage of being safe, because the exposed hotplate of the previous design is eliminated by incorporating a latched door. The major weakness of this design is the difficulty in manufacturing it. It not only contains many parts, but also parts that require high precision, in order for the collapsible aspect to function correctly.

4.3.2 Non-collapsible Concepts

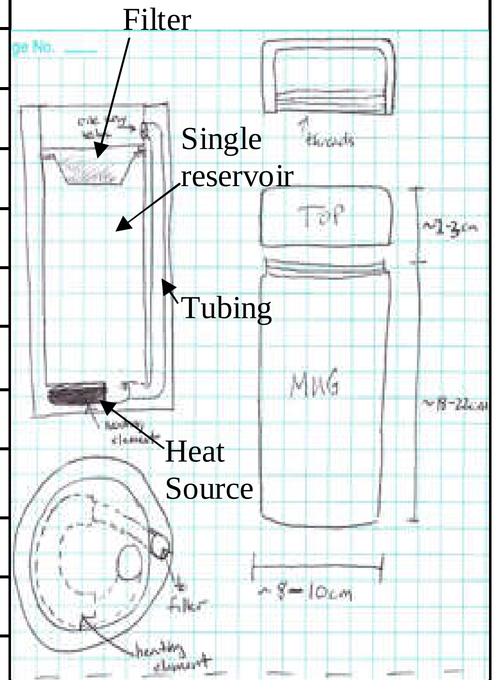
Concept #3	
Add Heat	*Tubular Calrod*
Direct Water	*Tubing*
Contain Water/Coffee	*Separate reservoir*
Disperse Water	*Drip-brew mechanism*
Contain Grounds	*Metal filter*
Reheat	*N/A*
Reduce Maintenance	*Removable permanent filter*
House Electronics	*With heat source*
Maintain Heat Control	*On/Off switch*
Simplify Housing	*Simple shapes*
Seal Components	*Threaded components*
Simplify Use	*Non-collapsible*
Reduce Noise	*Internal brew mechanism*
Reduce Brew Time	*Larger heating element*



Our first non-collapsible design is perhaps the simplest of our concepts. It consists of a water compartment, followed by a heat source and electronics compartment. There is then permanent filter followed by a mug. All of these components screw together to ensure sealing ability. There also consists of a threaded top for the water compartment.

The main strengths of this design include its sealing ability and multiple travel sizes. Because all of the components screw together, this ensures a tight and leak-free seal. This design also has multiple travel sizes, in that it may be carried with or without the mug. A separate threaded top would be made to accommodate this option. It also uses the drip-brew method which may be considered a strength. The weaknesses of this design include the lack of a reheat option. A special cup is also required in order to attach it to the brewing device. Another weakness is that the height is rather large in comparison to the base, which could lead to the device tipping.

Concept #4	
Add Heat	*Tubular Calrod*
Direct Water	*Tubing*
Contain Water/Coffee	*Single reservoir*
Disperse Water	*Percolating mechanism*
Contain Grounds	*Metal filter*
Reheat	*Internal/Shared*
Reduce Maintenance	*Removable permanent filter*
House Electronics	*With heat source*
Maintain Heat Control	*Automated controls*
Simplify Housing	*Simple shapes*
Seal Components	*Threaded components*
Simplify Use	*Non-collapsible*
Reduce Noise	*Internal brew mechanism*
Reduce Brew Time	*Larger heating element*



Our second non-collapsible concept is a percolating design. At the bottom of a thermos housing, a heat source boils the water/coffee mixture up through the tubing and through the filter. The top of the thermos device containing the filter screws off, allowing for the user to drink straight from the device.

The main strength of this design is its minimal volume. Because the device utilizes a shared reservoir, the total volume is effectively cut in half, although the percolating aspect of this feature may be considered a weakness. Like the first non-collapsible design, this is also well sealed due to the threaded components. The mug-like drinking device may also be considered an advantage over a cup, because it is easier to transport and seal. Aside from the percolating aspect, another major weakness this design is the requirement of a temperature sensor and control system to switch to a lower heat setting once the brewing process is complete.

5. Concept Evaluation and Selection

After generating high level designs, we discussed the strengths and weaknesses of each. Through this discussion we were able to separate the feasible from non-feasible and narrow our original concepts down to four. The original concepts and four selected concepts can be seen in Appendix D and above, respectively.

We began narrowing down our concepts by eliminating designs that did not meet our top three customer requirements of being safe, sealable, and transportable. During this process, we also considered what was feasible with our prototype manufacturing capabilities. Focusing on individual design weaknesses', we tried to refine each concept by comparing other designs and consulting material from our information search. Then using a Pugh chart (Figure 11, page 23) we compared our four best designs to arrive at the top two design concepts.

5.1 Safety

Once we began the refinement phase of our designs, we realized many of our designs had unacceptable safety hazards. The main hazard that we encountered was that of an exposed hot plate in our collapsible designs. In our non-collapsible designs, the hot plate was enclosed and not a hazard. In refined design #2, we combined the strengths of both by designing the entire hot plate to be enclosed inside a folding enclosure with a safety switch for when the enclosure is opened. A pressure switch refinement was also considered but this would not completely eliminate this hazard.

5.2 Sealing Ability

After dissecting our designs from a functionality stand point, it became obvious that we would have leak problems in our collapsible designs. For the collapsible designs where the coffee is brewed through the drip-brew method, we realized that we would need a spring loaded pour mechanism and a corresponding component to apply pressure on it to avoid leakage when the cup was removed from the coffee maker. This method was observed in coffee makers currently being manufactured (Figure 22, page 39). The threaded cup design was refined to meet this requirement by adding a threaded component between the grounds and cup so unthreading the cup would stop the flow of brewed coffee. In concept #1 and concept #2, the designs were refined to include a cup and pressure application lid combination to address the same problem.

Similar leak issues were encountered when refining designs with multiple components that separated or opened. To seal these designs for transport, we considered rubber seals and external casings but in the end found that threading the components together, as in concept #4, was the most effective way to satisfy this requirement and well within our manufacturing capabilities.

5.3 Transportability

After our initial designs, we realized that there were essentially two ways we were making our designs transportable. The first method was simply to minimize all of the dimensions into a single piece cylinder shape. This method resulted in a small and easily transportable coffee maker but limited our brew volume capabilities. The second method kept the traditional look of a coffee maker and made its parts detachable and stackable for travel. These designs had greater brew volume capabilities but had many different parts to manipulate. Each design provided a suitable but different method of making a coffee maker transportable. After realizing the strengths of the two methods, we combined them to create the enclosed cup concept where the design collapses but is kept in a single piece.

5.4 Manufacturability

As we began to refine our original eight designs we found that the best way to keep our concepts within our manufacturing capabilities was to maintain simple shapes and components. We refined the float separator design to be a simpler percolating design and changed many rubber seal concepts to threaded seals. We also looked into methods of eliminating telescoping hoses, as recommended by our design review, and replacing them with accordion style extensions or stretching hoses. The process of refinement for manufacturability will continue into the manufacturing process as we encounter problems and adapt our design to account for them.

5.5 Pugh Chart

After refining the concepts to better satisfy our three greatest customer requirements and eliminating those which were not feasible, we were left with four designs. To evaluate these fours designs against one another we used a Pugh chart (Figure 8, page 23). From the Pugh chart we were able to mathematically determine which design or designs were most promising. This was done by using the weights of each customer requirement from our QFD and a -1, 0, +1 evaluation system for how each design met the given requirement. For each requirement a design would be a given a number of points equal to the weight of the respective requirement multiplied by one of these three numbers. A design was then given a total point ranking equal to these sum the points given for all of the requirements. The result of this chart showed that the concept #2 and concept #3 were our two best designs.

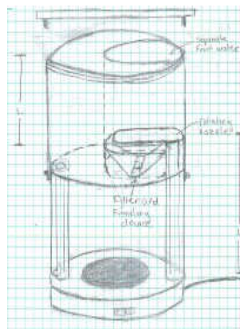
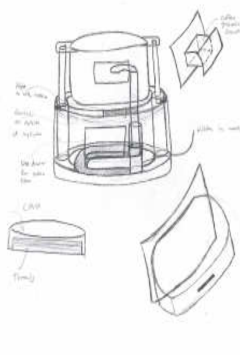
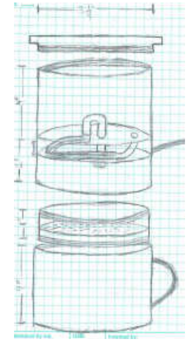
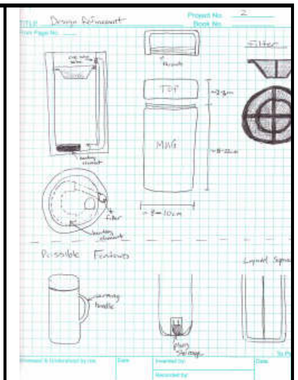
Customer Requirement	Weight	 (Datum) Concept 1	 Concept 2	 Concept 3	 Concept 4
Safe	**10**	0	+	+	0
Sealable for Transport	**10**	0	+	+	+
Transport Volume	**10**	0	0	-	0
Quality of Coffee	**8**	0	0	0	-
Sufficient Brew Volume	**8**	0	0	0	0
Quick Brew Time	**8**	0	0	0	0
Affordable	**7**	0	0	+	+
Easy Maintenance	**7**	0	0	+	0
Sufficient Coffee Ground Volume	**5**	0	0	0	0
Light Weight	**5**	0	0	0	0
Reheat Option	**5**	0	0	-	0
Low Noise	**4**	0	0	0	0
Visibly Pleasing	**3**	0	0	0	+
	Total +	0	2	4	3
	Total -	0	0	2	1
	Weighted Total	0	20	19	12
	RANK	4	1	2	3

Figure 8 - Pugh Chart

6. Selected Concept

The top four designs were then examined in greater detail and further narrowed to two designs using a Pugh chart. After presenting one collapsible (Concept #2) and one non-collapsible (Concept #1) design to our peers, supervising professor, and sponsor, we were able to select our final design. We selected the enclosed cup concept (Concept #2) as our final design. Further explanation of both designs are presented below, however, explanation of concept #2 is more in-depth since it is the final selected concept.

6.1 Refined Concept #1: Threaded cup

For our non-collapsible concept, we selected the threaded over-cup design. Sketches of this design can be seen in Appendix D, along with a CAD rendering in Figure 9 below. This concept threads a cylindrically shaped drip brew coffee maker onto a standard sized coffee cup with threads machined into its upper-inner lip. The first CAD rendering shows how the design would appear when coffee is being brewed. The five components are threaded to one another to make one long cylinder. In this configuration the whole design stands approximately 30 cm (9") high with a base of 9 cm (3.5"). When the coffee maker is traveling the cup and cup lid can be separated from the rest of the unit to give the user more options for packing it.

The second CAD image (Figure 10, below) shows an exploded view of this design. From top to bottom the parts are; water reservoir lid, water reservoir/electronics housing, electronics housing floor, grounds reservoir, and cup. Missing from this rendering is the cup lid which threads between the grounds and cup to apply pressure to the pouring mechanism.

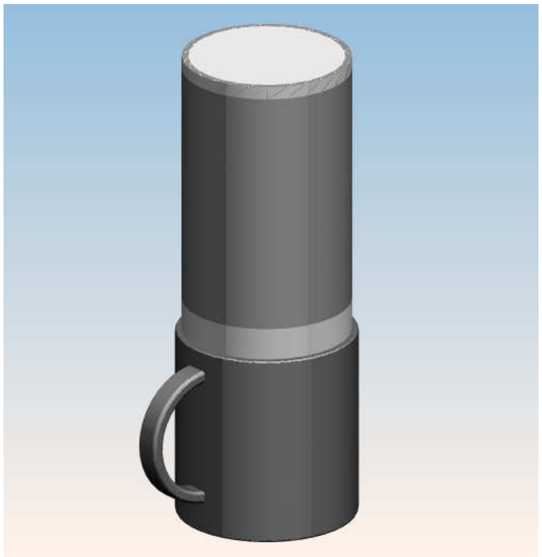


Figure 9 - External CAD Drawing of Selected Concept #1: Threaded cup

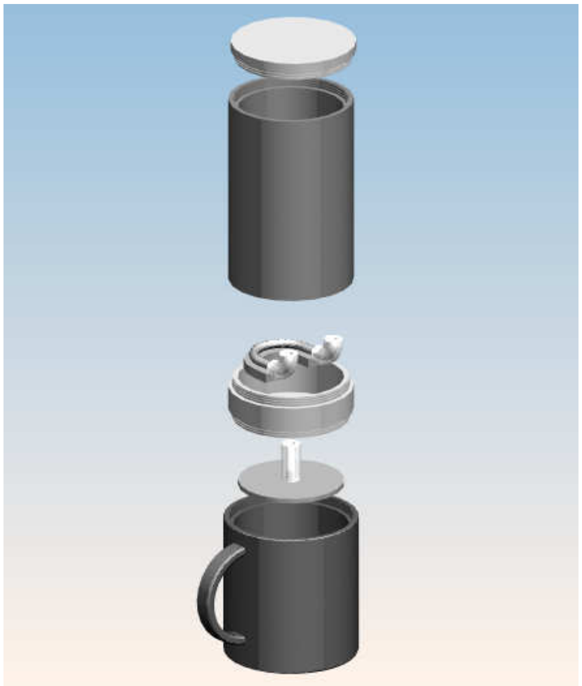


Figure 10 - Exploded CAD Drawing of Selected Concept #1: Internal Parts.

The third CAD image (Figure 11, below) gives a view of the internal parts and the functionality of this design. From this view it is easier to visualize the path the water takes in becoming coffee. A tube connected to bottom of the water reservoir is connected to the heating element sitting in the electronics housing. The heating element is powered by 110V AC power through a standard wall outlet. Once the water drips into the heating element it is boiled and pushed through a one way valve and into a tube which arcs up into the water reservoir and back down through the middle of the water reservoir and electronics housing floors. From here it is fed into a drip mechanism and dripped over the coffee grounds and into the cup below.

The majority of our coffee maker would likely be built of PVC. However, more materials analysis needs to be done before this is certain. The exact dimensions and material for tubing have not yet been determined although 13 mm (1/2") OD x 1/16" (3 mm) wall thickness appears standard from our teardowns. The heating element will likely be a formable Calrod which can be purchased over the internet while the drip mechanism will be modified from an existing coffee maker.

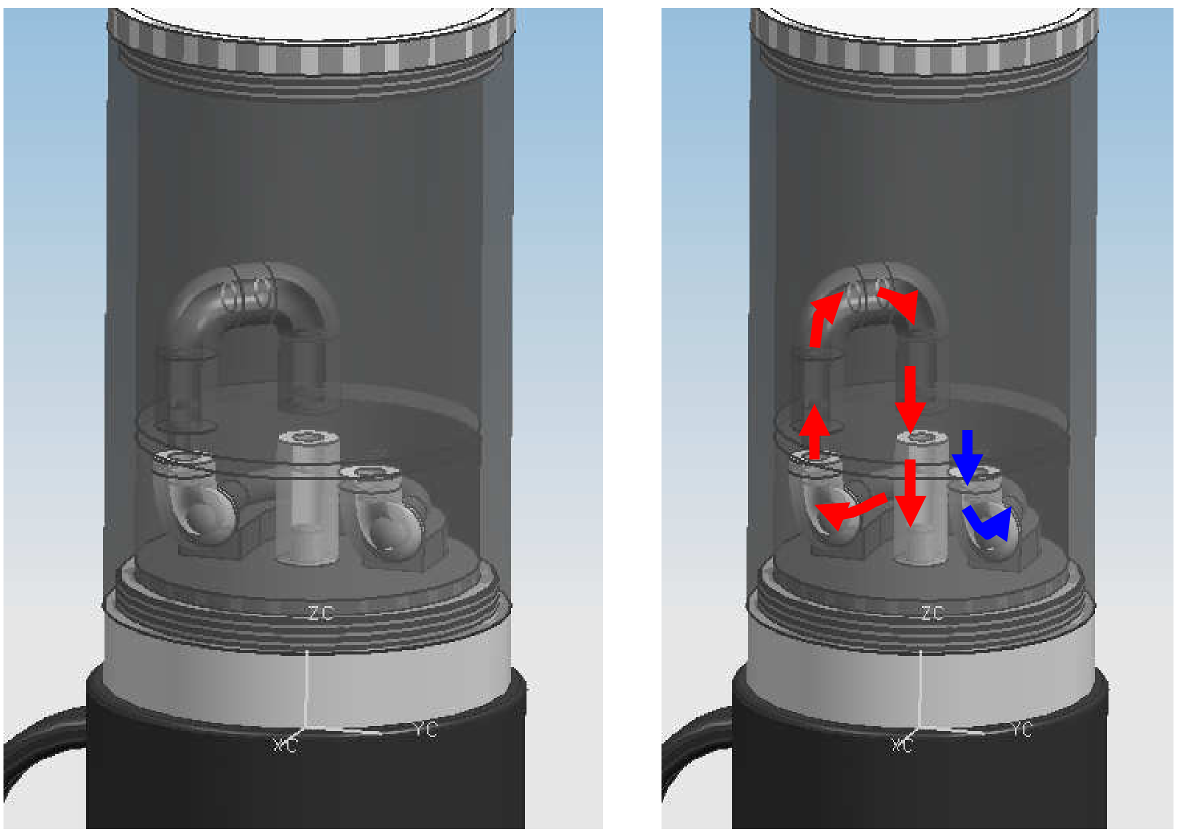


Figure 11 - Internal CAD Drawing and Schematic of Selected Concept #1: Threaded cup

6.2 Selected Concept: Enclosed Cup (Concept #2)

Explanation of Concept. Figure 12, 13, and others below show our second concept that was selected using the Pugh chart in Figure 8, page 23. This concept incorporates the ability to be collapsible, sealable, possesses a reheat option, and also allows the user to brew coffee into a "standard-sized" coffee mug. We chose to have a circular casing so we could allow our tubing for water and coffee to remain in-tact when the design was collapsed. This casing will also allow for manipulation of tubing. Furthermore, this design allows the casing to open in order to remove the coffee cup from the reheat pad. The coffee filter was determined to be a drawer so it could be easily stored in the water tank and then both of them could be easily collapsed into the casing. The sealing mechanism on the coffee filter mimics the inside of the complete wall of the water tank in order to keep water out of the filter. This feature, in collaboration with sealable o-rings lining the perimeter and the pressure from the water pushing on the sealing mechanism was determined to be ample for sealing leaks. The lid on the coffee filter is so hot water does not splash on the user when brewing, but also allows for pressure build up from the hot water to be released. The water and coffee filter designs incorporate existing coffee maker technology of tubing spring seals for allowing fluids to drain. We decided to use telescoping rods to support the water tank because these can be easily stored inside each other, and also allow for easy collapsibility. Finally, we decided to add latches to the top of the water tank so it can be easily cleaned and refilled along with the removable coffee mug.

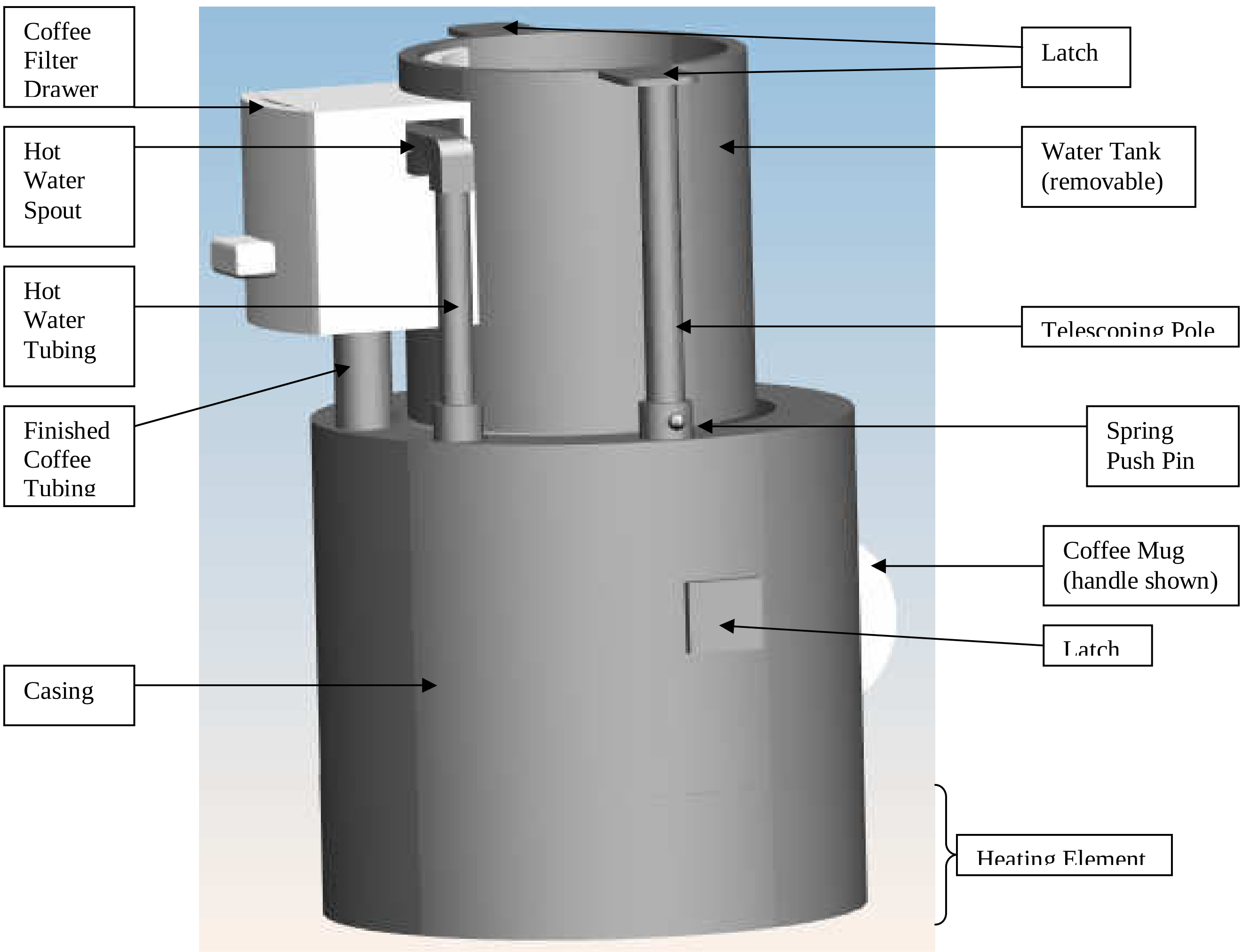


Figure 12 - External CAD Drawing for Selected Concept #2: Enclosed Cup

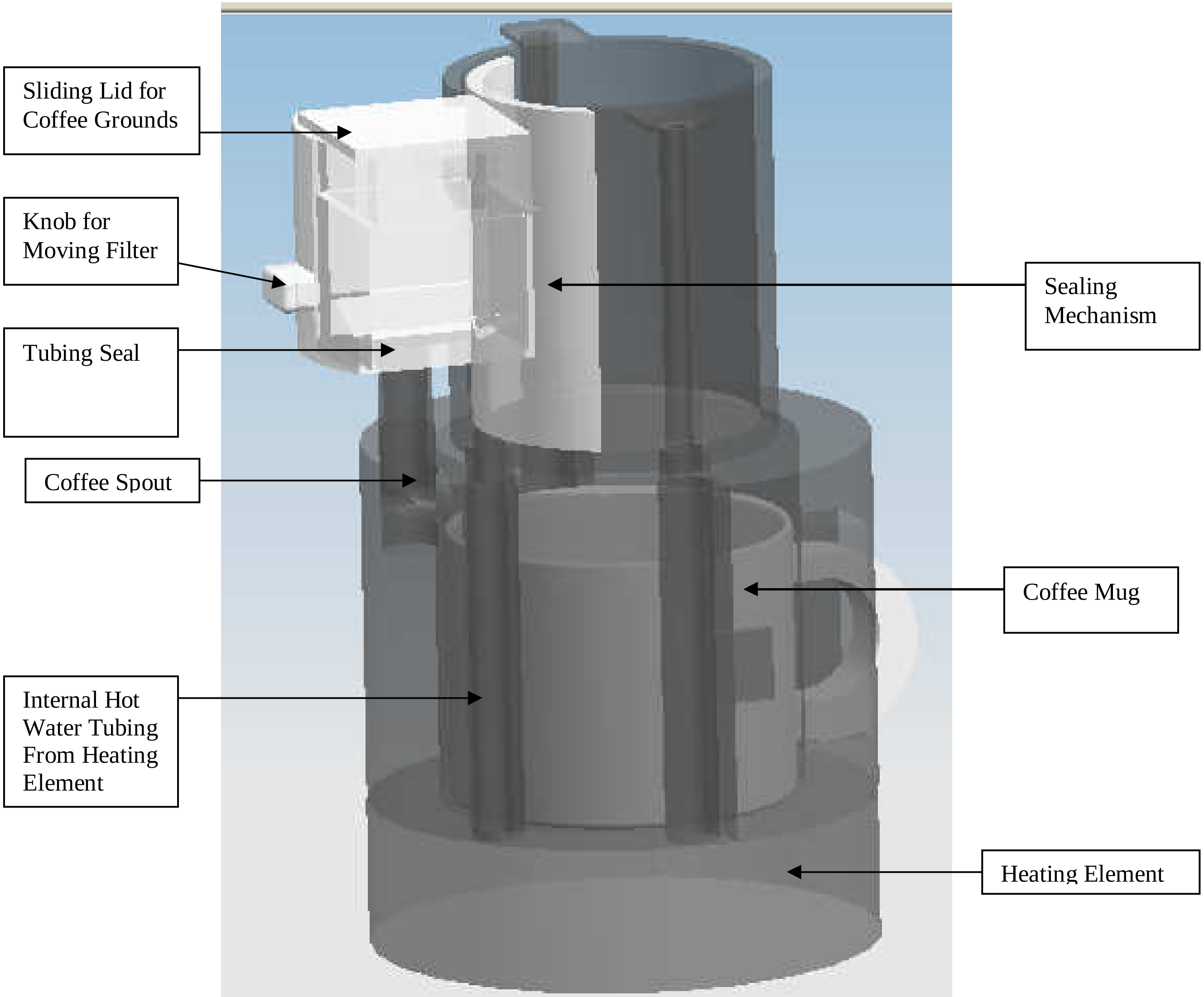


Figure 13 - Internal CAD Drawing of Selected Concept #2

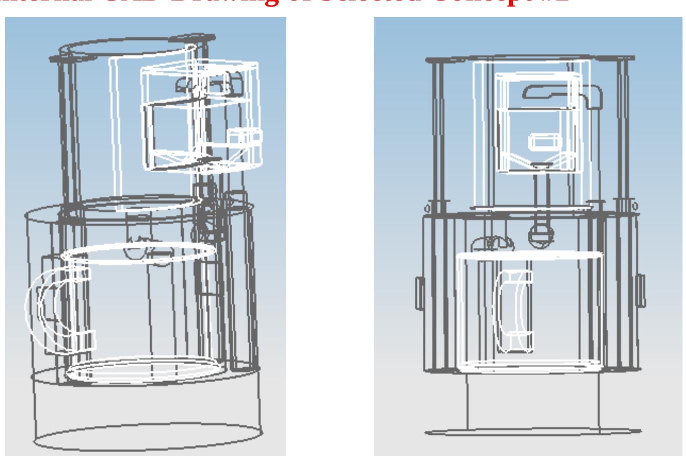


Figure 14 - Wire Frame CAD Drawings of Selected Concept #2

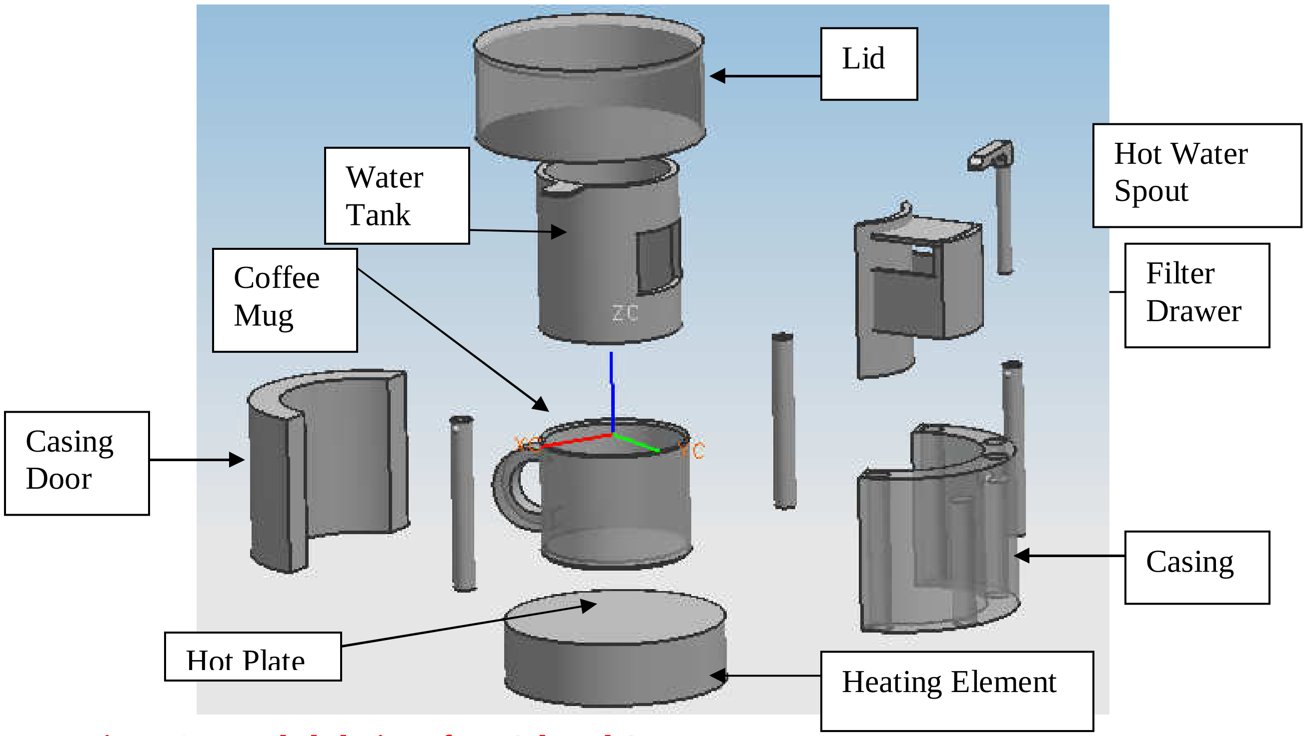


Figure 15 - Exploded View of our Selected Concept

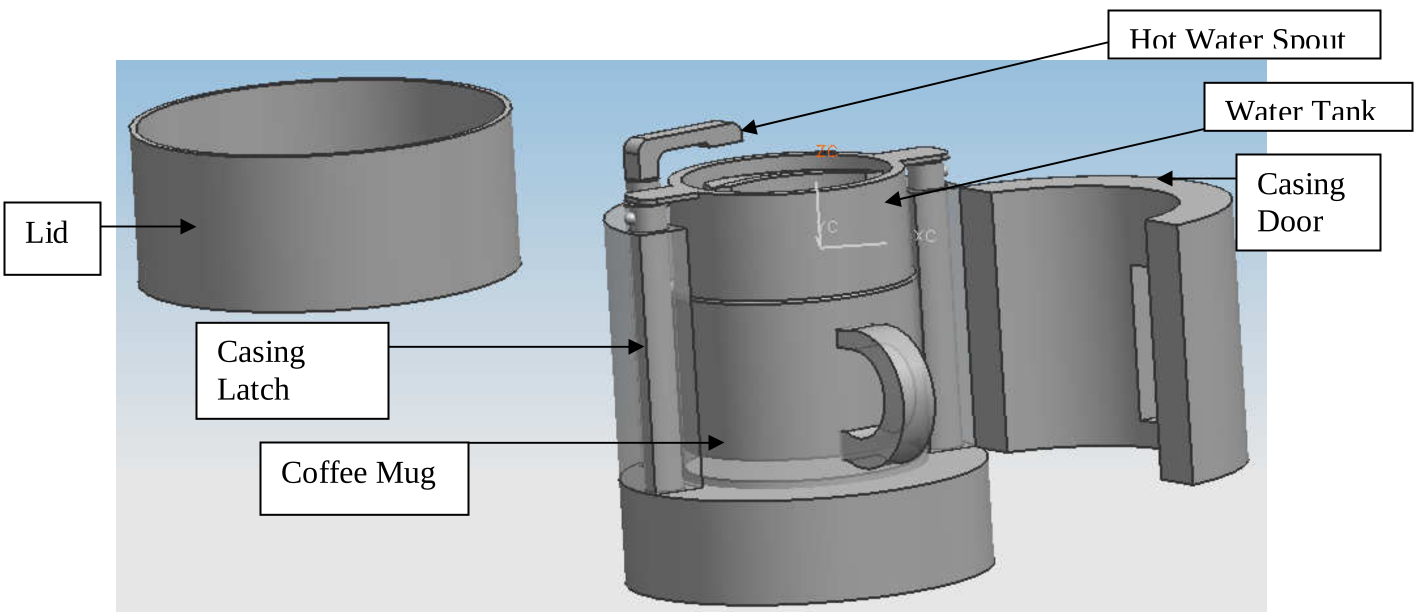


Figure 16 - Semi-collapsed Views of our Selected Concept

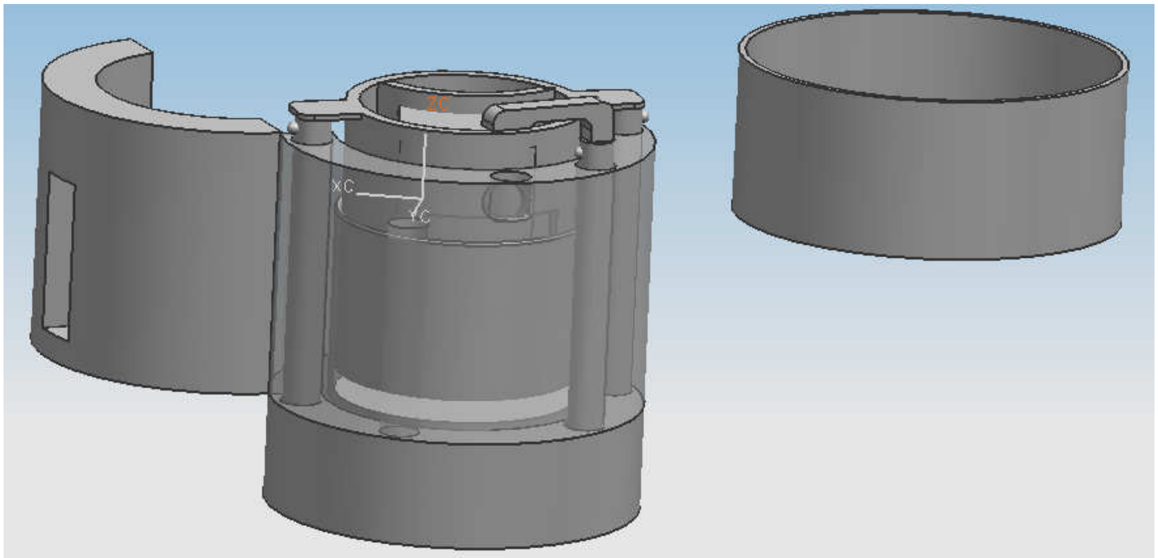


Figure 16 cont. - Semi-collapsed Views of our Selected Concept

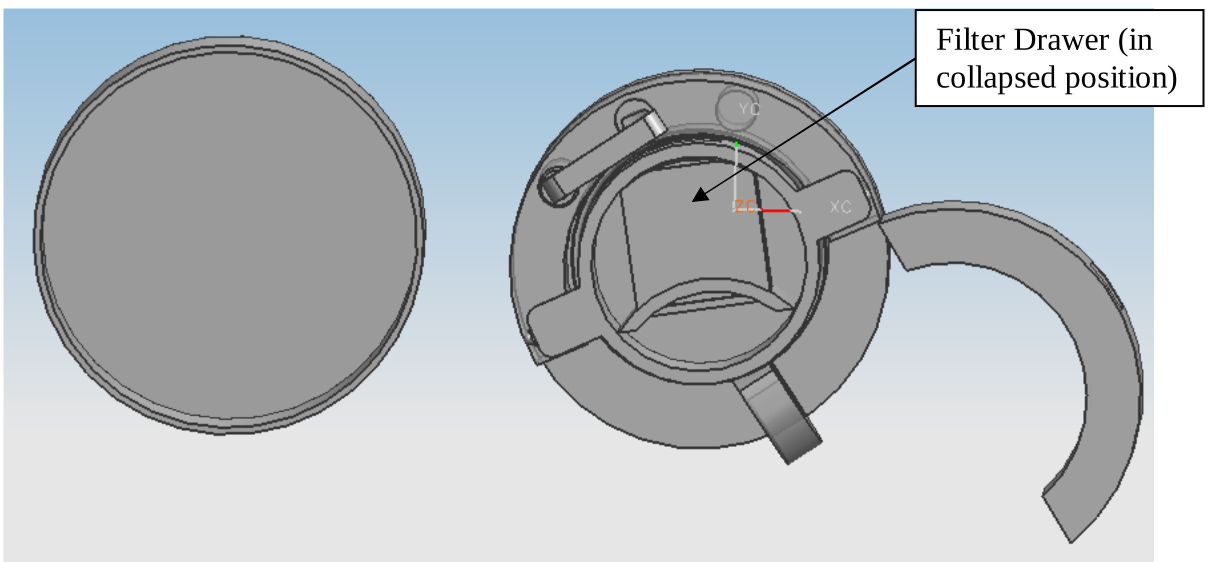


Figure 17 - Top View of Semi-collapsed Selected Concept

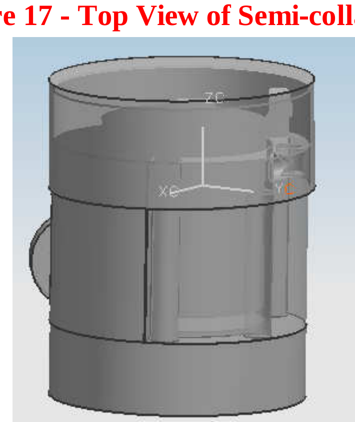


Figure 18 - Fully Collapsed View of our Selected Concept.

Rough Dimensions. Rough dimensions of our selected concept can be seen below. These dimensions are rough and subject to change after further engineering analysis and design refinement.

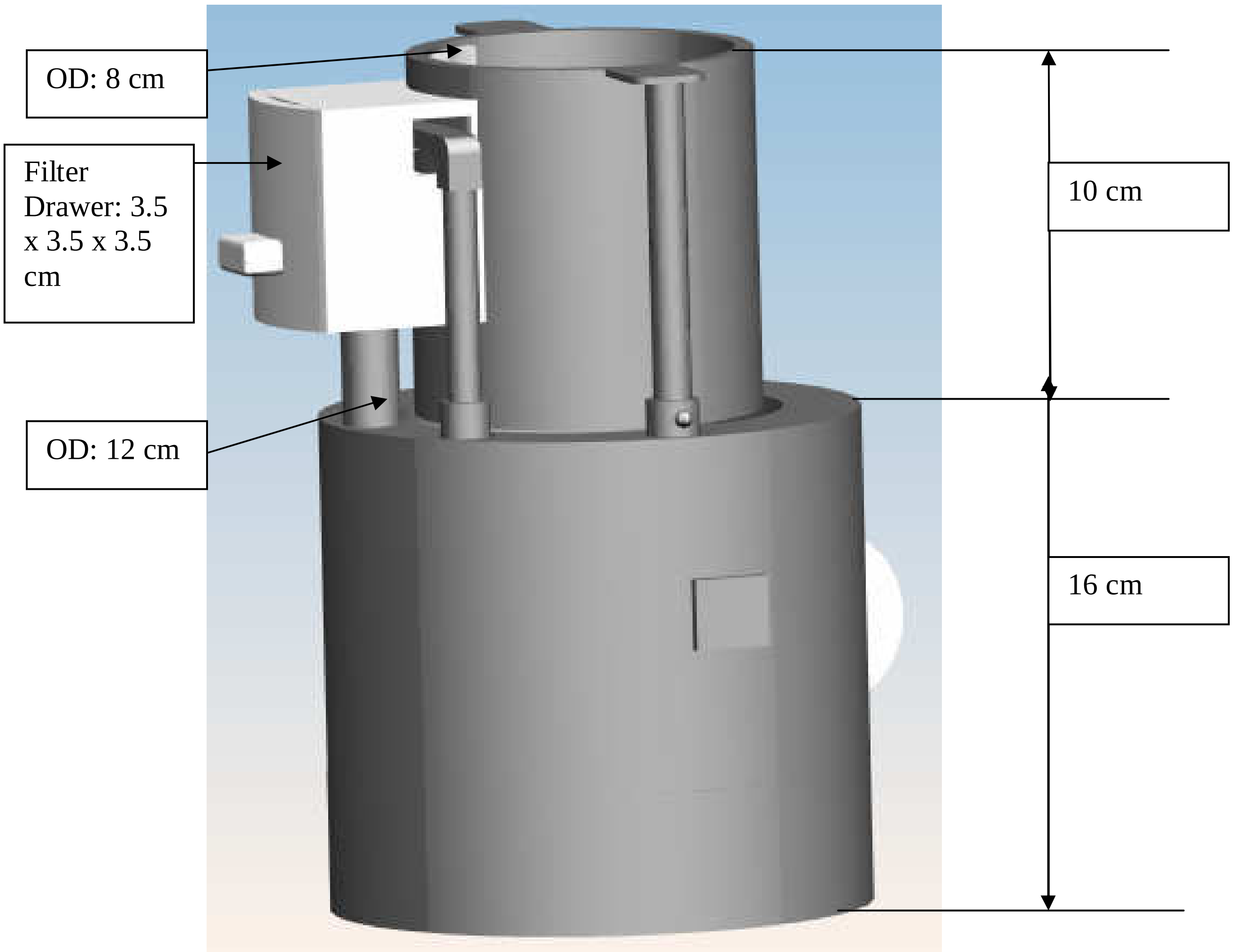


Figure 19 - Rough Dimensions of Collapsible Concept (expanded)

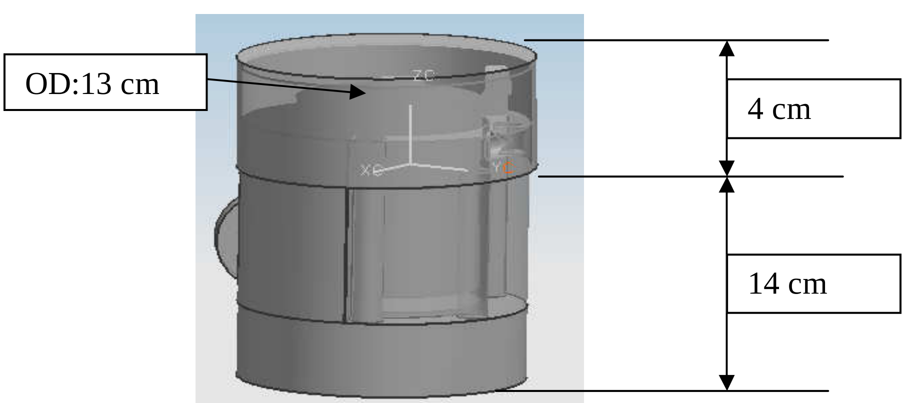


Figure 20 - Rough Dimensions of Selected Concept (collapsed)

How to Use. The Figures below show how to use our selected collapsible concept.

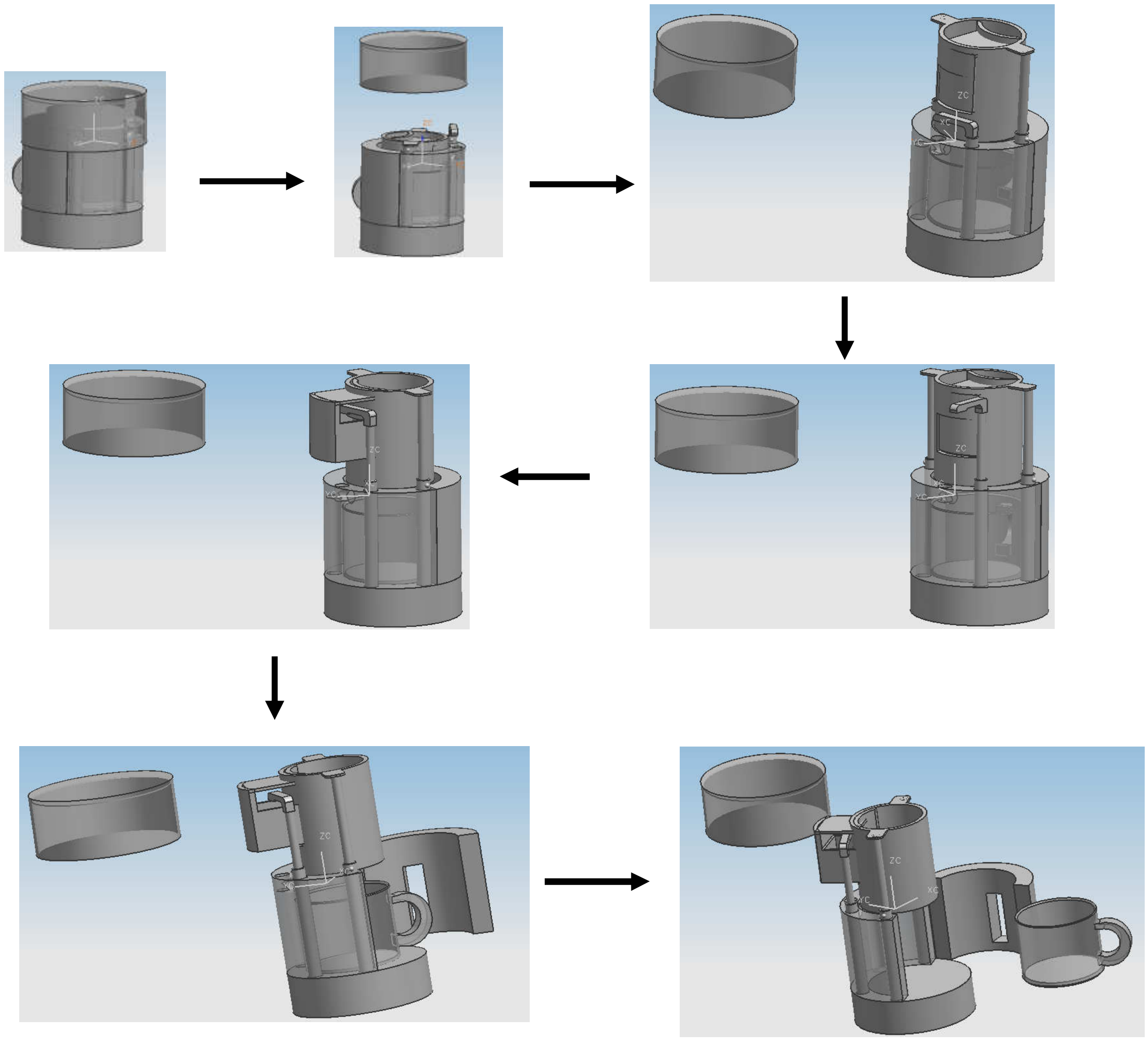
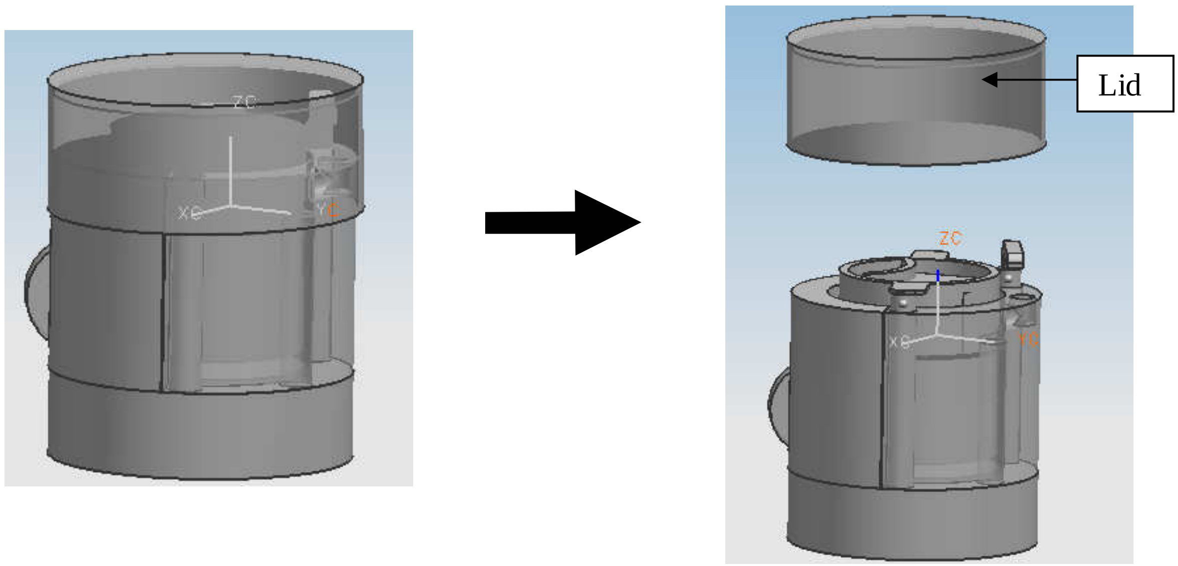


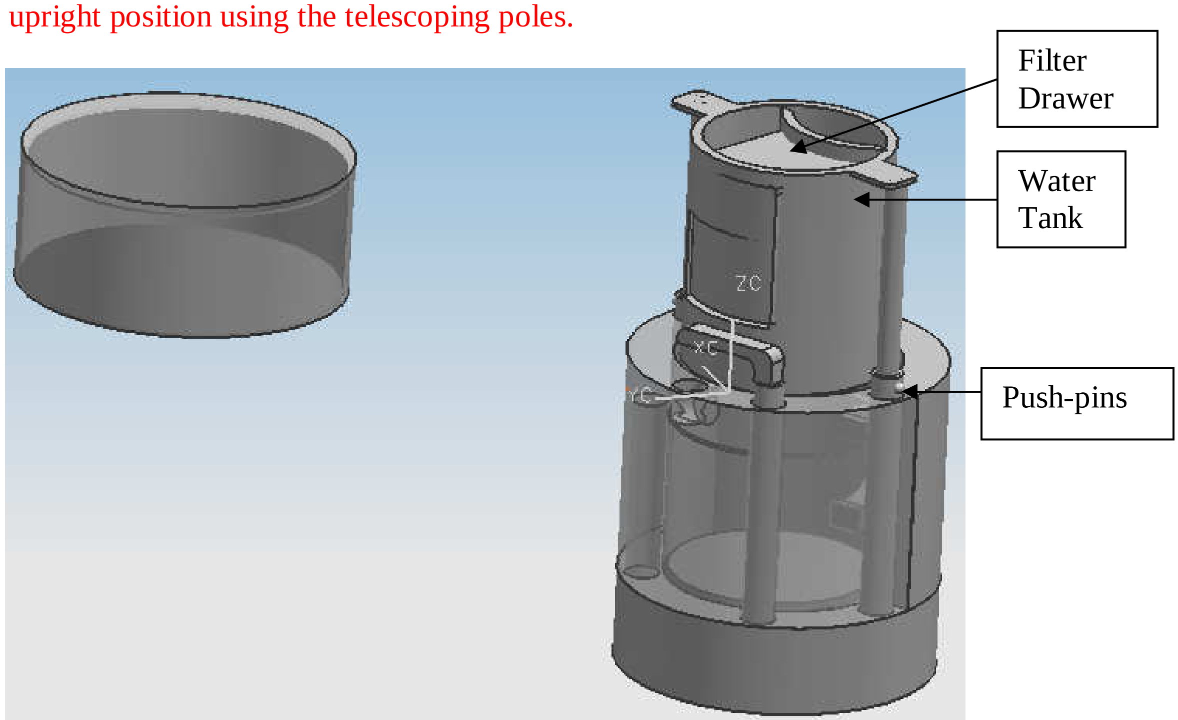
Figure 21 - Succession of Collapsible Steps for our Selected Concept

Step by step explanation of this succession of collapsible steps can be seen below (Figure 21 cont.)

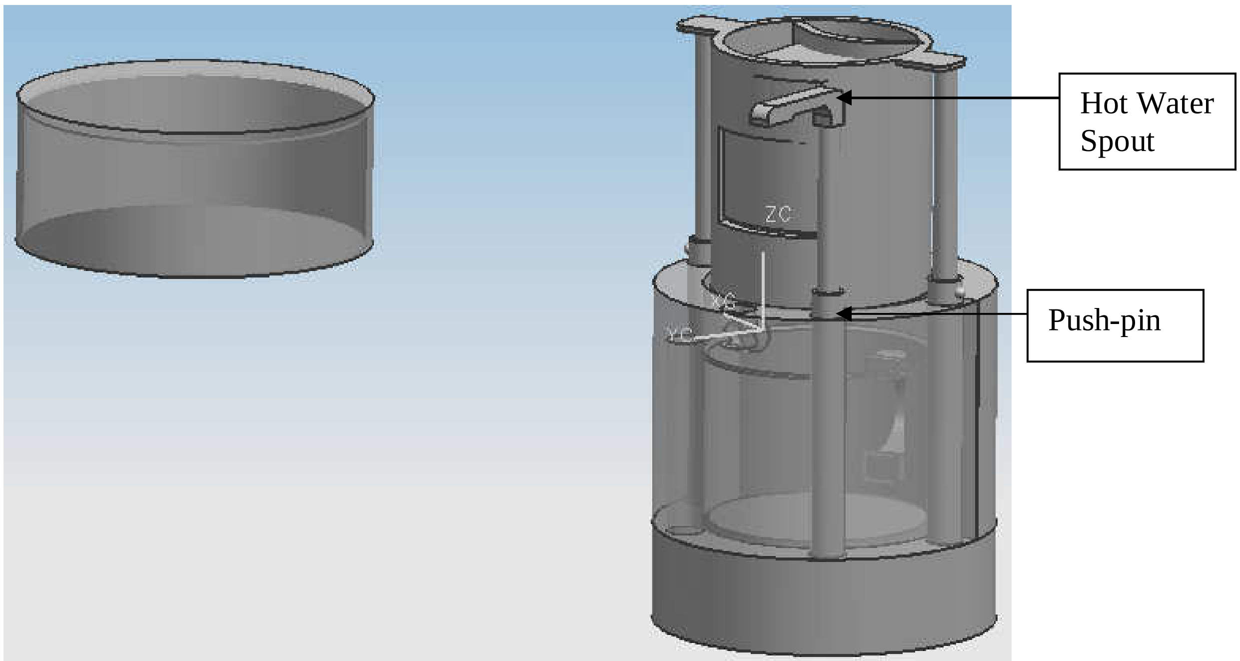
Step 1: Unscrew lid and remove from coffee maker base.



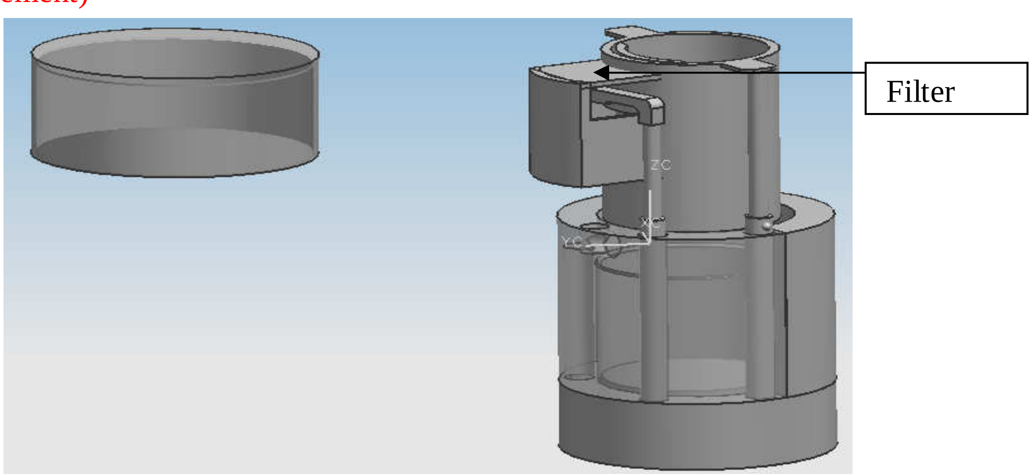
Step 2: By activating spring push-pins on the side of water tank, slide the water tank to its locked and upright position using the telescoping poles.



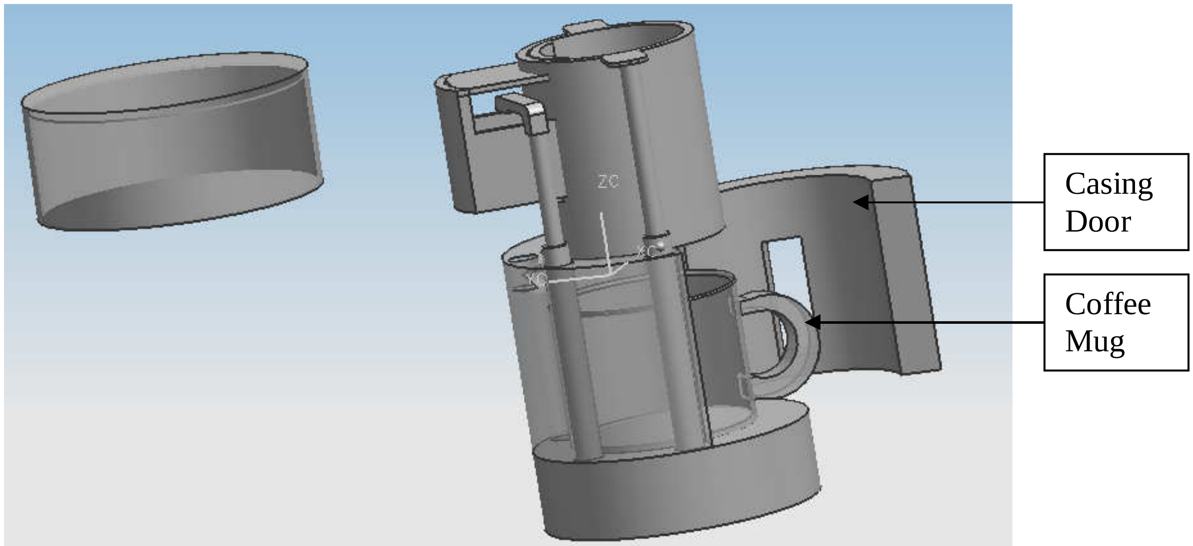
Step 3: Using the spring push-pins located on the bottom of the hot water spout tube, slide and rotate the hot water spout upwards and 90° away from the coffee maker. This is the position the water tank is in when brewing coffee.



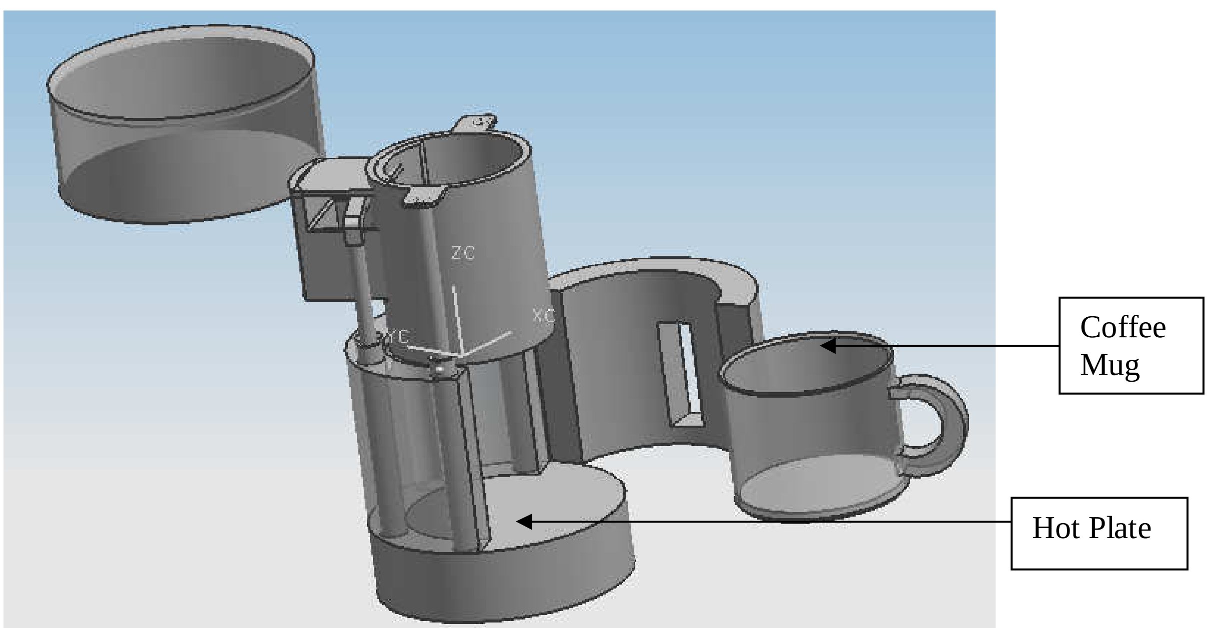
Step 4: Remove the filter drawer from the water tank. Once the filter drawer is removed, slide the lid off the filter. The coffee filter can now be filled with coffee grounds and a removable filter. Next, slide the hot water spout upwards above the top of the filter and rotate it 90 back towards the coffee filter (so the hot water spout is now elevated above the filter drawer. Now, slide the hot water spot down to its locked position and replace the filter lid. Coffee can now be brewed. (Not shown in this picture: tube connecting filter to casing to direct finished coffee into cup; tube connecting water tank to casing to drain water from tank and direct through casing into the heating element)



Step 5: After allowing the coffee to brew (achieved in less than 5 minutes), the casing door can now be opened using a latch and hinge system located on the sides of the casing. After opening the door, the coffee cup can remain here to benefit from the reheat option incorporated into the casing.



Step 6: To drink the coffee, simply remove the coffee cup from the hot plate and enjoy your freshly brewed cup of coffee! If you desire to keep your coffee cup warm over the course of your indulgence, you can simply replace the coffee cup on the hot plate with the casing door open.



Flow of Water and Coffee. Figure 22 below shows a schematic of moving water and coffee from start to finish. As with traditional coffee makers, the process starts out with cold water in a water tank. This water is then gravity fed down through tubing which then runs through a Calrod heating element. After passing through the Calrod, the now hot water passes up through tubing and is then sprayed over coffee grounds. The coffee grounds mixed with this hot water then drip down through a filter into a reservoir for finished coffee.

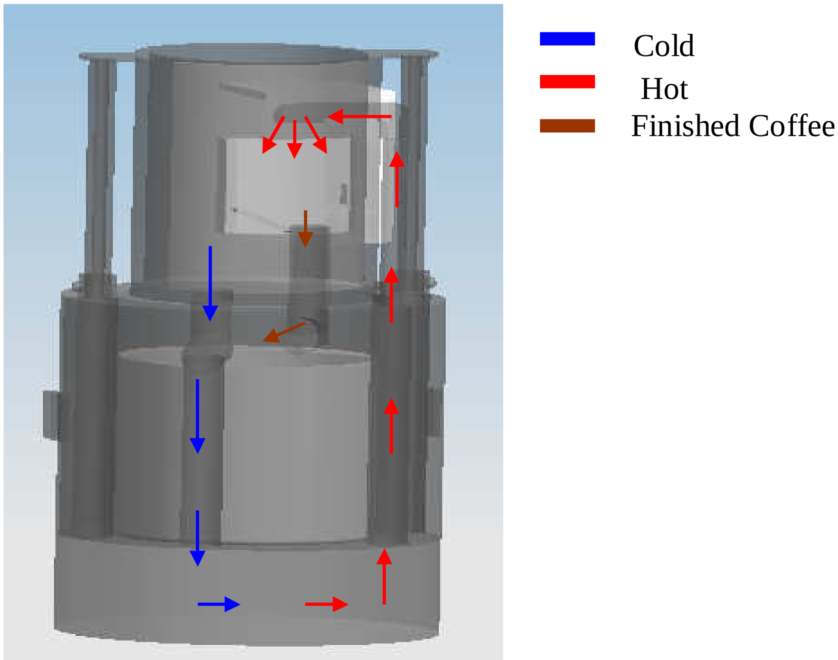


Figure 22 - Schematic of Water and Coffee Flow

6.2.1 Individual Components.

Below are figures of the individual components of selected concept #2. We intend to manufacture the coffee filter housing out of PVC and purchase or use existing technology for the filtering of our coffee. The sealing mechanism for the coffee filter drawer will also be made out of PVC and possibly incorporate o-rings around the perimeter to increase its ability to seal out water. Currently, the dimensions of the coffee filter are rough due to the shape complexity, but the filter will be able to achieve a minimum coffee ground volume of 40 cm^3. Furthermore, for aesthetics, the outside of coffee filter will be rounded with the same curvature radius as the water tank. The only protrusion seen will be a small knob used for opening and closing the water filter drawer.

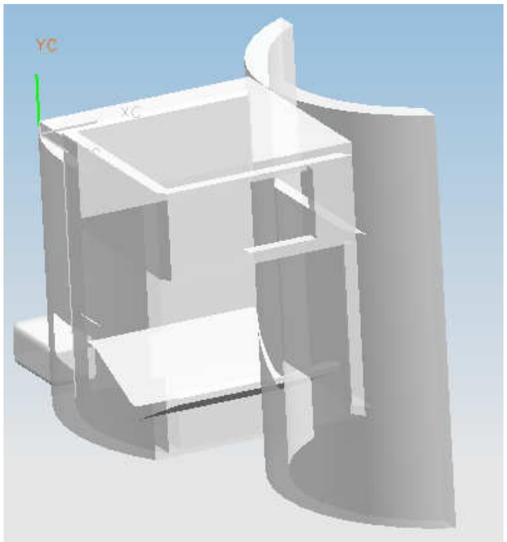


Figure 23 - Coffee Filter

Figure 24 shows a picture of the water tank. This water tank will be manufactured out of PVC. The bottom of this tank will also contain a hole for water drainage where a tubing seal will be places allowing water to leave only when tubing on the other side is attached. The minimum volume of this water tank will be 500 cm^3, enough to make 473 mL of brewed coffee. Rough dimensions of this tank are expected to be 4 cm in radius and 10 cm in height. The latches on the top of this water tank will be purchased and be able to easily attach the water tank to the telescoping poles. This will allow for easy maintenance and filling of the water tank.

Figure 25 shows a picture of a coffee mug. This coffee mug will be manufactured out of purchased PVC. After further engineering analysis, we will determine exact thickness and other insulating materials required (mainly for the coffee mug handle) in order to ensure user safety. The rough dimensions of this coffee mug will be similar to that of a standard-size coffee mug. Currently, we determined rough dimensions to be 4.5 cm in radius and 8 cm in height.

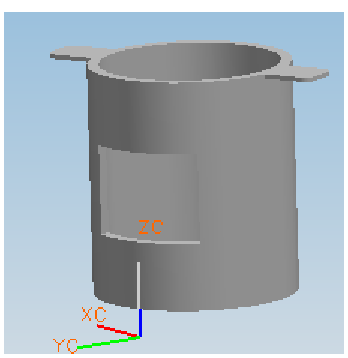


Figure 24 - Water Tank

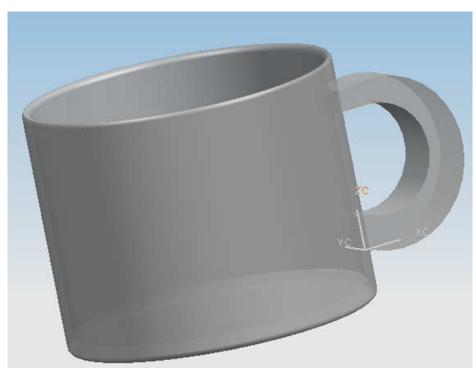


Figure 25 - Coffee Mug

Figure 26 below shows a picture of the coffee maker casing with heating element. The purpose of this casing is to house all of the tubing for the coffee maker while maintaining collapsibility. This casing also splits in half via a purchased latch and hinge system so that the coffee mug can be removed from the heating pad on the inside. Because accurate dimensions of this casing are dependant on the rest of our design dimensions, we determined rough outer dimensions to be 6 cm in radius and 16 cm in height. Furthermore, the top of the casing will be threaded so that a threaded cap counterpart can be screwed on to make the collapsible form of the design completely sealable.

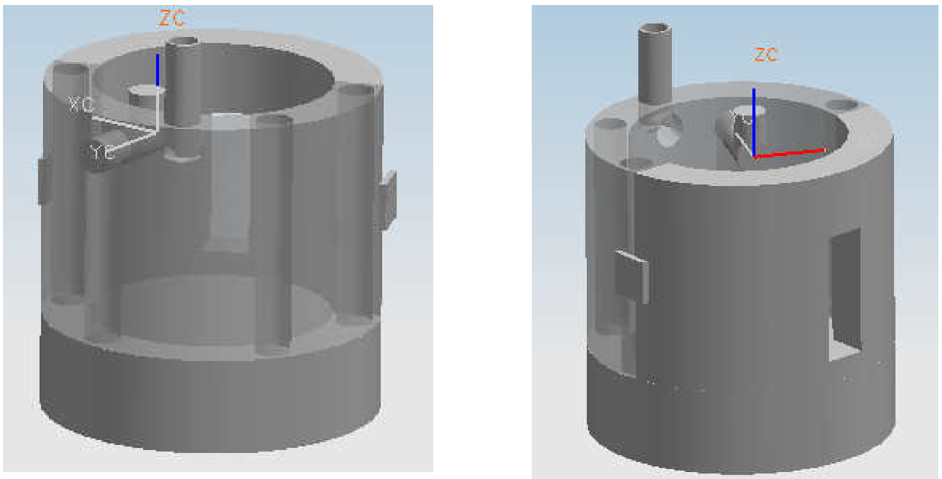


Figure 26 - Casing

Figure 27 shows a standard coffee maker Calrod heating element. We expect that we will be purchasing a heating element similar to the one shown with an approximate power output of 600 W. We plan to perform engineering heat transfer analysis to obtain an efficient Calrod wattage.

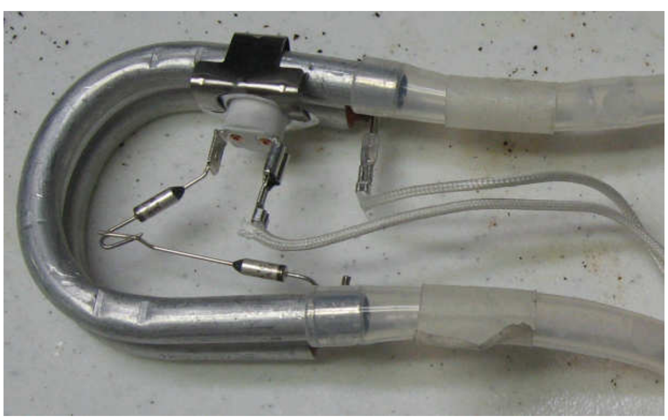


Figure 27 - Heating Element

Figure 28 below shows telescoping rods with spring push pins that we will be using in our collapsible design to help elevate the water tank and hot water spout. We are in the process of finding a supplier of these telescoping rods, however, for the exact use of our design, we are leaning towards manufacturing these rods in-house. If this is the case, we will use PVC or aluminum rods with a manipulated push pin subsystem. Rough dimensions of these rods are dependent on other aspects of our design will be determined exactly in the near future. Currently, we expect the rough dimensions of these to be rough 1 cm in diameter and a total telescoping height of 26 cm.

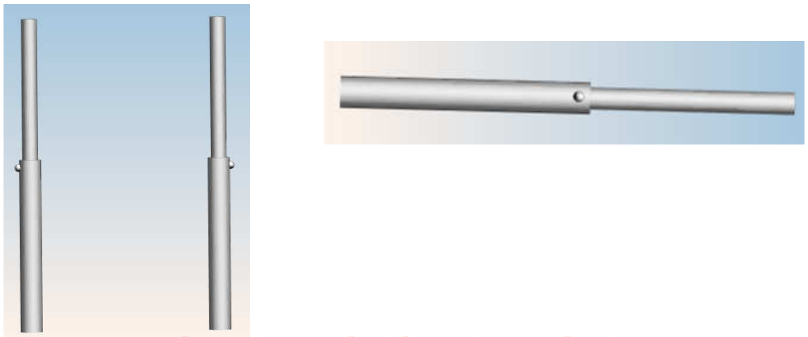


Figure 28 - Telescoping Rod with Spring Push Pins

Sealing Interfaces

The figure below shows call outs for interfaces that need further consideration for leak prevention. As you can see, tubing seals are needed for connection of the hot water tube to the hot water spout, the coffee filter to the casing (which flows to the coffee cup), and from the water tank to the casing. Furthermore, some solutions are provided for the sealing of these interfaces.

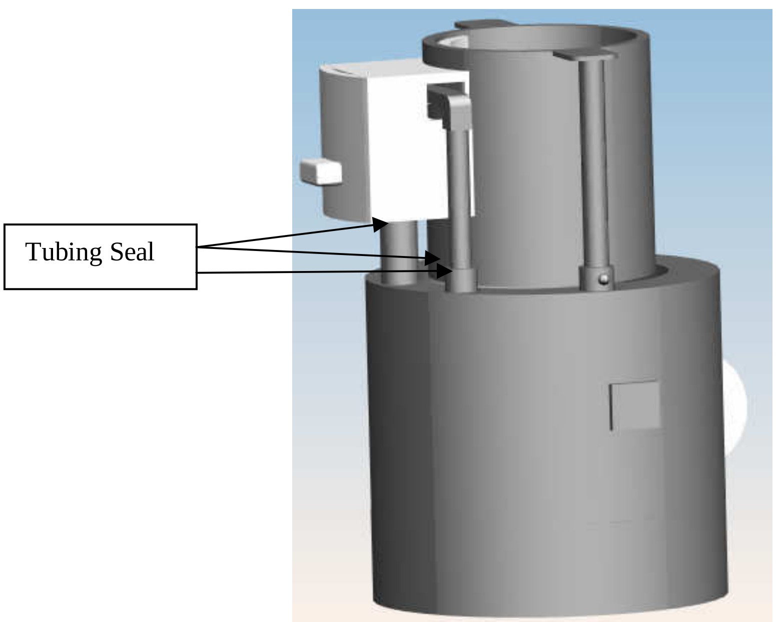


Figure 29 – Tubing Seal Locations

Figure 30 shows the fluid tank pressure valve. We hope to purchase this component or modify one from an existing coffee maker. We will also attempt to look further into these spring designs to see if manufacturing these springs in house would improve the functionality of our design. If we choose to manufacture these springs in-house, we anticipate using PVC or modified plastic washers with purchased springs to build these tubing seals. Dimensions for these tubing seals will be a little larger than 1 cm if our current tubing diameter remains at 1 cm.

External Views:

Not Depressed (no fluid flow)

Depressed (fluid will flow)

Internal Views:

Not Depressed (no fluid flow)

Depressed (fluid will flow)

Figure 30 - Internal and External Views for Coffee Filter and Water Tank Pressure Valve

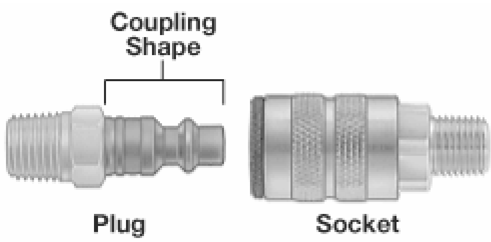


Figure 31 - Quick Disconnect Hose Couplings [6]

We are considering the quick disconnect hose coupling as a possible solution to the interface between the hot water spout and the casing. Furthermore, we are considering the use of these quick-disconnect hose couplings to connect the heating element tube to the water tank. This coupling allows for the quick connection of tubes in an easy and timely manner while making the interface of the tubes free of leakage.

7. Engineering Analysis

7.1 Dimensions

Because the size of our concept and its parts are very important in satisfying customer requirements and engineering specifications, dimensions were an important part of the design process. To begin dimensioning our final design, we started with the engineering specifications dealing with volumes. These included the 40 cm^3 for the coffee grounds, the 473 cm^3 for the brewed coffee, and enough volume in the water tank to produce the required amount of coffee. The volume of water required to produce the required amount of coffee was a result of our benchmark testing, in which about 12 cm^3 of water was absorbed in the coffee grounds (See Appendix A). We further needed to take into account the volumes occupied by the filter and tubing that are enclosed in the water tank (131 cm^3 and 9 cm^3, respectively).

We created a simple spreadsheet algorithm to calculate the required dimensions of the main housing and water tank based on an input of the coffee cup diameter. We then altered this input until we agreed upon a reasonably shaped coffee cup that satisfied the engineering specifications.

Aside from satisfying the engineering specifications, we also dimensioned our final design for manufacturability. For example, we used standard shapes such as rods and tubes for nearly every component of our design. This makes manufacturing easier in that many required dimensions will already be satisfied by the supplier, therefore reducing the amount of machining required. It also reduces cost by saving time and amount of material purchased. We further used standard dimensions, allowing us to easily find choices for drill bits and end mills. For example, our holes used to guide the fluids through the housing walls are ¼" diameter, which can be easily manufactured using a ¼" drill bit. We originally considered using a varying wall thickness in the water tank to decrease the overall size of the design, but ultimately worked around this problem by redirecting the tubing, allowing for a constant wall thickness and therefore increasing manufacturability.

7.2 Tolerances

When tolerancing our design we initially decided to keep non-critical dimensions at ±.01", taking into account both the capabilities of the machines we would be using and the customer requirement to minimize the overall dimensions of our coffee maker. However, after more consideration of our machining experience we changed these tolerances to ±.0625". After reviewing our design we found four areas where tight tolerancing was critical to the ability of our design to either collapse or seal in liquids. These four areas were the interface between the inner diameter of the cup and the outer diameter of the water tank (Figure 46), the combined heights of all parts well collapsed, the interface between the casing and the water tank, and the circumferential position of the guide rod holes. The first three areas were analyzed under root mean square and worse case stack up conditions using a tolerance of ±.0625". From this it was determined that a tighter tolerance of ±.01" was desirable to ensure proper functionality of our coffee maker. The root mean square and worse case stack up calculations can be seen in Appendix G.

7.3 Material Choice

After finalizing the dimensions of our design, we investigated possible material choices. We considered things like cost, availability, manufacturability, physical properties, and effects on the environment before finally deciding on polypropylene and polycarbonate. The most important factor we considered when deciding on our materials was temperature. Because our design uses a 600 W heating element and transports water at 90 ºC, we needed materials that could withstand these high temperatures. We considered using several metals to manufacture our prototype, however, after considering the thermal resistance of these materials, we decided that there would be to much heat transferred through the materials. This could cause potential harm to the user and also cause the coffee mug to lose heat easily after brewing. Polypropylene and polycarbonate both maintain their physical properties for operation temperatures of over 100 ºC. They have good impact strength and a Rockwell R85-R120 hardness rating. Polypropylene is also approved by the FDA to be used as a food and beverage container. They are also environmentally friendly, as both made of thermoplastic material which allow for easy breakdown and reuse of the coffee maker material. Thus, focusing our environmentally friendly aspects of our prototype on materials are easily recyclable.

7.4 "Off-the-Shelf" Components

Because of the complexity and cost of some of the parts required for our design, we decided to use some parts from pre-existing coffee makers. These include some solid tubing, which eliminates some assembly problems that we may have had with our original design that used flexible tubing. We will also be using a 600W Calrod heating element from the Mr. Coffee TF4 Coffee Maker. We decided to use this heating element because it fit our design and custom heating elements are rather expensive. It has further environmental and safety benefits of containing an automatic shutoff once a certain temperature is reached.

7.5 Suppliers

We chose McMaster-Carr as our main supplier because of satisfaction with past experiences and inventory selection. They carried nearly all of the parts we were looking for, and we received our products within 2 days for a reasonable price. Other parts like elbow fittings we decided to purchase from Home Depot in Ann Arbor, because of the proximity and chance to see the parts first-hand before purchasing. The breakdown of our materials and suppliers can be found in the bill of materials (BOM), in Figure 32 on pg 42.

Quantitiy	Part Description	Purchased From	Part Number	Price (Each)	Cut Price
1	3.75” ID x 4” OD” x 3.5” L Polycarbonate Cylinder (ID,OD ± 0.025”)	McMaster-Carr	8585K22	$18.19/ft	$18.19
1	4” OD x 0.125” L Polypropolene Disk (+0.1664”)	McMaster-Carr	8658K65	$29.58/ft	$29.58
1	3.25” ID x 3.5” OD x 4.5” L Polycarbonate Cylinder (ID, OD ± 0.025”)	McMaster-Carr	8585K33	$14.18/ft	$14.18
1	3.5” OD x 0.5” L Polypropolene Disk (+0 .146”)	McMaster-Carr	8658K64	$21.78	$21.78
1	3.5” OD x 4.5” L Polypropylene (+0.146”)	McMaster-Carr	8658k64	$21.78/ft	$8.17
1	6” OD x 5.75” L Polypropylene Disk (+ 0.25”)	McMaster-Carr	8658K67	$63.48/ft	$63.48
1	6” x 6” x 2” Polypropylene Bar Stock	Mcmaster-Carr	8742K97	$13.37	$13.37
2	0.25” OD Polyproylene Rod (+ 0.104”)	Mcmaster-Carr	8685K51	$0.74/ft	$1.48
1	1.5’ ¼” ID x ½” OD Polypropylene Cylinder (±0 .015”)	Mcmaster-Carr	8585K52	$0.20/ft	$0.30
1	¼” ID x ½” OD Blended Rubber/Plastic	McMaster-Carr	52035K23	$1.54/ft	$12.32
2	3.5” OD x ¼” AISI 304 (OD ±0.12”, L +1/8”)	University of Michigan		-	-
1	600 W Heating Element	Mr Coffee TF4 Coffee Maker	-	-	-
1	3/8” OD One-way Valve	Mr Coffee TF4 Coffee Maker	-	-	-
1	Mesh Filter Material	Mr Coffee TF4 Coffee Maker	-	-	-
2	¼” Barb to ¼” Male Pipe Fitting	Home Depot		$1.99	$1.99
2	¼” Barb to ¼” Male Pipe Fitting 90^{o} Male Elbow	Home Depot		1.99	$1.99
1	High Temperature Water Resistant Epoxy	Home Depot		4.99	$4.99
3	O-rings	Home Depot		0.79	$2.37
4	Latches/Hinges	Home Depot		$3.99	$7.98
				Total	$202.17

Figure 32 – Bill of Materials

7.6 Quantitative Analysis

Once we chose our heating element, we needed to perform some heat transfer calculations, in order to determine the material of the hotplate for the reheat option in our final design. This was done by using an infrared temperature sensor courtesy of Professor Massoud Kaviany to measure the surface temperature of the heating element during use. We then calculated the surface area of the heating element that would be in contact with the hotplate. We also set the desired coffee temperature to a "warm to the touch" temperature of 60 ºC. These calculations revealed the impossibility of having a 1/8" polycarbonate bottom on the coffee cup, due to the low thermal conductivity polycarbonate. We set up a spreadsheet to alter the thicknesses and thermal conductivity of the hotplate and cup-base to determine appropriate materials. (See Appendix H)

Following our design review presentation and the feedback we received, we decided that the reheat option was not necessary due to the small volumes of coffee being produced. Furthermore, using a material like aluminum for the bottom of the cup in order to warm the coffee, creates the problem of the coffee cooling down even quicker once removed from the hotplate. Therefore, we reworked the heat calculations using a steel surface to mount the Calrod, in order to determine the maximum temperature of the "hotplate" surface (See Appendix I). We chose steel based on its low thermal conductivity. Using this, the surface temperature is less than 50 ºC, which is less than "warm to the touch". Although this eliminates the reheat option, which is an original customer requirement determined from our student survey, it makes the device safer and allows us to go with the original plan of using a polycarbonate bottom for the coffee cup. (See Appendix I)

The last of our calculations dealt with the handling temperature of the housings of the coffee maker. We needed to determine the "cool-down" time, or the time at which the coffee maker is safe to handle after operation. After performing some more basic heat transfer calculations using a worst-case scenario for assumptions, we determined that the parts most likely to be the hottest (the outer wall of the tubes carrying the hot water) will only reach approximately 35 ºC (See Appendix J). This is due mainly to the large wall thickness and the extremely low thermal conductivities of both polycarbonate and polypropylene. Therefore, our coffee maker can be handled immediately after use.

7.7 FMEA

Because our selected design was collapsible, there are many complex components and interfaces that could fail. To help minimize the modes of failure of our final design we preformed a Failure Mode Effect Analysis, or FMEA. The first step in the FMEA was to identify all components of the design, how each could fail, effects of such failures, and the severity of each failure (S). The possible causes of these failures were then considered, as well as the rate of occurrence of each failure (O). Then, the methods of detection for each failure were listed and given a detection value (D). The values of severity (S), occurrence (O), and detection (D) are multiplied together to form the component RPN values, and all these are added to yield the Overall RPN.

The real value of FMEA is in the step where recommended actions are considered to improve the RPN values of the individual components. In this step, new values for severity (S), occurrence

(O), and detection (D) are designated with respect to the new improvements. The new Overall RPN value allows for a comparison of the initial design to the improved design.

In our project we were able to reduce our Overall RPN from 656 to 310. This reduction was due mostly to improving the many liquid interfaces in the design. For example, the tubing interfaces between the water tank and main housing are one of the most likely failure modes, as seen in Figure 33 below. By sealing these interfaces, we were able to reduce the RPN of this component by 48. Another component that had a large failure occurrence was the filter drawer, due to the likelihood of leaking. We significantly reduced the RPN value of this component by permanently affixing the filter drawer inside the water tank, as opposed having the drawer slide out.

Product Name: Collapsible Coffee M **Development Team:** Matt Plunkett, Kurt McFarlane, Tyler Howard, Kyle Dart

Part # & Functions		Potential Failure Mode	Potential Effects of Failure	Severity (S)	Potential Causes/ Mechanisms of Failure	Occurrence (O)	Current Design Controls/Tests	Detections (D)	Recommended Actions	RPN	New S	New O	New D	New RPN
Calrod heating	Add heat	Electric short	Coffee maker inoperable	8	Faulty wiring or water	2	Ammeter / Fuse	6	Insulate all wires	**96**	8	1	6	**48**
Water tank	Contain water	Dropped, Incorrect Material, Thermal Cycling	Failure of water tank, Leaking	5	Excessive use wear	2	Normal operation	1	Tolerance tank correctly	**10**	5	1	1	**5**
Power cord/ switch	Supply electricty	Electric short	Coffee maker inoperable	8	Faulty wiring or water	2	Ammeter / Fuse	4	Insulate all wires	**64**	8	1	4	**32**
Dispenser supply tube	Drip water	Cyclic Wear	Difficult to move filter drawer	3	Excessive Use	2	Normal operation	3	Material selection and tolerancing	**18**	3	1	3	**9**
Filter	Contain grounds	Tearing	Grounds enter brewed coffee	3	Removing filter	2	Sight	2	Make filter easy to remove and robust	**12**	3	1	2	**6**
Filter drawer	Contain grounds	Leaking	Creates mess	8	Poor sealing	5	Sight	1	Permantly affix drawer in water tank	**40**	8	1	1	**8**
O-ring	Seal components	Leaking	Creates mess/safety hazard	6	Wear, cracking, incorrect installation	3	Sight	3	Material selection and tolerancing	**54**	6	2	3	**36**
Guide rods	Guide housing collapse	Wear	Seizure of water tank	5	Excessive use wear	3	Normal operation	2	Material selection and tolerancing	**30**	5	1	2	**10**
On/off switch	Maintain heat control	Electric short	Coffee maker inoperable	8	Faulty wiring or water	2	Ammeter / Fuse	5	Insulate all wires and connections	**80**	8	1	5	**40**
Tubing	Guide liquids	Leaking	Creates mess/safety	8	Multiple interfaces	5	Sight	3	Seal interfaces	**120**	8	3	3	**72**
Calrod housing	House electronics	Burning	Creates safety hazard (burn)	8	Calrod too hot	2	Thermo couple	3	Material selection or vent	**48**	5	1	3	**15**
Main housing door	Stop heat/Reduce Noise	Wear	Door can seize/become inoperable	4	Excessive Use	3	Normal operation	2	Sturdy hinge selection	**24**	4	1	2	**8**
Hotplate	Reheat coffee	Thermal Expansion	Crack Main Housing	6	Tight fit/tolerances	2	Sight	5	Space to allow for expansion	**60**	7	1	3	**21**
									Total:	**656**				**310**

Figure 33 – Table of results for Failure Mode Effect Analysis (FMEA)

7.8 Design for Manufacturability

In order to make our design physically feasible and to cut down manufacturing and assembly time, we analyzed our design for manufacture ability. We used standard material shapes, like tubes and rods, for all of the components of our design. This allows parts to be easily ordered from suppliers, and reduces machining time. We also used standard dimensions, allowing us to easily find the required tools such as drill bits. For example, for the tubing inside of the housing we designed the holes to use a standard ¼" drill bit. We avoided long, bent holes to reduce manufacturing difficulties. Our original design called for a bent hole in the Calrod housing, which we realized would not be possible to machine accurately. We avoided this problem by having the tubing connected to the Calrod make the turn instead of an internal hole. We also considered a varying wall thickness on the water tank to increase the volume of the water tank while still fitting internal tubing in the walls. A varying wall thickness is difficult to machine, and we eliminated this problem by using a tube inside of the water tank instead of holes through the wall. This allowed us to use a uniform and thinner wall thickness.

7.9 Design for Environment

We also considered the environment when finalizing our design. In order to reduce the environmental footprint of our product, we used renewable materials such as polypropylene and polycarbonate. We reduced the use of consumables by making a reusable filter. We also reduced energy consumption by choosing a Calrod with an automatic heat shutoff system. Our final design integrates product functions by including a reheat option, and is easy to maintain and replace parts for repair, eliminating the need to purchase an entire new product when something fails.

8. Final Design

8.1 Final Prototype Design

Figures of the final prototype design assembly and individual components can be seen in the following section. Changes have mainly been made to the filter and water tank. We chose to alter the design of these parts per a request of our sponsor, April Bryan, to help minimize user safety hazards and maximize the functionality of the coffee maker. To redesign these parts, we focused on integrating the filter into the inside of the water tank. We also chose to move any exposed tubing outside the coffee maker to the inside to prevent burning the user.

We will be able to manufacture our final design in working, full-scale prototype form using materials listed in the Bill of Materials (BOM) in Figure 32 and traditional manufacturing methods seen in the Manufacturing section.

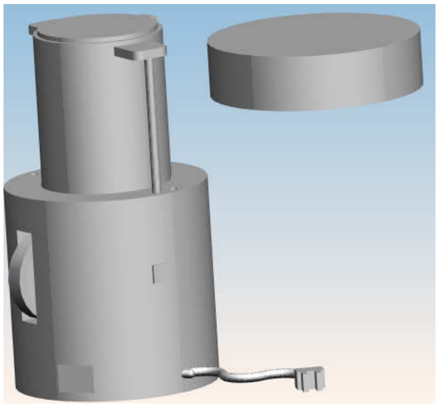


Figure 34 – Isometric View of Assembled Coffee Maker

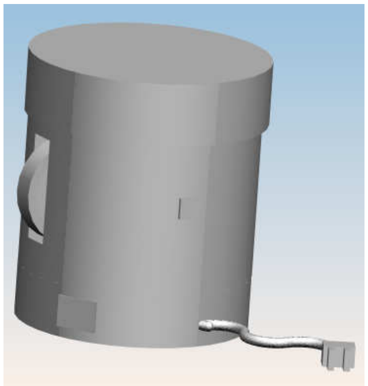


Figure 35 – Isometric View of Collapsed Coffee Maker

The final prototype design collapses very similar to the selected final concept design. To collapse, simply remove the water tank permanent rods from its holes located at the edge of the casing. Then, slightly rotate the casing and place the permanent rods in the holes located in the door and casing. The figures help illustrate the collapsing of the water tank into the rest of the coffee maker.

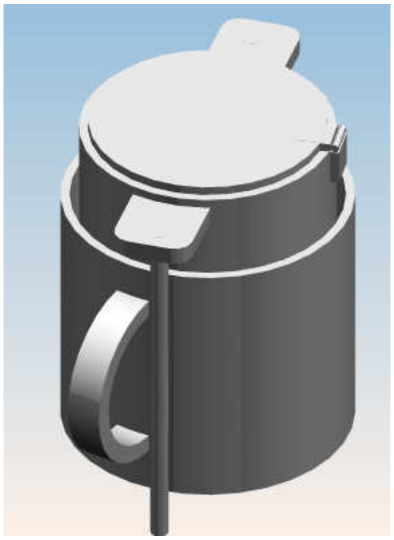


Figure 36 – View of Water Tank Collapsing into Coffee Mug

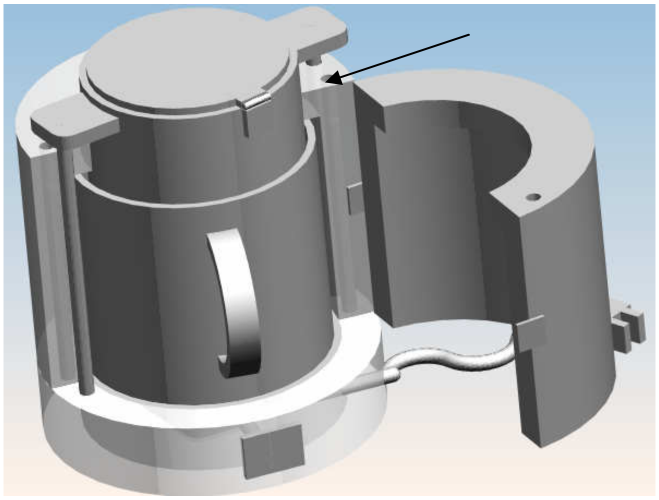


Figure 37 – Semi-collapsed View of Coffee Maker Assembly

8.2 Individual Components

Below are figures of the individual components of the coffee maker. These components are very similar to the original components discussed in the Selected Concept section. As mentioned above, we decided integrate the filter and water tank to improve functionality and prevent burning. For the purpose of clarity, we have separated the filter and water tank images for the purpose of this report only. They will appear as one part in the final prototype.

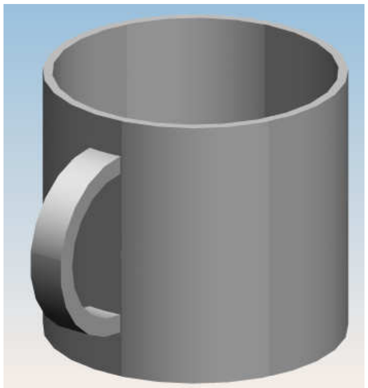


Figure 38 - Isometric View of Coffee Mug

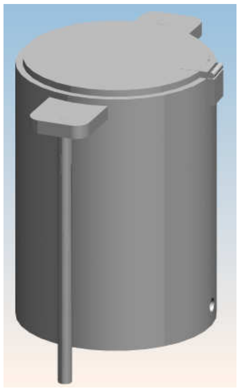


Figure 39 - Isometric View of Water Tank

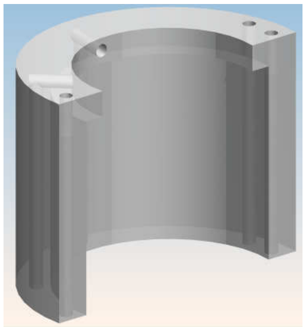


Figure 40 - Isometric View of Casing

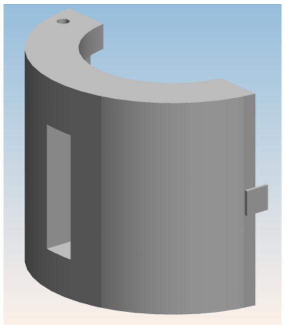


Figure 41 - Isometric View of Casing Door

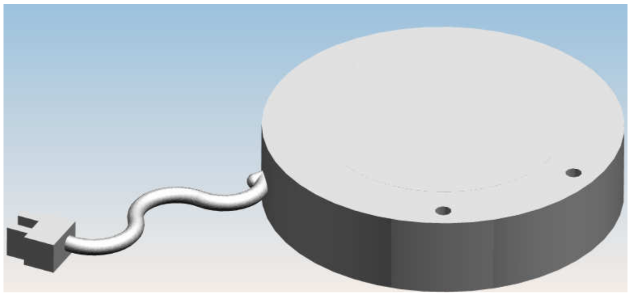


Figure 42 - Isometric View of Heating Element

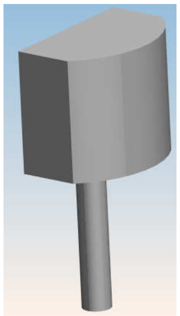


Figure 43 - Isometric View of Filter

8.3 Changes to Selected Concept

Integration of the Filter and Water Tank. To integrate the filter and water tank, we focused on keeping a relatively similar filter shape while maintaining adequate volume of both the water tank and the filter. This will allow the coffee maker to hold enough water and coffee grounds to make the desired 473 mL (16 oz.) of brewed coffee. The filter will be placed towards the top of the water tank and will have a lid to keep any water out that may try to enter through the top of the filter. Hot water will enter through the bottom side of the water tank, travel up a tube located on the side of the water tank, and then sprayed over the coffee grounds. The lid on the filter will keep any hot water from flying out of the tank and potentially harming users. A schematic of this water flow can be seen in Figure 45.

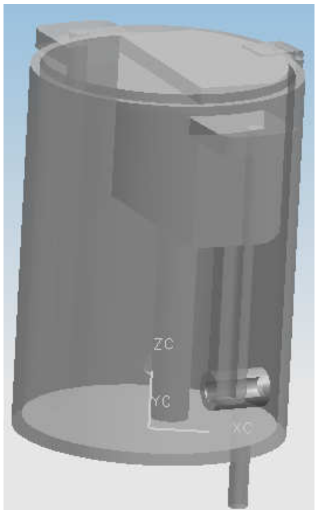


Figure 44 - Integrated Filter and Water Tank

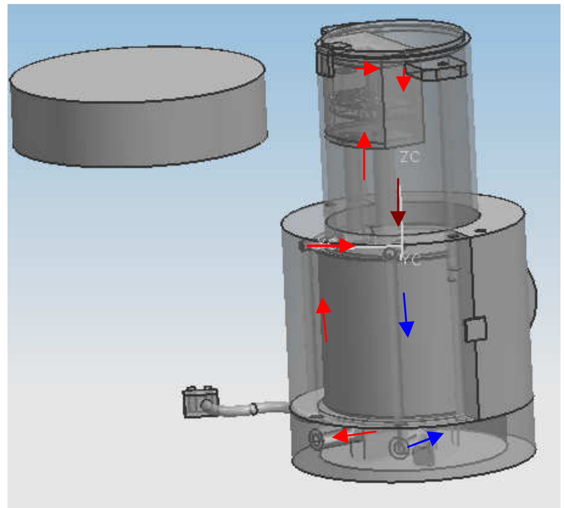


Figure 45 - Schematic of Prototype Water Flow

Integration of the filter and water tank will also increase the manufacturability of our coffee maker. Previously, the filter and water tank would be connected by the filter sliding in and out of the water tank. This would require manufacturing half of the filter and then assembling it with the water tank, similar to how a dresser drawer works. By integrating the filter and water tank, we are able to fix the filter to the top of the water tank. This will improve manufacturability because we will not have to worry about the precise lining of holes for water flow when the filter slides. With the integration of the two parts, the holes that allow for water or coffee ground flow will be fixed and not require precise dimensions.

Replacement of Spring-loaded Sealing Mechanisms with O-rings. After considering solutions to help minimize leaking both during use and transport, we have decided to switch from spring-loaded sealing mechanisms (as seen in Figure 30) to standard O-rings and dimensions with tight tolerances where there is critical fluid flow. Figure 46 shows where O-rings will be used in our prototype, however, due to the complexity of our design, O-ring location may be hard to see. The locations of O-rings are mainly where there is any tubing that is broken into parts and then there will be an O-ring to help seal the tubing when the pieces are fit together. For example, we will use an O-ring to help seal the cold and hot water tubes in the casing to the water tank. This solution should allow for leak-free fluid transport and will not be limited by the dimensions of the spring-loaded sealing mechanism. Furthermore, the replacement of the spring-loaded sealing mechanism with O-rings should reduce both prototype and mass production cost.

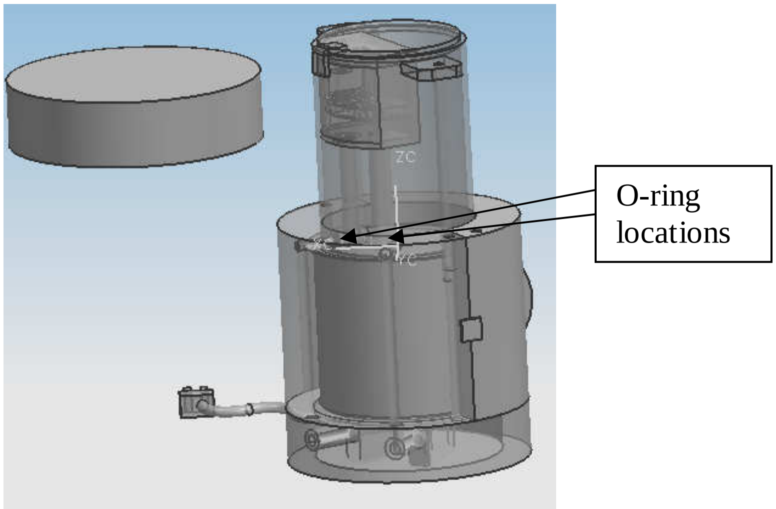


Figure 46 - Location of O-rings

Replacement of Telescoping Poles with Permanent Rods. For our final prototype, we decided to replace the telescoping poles on the side of the water tank with permanent rods. The main reason for this change is because we desired very small telescoping rods, smaller than what we were able to find after consulting several internet sources. The same function of the telescoping poles can be achieved using permanent rods which also prove to have some added benefits and will not require us to the spring-loaded push pins as mentioned earlier in the report. Permanent rods allow for easy removal of the water tank and filter to make cleaning easier. These rods will also ensure that when the coffee maker is in its fully collapsed position, the two rods will accompany the hinge and lock in securing the door to the casing by simply playing the rods in their "brewing position holes" or their "collapsed position holes." These holes are drilled to a certain desired depth and then the rods are inserted in one of the two sets of holes depending on whether you desire to brew coffee or collapse the coffee maker. This can bee seen in Figure 47 below.

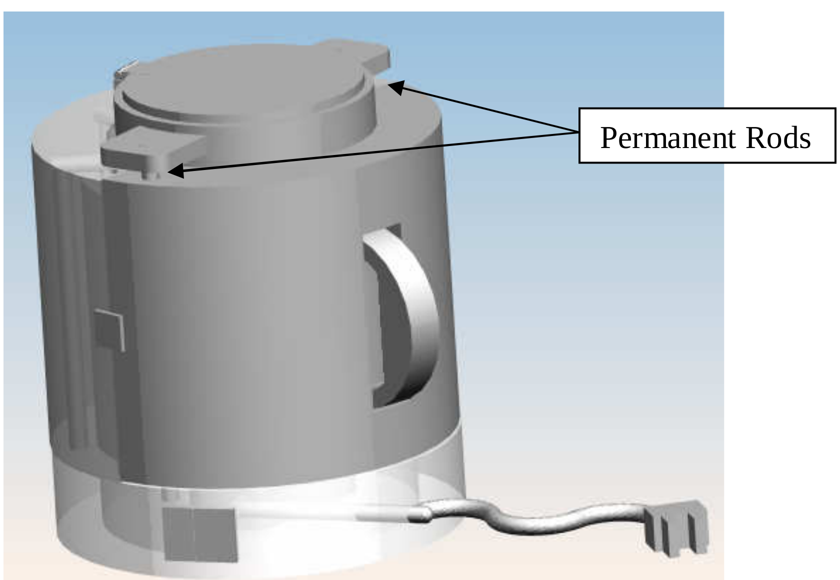


Figure 47 - Permanent Rods to Secure Casing Door

8.4 Engineering Drawings

Figures 48 and 49 below show the coffee maker assemblies. Engineering drawings of the individual coffee maker components can be seen in Appendix K. Dimensions of these drawings were determined based of our original engineering specifications given to us by our sponsor, April Bryan. Important engineering specifications, such as coffee brew volume and volume of coffee grounds, determined other dimensions of our coffee maker. We needed to make sure that our final design would be able to meet these heavily weighted engineering specifications. Other important dimensions were hole sizes and the wall thickness of the casing. Furthermore, to ensure that our water tank would be able to collapse into our coffee mug, we had to make sure that there the outer diameter of the water tank was slightly smaller than the inner diameter of the coffee mug so they would easily fit into each other. Explanations for these engineering drawing tolerances can be seen in the Engineering Analysis section above. All dimensions are in inches. Inches were used because this was the measurement unit used by our material suppliers and machines used for manufacturing.

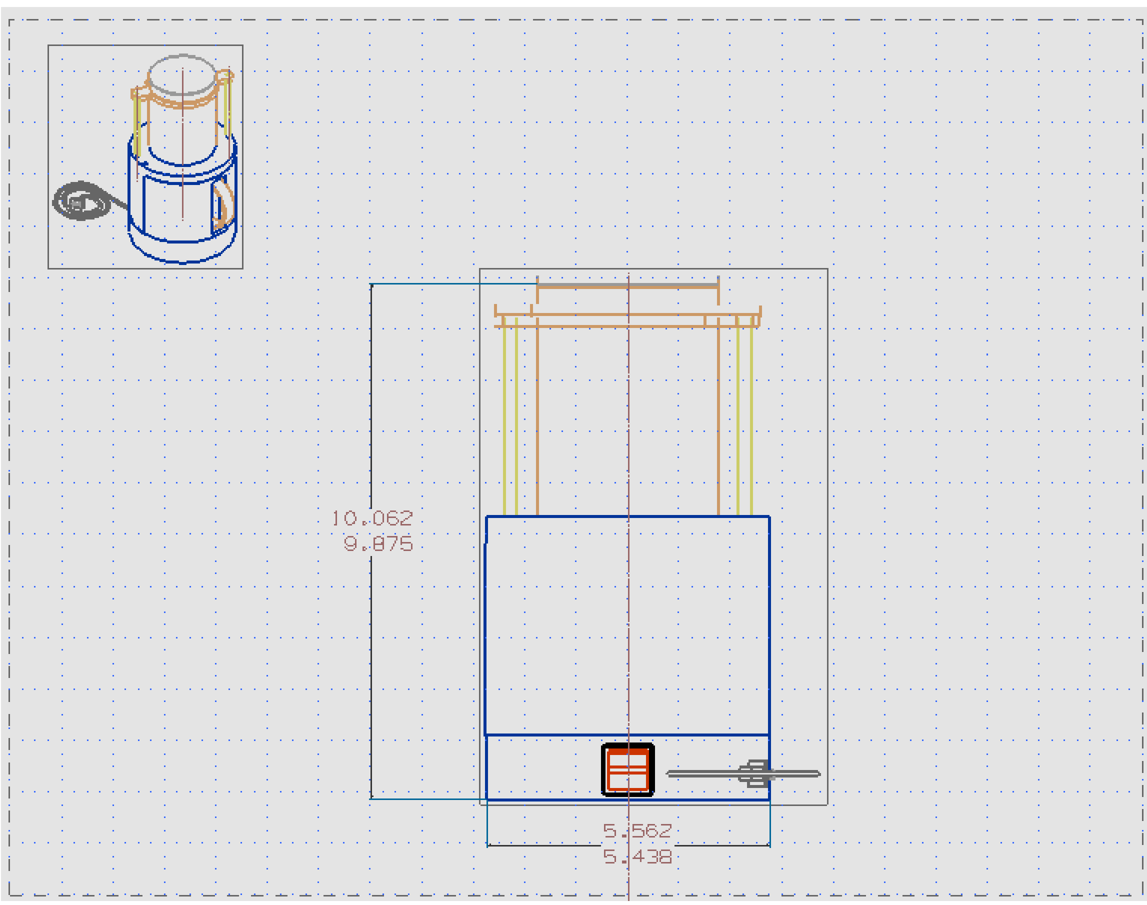


Figure 48 - Engineering Drawing of Coffee Maker Assembly in Expanded Position

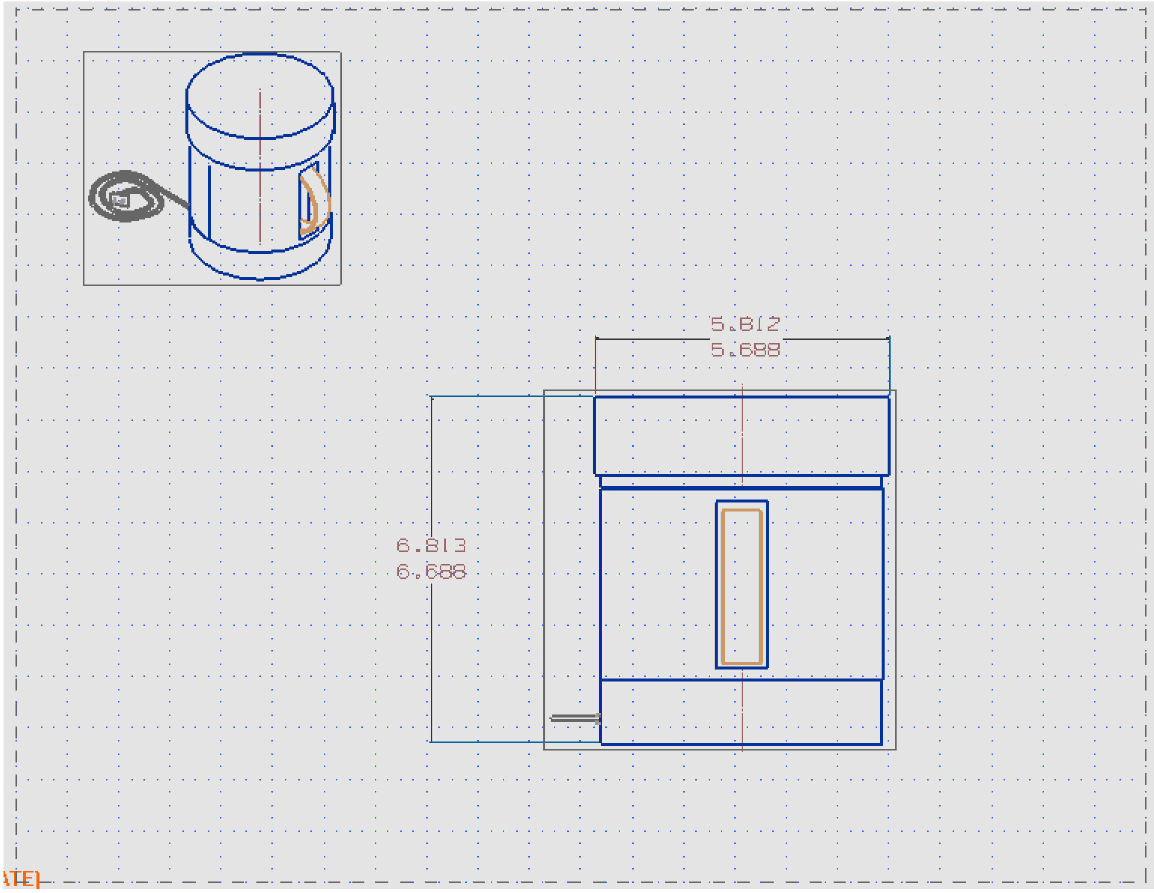


Figure 49 - Engineering Drawing of Coffee Maker Assembly

8.5 Achieved Engineering Specifications

The table below shows our original engineering specifications, whether our prototype has met these engineering specifications and if so, how they were achieved.

Table 5 - Achieved Engineering Specifications

Engineering Specification	Target Value (Actual)	Specification Achieved?	Description
No. of Hazards	0 (0)	Y	Internal tubing and heating element. Removal of reheat hot plate
Volume Leakage	0 mL (0 mL)	Y	O-rings with tight dimensional tolerances
Volume of Coffee	473 mL (490 mL)	Y	Adequate water tank volume
Volume of Grounds	40 cm^3 (40 cm^3)	Y	Adequate filter volume
Brew Temperature	93 °C	Y	Use of existing

	(98 °C)		coffee maker heating element
Travel Volume	2300 cm^3 (2262 cm^3)	Y	Collapsible water tank into coffee maker casing
Brew Time	300 s (266 s)	Y	Use of existing coffee maker heating element
No. of Parts	6 (3)	Y	Integration of filter and water tank
Decibel Level	50 dB (35 dB)	Y	Internal tubing and calrod housing
Weight	1.8 kg (1.2 kg)	Y	Thermoplastic material with low density
Reheat Temperature	60 °C (45 °C)	N	Removal of hot plate to reduce safety hazards
Price	$35 ($22)	Y	500,000 cycle mold with 2 cavities
No. of Colors	4 (3)	N	Use of dyes with injection molding

As you can see from the above table, our final prototype meets the majority of our engineering specifications. We did not meet the specifications of the reheat plate; however, this specification was weighted with little importance in our QFD diagram (see Figure 5) and was likely the result of changing the hot plate material from aluminum to steel. We also did not meet the customer specification of No. of Colors because of the difficulty in painting individual pieces after assembly. To determine if our final design meets the engineering specifications of Price (mass production), No. of Colors, Decibel Level, and Weight, we need to perform prototype testing and a mass production cost analysis. We were also under our $400 prototype by about $150, which puts the total cost of our prototype at about $250.

9. Manufacturing and Testing Plan

9.1 Prototype Manufacturing

Due to the large number of parts required by the final design, manufacturing processes will play a major part in our project. Following the correct orders of operations will be imperative to ensure a successful final prototype. We have determined and described these operation orders for each component, as seen in the process plan sheets in Appendix L. As can also be seen in these process plans, no one component is very complex. However, the large number of components, and the interaction of these components presents difficultly and basis for much of the manufacturing work.

Very few components of the prototype design will be purchased or used from other coffee makers. The components that will be include the heating element, supporting electronics and a one-way valve. All of these components will be taken from an existing coffee maker model, the Mr. Coffee TF4. There will also be one plastic fitting which will be purchased at a hardware store, which will be used to connect tubing. The epoxy, and other assembly tools needed, will also be purchased from the hardware store.

The components of our design that we manufacture ourselves will include the main housing, main housing door, water tank, filter compartment, filter, guide rods, guide rod supports, Calrod housing, hot plate, all lids and all the tubing. The hotplate will be manufactured using 1/8” steel sheet, while the rest of the components will be manufactured using high temperature, plastic materials. The main housing, main housing door, filter compartment, Calrod housing and lids will be manufactured using Polypropylene. The remaining components will be manufactured using Polycarbonate materials. The reason for the two different plastics is due to availability and price of the stock material needed for certain components. Both materials have an operating range well above 200 ^{0}F as described previously. All material stock will be ordered from McMaster-Carr, no later than November 12th, 2007, to allow for manufacturing to begin on November 16th, 2007.

9.2 Mass Production

Although our design requires a large number of individual components, mass production of our design would utilize an entirely different manufacturing process. Injection molding would vastly simplify manufacturing, as the entire design could be produced with as little as two molds. Furthermore, injection molding could also allow to a new interface design between the main housing and water tank, leading to better function and reliability. Injection molding would also allow for an improved telescoping mechanism, eliminating the need to remove the water tank entirely. Finally, injection molding would also allow dimensions to be optimized and more aesthetically appealing shapes and colors to be used.

In addition to injection molding, with mass production, a heating element which was tailored to the design application could be developed. This would allow for decreased energy use, decreased operation cost and a decrease in the overall production cost of our product. All of these mass production improvements would lead to faster production time and lower manufacturing costs, allowing the final product to be competitive with other models on the market. Mass production would also use all recyclable materials to improve environmental “friendliness” of product.

Performing some cost analysis for our desired mass production, we would be able to use a 500,000 cycle mold with 2 cavities per mold for our medium complexity coffee maker pieces. We would continue to use polypropylene with injection molding, which would be the primary cost of our mass production. The table below summarizes our mass production calculations [7].
The category of Other below accounts for things such as hinges (latches would be snap-fit mechanisms), thermal paste, and dyes to improve the aesthetics. We found that using this process, we could produce our coffee maker for approximately $22.

Table 6 – Mass Production Summary

Material Type	Polypropylene
Mold	500,000 cycles
Process Cost	*$1.00*
Materials	*$15.000*
Tooling Cost	*$0.05*
Heating Element	*$5.00*
Other	*$1.00*
Total Cost	*$22.05*

9.3 Future Improvements

The functionality of our design was exactly how we intended and leaves little room for improvement. Focusing on the aesthetics and reducing the overall volume of the product however are the main areas that could be improved upon. The overall dimensions of the coffee cup and water tank could be altered to produce a leaner but taller overall size. This would make it easier to fit into something like a backpack. Also if the design were injection molded tighter tolerances could be held and the overall volume of the coffee maker would be significantly reduced.

The aesthetics of the design could be improved upon by possibly eliminating sharp edges with rounded ones, or implementing a tapered design on the outer housing. If it were injection molded the cylindrical shape could be re-designed to improve aesthetic appeal.

9.4 Testing Plan

As with any design prototype, thorough testing of the final prototype will be required to ensure all design requirements are met, and necessary improvements can be made. Upon completion of our prototype, we plan to test our prototype for the following; proper function, brew time, brew capacity, brew temperature and cooling time of brewed coffee.

Proper Function. For proper function, the prototype must be able to brew without any leaks forming. If leaks were to form, sealing at liquid interfaces would be improved until leaks cease. To test for leaks, we ran the coffee maker under normal conditions and inspected the coffee maker for any leaks. At the end of manufacturing, our prototype had a leakage volume of 0 mL, fully meeting our engineering specification.

Brew Time. To test brew time, the prototype must average a brew time less than five minutes. If test for brew time fails, it is possible to replace the heating element to decrease the brew time. This can be accomplished by either increasing the volume of the heating element, or increasing the power input to the heating element. After performing several test runs for the coffee maker we found the average time to brew 473 mL of coffee, as 266 seconds or 4 minutes and 26 seconds.

Brew Capacity. The test for brew capacity will test for the volume of coffee brewed, to ensure the final volume of coffee is at least sixteen fluid ounces. If this final brewed coffee volume is found to be less than the required amount, the size of the water tank can be increased, although this would be dependant on the amount of time available. We ran our coffee maker with the desired engineering specifications of approximately 500 mL of water (enough to brew 473 mL of coffee with saturation through 40 cm^3 of coffee grounds). After brewing, we found that the coffee maker brewed 490 ml which exceeds the minimum amount of 473 mL of coffee.

Brew Temperature. Brew temperature as previously defined in the report is the temperature of the water leaving the heating element. Measuring such a temperature would require the use of a thermocouple which is not feasible for our project. However because we used the heating element from the Mr. Coffee Maker T4 coffee maker we thought it reasonable to assume that this heating element was designed for the desirable brew temperature of 93 ºC.

Cooling Time. While no specific requirements were created or given about the cooling time of our coffee, with the elimination of the reheat option, we want to ensure the brewed coffee does no lose heat too quickly. To accomplish this, we will measure the variation of coffee temperature with time, beginning as soon as the coffee is brewed. If cooling time is determined to be to short, changes can be made to the coffee cup to increase this period of time, most likely thermal properties. To measure the cooling time of the coffee, we took the temperature of the brewed coffee immediately after it was made. Temperatures were taken every minute until the coffee maker reached room temperature. After performing this test, we determined that the coffee reached approximately room temperature (25°C) after approximately 20 minutes.

Decibel Level. To test the decibel level of our prototype, we will use a decibel meter and monitor the coffee maker throughout the coffee making process. We will compare this with current coffee maker data to see if there is any noise reduction due to internalized filter components. Using a decibel meter to measure the approximate amount of noise made by the coffee maker during brewing, we found that the maximum amount of decibels emitted by the coffee maker when running was 35 dB, approximately the noise level of an office. This is approximately a 15 dB reduction from current designs which is desirable for a quiet library atmosphere.

9.5 Engineering Change Notice

As we began manufacturing, difficulties arose that required us to change our final design. These changes were made both to simplify our design and ease the manufacturing process. The largest of these changes was eliminating the sliding motion of the filter box so that the filter box was stationary within the water tank. This was done to eliminate the possibility of leakage at the opening where the filter box came through the water tank wall and didn't affect the designs collapsed height. Making the filter box stationary also allowed us to replace two sliding tube interfaces with two stationary interfaces making our final design more robust. The second change we made was to eliminate the hot plate per suggestions of design review 4. We decided to eliminate the hot plate for two reasons. First, the material used for the cup was chosen for its ability to resist heat conduction. Therefore it would not serve as a good conductor between the hot plate and coffee, and changing to a more conductive material would pose a safety hazard. Second, the volume we are brewing is sufficiently small and is intended to be consumed in one sitting, a time frame which the cup is capable of keeping the coffee hot for. However a steel hot plate was used in place of the aluminum hot plate because it was rigid and fit the thin profile that we had planned for the aluminum hot plate and had a much lower thermal conductivity thus posing no hazard to the user. The third change made to our final design was eliminating the lid latch and threads and manufacturing the lid as press fit to eliminate additional parts and assembly processes. Lastly, the casing door was cut ½" below its top surface opposed to through the top surface as planned. This was done to better support the water tank when the door is opened and to add aesthetic appeal.

10. Project Plan

For the first month of our project our tasks and their completion were determined primarily by the ME 450 class timeline and our sponsor's requests. Thus far the team has been able to complete all tasks assigned within their respective timelines. As we continue further into the design stage, the tasks necessary to the completion of our project will be less universal and more specific to our group. To help our understanding of what these tasks are and how they fit into the timeline of the semester, we created a Gantt chart (Appendix C).

The Gantt chart shows a timeline for our project from initial research to prototype completion and display at the design expo. While many tasks can be simultaneously completed, there are essentially four stages to our project whose order is crucial to a successful final product. These stages are research, design, prototyping, and review. We have finished the research and design stages. We have finished the engineering analysis, both quantitative and qualitative, and have begun manufacturing our prototype.

The completion of this report signifies the end of our collapsible coffee maker senior design project.

11. Conclusions

Through market research and customer surveys we discovered a demand for portable coffee makers amongst college students and a lack of such products in the current market. We then benchmarked and disassembled coffee makers currently on the market to better understand their technology and what should be expected from our portable coffee maker. Compiling this test data, with suggestions from our sponsor and survey results, we developed 13 customer requirements. With these requirements we determined engineering specifications for our project. Understanding what is necessary for our project, we then laid out a plan to guide our work through the rest of the semester.

After performing a functional analysis using a FAST diagram, developing individual concept ideas using a morphological chart, and evaluating our highly-refined design ideas using a Pugh chart, we were able to arrive at 2 final design concepts. These 2 concepts, which can be found in the Selected Concepts section above, consisted of one collapsible design and one non-collapsible design. After further discussion with our sponsor, April Bryan, our senior design professor, Yoram Koren, and a discussion with our peers, we determined that selected concept #2 (enclosed cup) was the most favorable design.

Next, we refined our selected concept through qualitative analysis such as designing for manufacturability, designing for the environment, and failure mode effect analysis. We further performed quantitative analysis through heat transfer calculations and moment balances to determine both dimensions and physical properties of required materials. After completely refining our concept into a final design, we produced manufacturing plans and ordered materials to begin prototyping.

From initial research to a final prototype, we've learned a great deal about the design process. It's a long and grueling progression, with the success of each step depending critically on all of the previous steps. Performing an initial thorough research and benchmark testing allowed us to formulate accurate customer requirements. These were then translated into engineering specifications, allowing us to produce feasible concepts satisfying the required specifications. With various quality concepts we were able to combine and select the best aspects of each to form a single design. We then analyzed this design and formed a final design, ready for manufacturing. Investing time and effort in every step allowed us to create a successful prototype and final design ready for mass production.

12. References

[1] www.amazon.com

[2] http://www.google.com/patents

[3] The National Coffee Association of USA, (www.ncausa.org)

[4] http://en.wikipedia.org

[5] http://www.klamathfallsairport.com/Master_Plan/06-Figure_6A.pdf

[6] http://www.mcmaster.com

[7] http://kazmer.uml.edu/Software/JavaCost/index.htm

13. Acknowledgements

We would like to thank our Professor Yoram Koren and sponsor April Bryan for all of their valuable time and effort in instructing and guiding us through the design process. Their contributions were a large part of the success of our project.

14. Bios

Kyle Dart

My name is Kyle Dart and I was born and raised in southwest Michigan, about one and a half hours directly west of Ann Arbor. I grew up on golf courses, the family business, and as a result like to golf and drive golf carts around. I also played many other sports growing up, including soccer, tennis, baseball, basketball, and hockey. When I was sixteen, I got my first car which was a GMC pickup truck. Since then, I have developed a strong interest in all cars, and specific interest in classic cars. I am a member of MRacing, the Formula SAE team, and I worked for automotive restoration company during the summer. I have also restored my own cars and helped with friends. My strong interest in cars is what led me to be a Mechanical Engineer. I hope to find a career in the automotive industry, working with drive train manufacturing. I would like to get an MBA, and eventually open my own business, in either automotive restoration or real estate development/management.

Tyler Howard

My name is Tyler Howard. I was born and raised in Kalamazoo, MI. I have one older brother, Chad who in the last year and a half graduated and got married so that has been a lot of fun. Despite only having one sibling, I still have a huge family and they are a big part of my life. I also have a girlfriend of almost six years. She attends Grand Valley State University in Allendale, MI.

I decided to become a mechanical engineer because of my interest in cars and overall curiosity in how things work. I think mechanical engineering stood out over other disciplines simply because of my interest in the automotive industry. Over the summer I worked for Parker Hannifin in Otsego, Michigan in their research and design department. My main tasks involved creating 3d models of brass fittings for industrial trucks from engineering drawings. I enjoyed the job and it was my first internship so I learned a lot from it. I am currently working for SABO USA who provides liquid seals for the big three and a few other companies. I started there in August and have been working part time through the school year. I really enjoy my job and the people I work with and wouldn't mind beginning my career there or with a similar company. Through SABO I have gotten a lot more experience in how industry works through plant visits and sales meetings. It has been a lot different than my experience with Parker mainly because our office for SABO has only twenty people. I think it is really nice to know everyone you are working with on such a personal level.

I am excited for graduation although like everyone else I don't know what to expect. I'd like to stay around Michigan for the time being because of my family ties and also my girlfriend. Once I find a job and get settled in I'd like to look into a masters program, in something like engineering management. Later on I'd also like to get my teaching degree to teach math or maybe something more hands on like drafting or automotive class. I think teaching would be a really rewarding experience and a great way to give back.

Kurt McFarlane

Kurt is from Romeo, MI, a town about 30 minutes north of Detroit, MI. He is a graduate of Romeo High School where he was a member of the Varsity Lacrosse team, a reporter for the school newspaper, and also took several classes in Math and Science. He will be graduating in December 2007 with a degree in Mechanical Engineering and a minor in Mathematics.

During summer 2007, Kurt worked in Dubuque, IA as an engineering intern for John Deere & Company. Dubuque, IA is located right where Illinois, Wisconsin, and Iowa meet on the Mississippi river. During this experience, Kurt was able to work on several projects pertaining to construction & forestry equipment, including the redesign of several Backhoe Loader components. In addition to helping with the engineering of these products, Kurt was also able to drive several of the construction and forestry equipment. His favorite piece of equipment to operate was the John Deere 450 D Excavator and the Tracked Feller Buncher. He liked these machines because they were the most interactive with the environment. With the Excavator, you are able to move large amounts of dirt in a small amount of time. With the tracked feller buncher, you are able to harvest and group large trees in a small amount of time.

After graduation, Kurt hopes to pursue a career in product design or control system design for a large, multinational corporation. In his spare time, Kurt enjoys a wide variety of activities, ranging from volunteering in the community to trading stocks and options.

Matt Plunkett

I was born in the NYC suburb of Harrington Park, New Jersey. Both of my parents grew up in Harrington Park and still currently live there. I have an older sister currently teaching in West Palm Beach, Florida, and a younger brother in high school.

I attended Old Tappan High School where I became interested in subjects like math, physics, and technical drawing. I always knew growing up I would become an engineer or an architect, and ultimately decided on mechanical engineering. I chose Michigan because I wanted a school that could provide both a good education and a good sports program. I am an avid football fan, having played from the 2^{nd} grade through High School and having attended New York Jet games throughout my life.

I've worked at a local country club for 7 years both caddying and working in the bag-room. In the summer of 2006, I participated in a 6-week study abroad program in Berlin, Germany. The following summer of 2007, I obtained in internship with Porsche in Leipzig, Germany. I worked there for 3 months in the program planning and control department at their Cayenne factory. I simulated production lines, worked a little bit with PLCs, and created algorithms for unloading car bodies from a train. Following the internship I traveled to Italy for 2 weeks (Picture is taken in Florence) and Ireland for a week with my family.

In the next coming months I hope to obtain a job in the defense industry or a government agency working with control systems and perhaps utilizing my knowledge of German. I plan to minor in Mathematics and continue taking German language classes. As far as hobbies go, I enjoy reading classical literature and modern non-fiction, and working on and building computers.

Appendix A - Full Comparison Test Results

Model	Grinds	Volume In	Volume Out	Volume Grinds	Brewing Time	Coffee Temp	Reheat Temp	Avg. Time	Avg. Temp
Cuisinart 10 Cup	Folgers Coffeehouse Series Breakfast Blend (Mild)	(1.5 fl. Cups)	1.25 fl cups	2 level tbsp.	~4:30	140*			
	Folgers Coffeehouse Series Gourmet Supreme	(1.5 fl. Cups)	N/A	2 level tbsp.	3:29	138*			
	Folgers Coffeehouse Series 100% Columbian	(1.5 fl. Cups)	1.25 fl cups	2 level tbsp.	3:00	131*			
	Meijer House Blend Coffee	(1.5 fl. Cups)	1.25 fl cups	2 level tbsp.	4:47	140*		3:57	137
Braun 4 Cup	Folgers Coffeehouse Series Breakfast Blend (Mild)	(1.5 fl. Cups)	1.125 fl cups	2 level tbsp.	~4:10	130*			
	Folgers Coffeehouse Series Gourmet Supreme	(1.5 fl. Cups)	N/A	2 level tbsp.	3:34	130*			
	Folgers Coffeehouse Series 100% Columbian	(1.5 fl. Cups)	1.25 fl cups	2 level tbsp.	3:40	134*			
	Meijer House Blend Coffee	(1.5 fl. Cups)	1.25 fl cups	2 level tbsp.	3:32	138*	142*	3:44	133
Mr. Coffee 4 Cup	Folgers Coffeehouse Series Breakfast Blend (Mild)	(1.5 fl. Cups)	1.25 fl cups	2 level tbsp.	~5:00	140*			
	Folgers Coffeehouse Series Gourmet Supreme	(1.5 fl. Cups)	1.125 fl cups	2 level tbsp.	3:47	130*			
	Folgers Coffeehouse Series 100% Columbian	(1.5 fl. Cups)	1.375 fl cups	2 level tbsp.	3:47	120*			
	Meijer House Blend Coffee	(1.5 fl. Cups)	1.25 fl cups	2 level tbsp.	4:00	125*	139*	4:08	129
Sanyo 6 Cup	Folgers Coffeehouse Series Breakfast Blend (Mild)	(1.5 fl. Cups)	1.125 fl Cups	2 level tbsp.	~4:00	130*			
	Folgers Coffeehouse Series Gourmet Supreme	(1.5 fl. Cups)	0.875 fl cups	2 level tbsp.	6:55	120*			
	Folgers Coffeehouse Series 100% Columbian	(1.5 fl. Cups)	1.125 fl cups	2 level tbsp.	2:55	138*			
	Meijer House Blend Coffee	(1.5 fl. Cups)	1.25 fl cups	2 level tbsp.	3:10	130*		4:15	130
Avg.								**4:01**	**132**

	REHEAT PLATES	
Model	**Time**	**Temp**
Braun 4 Cup		
	10 min	138*
	17 min	146*
Mr. Coffee		
	10 min	142*
		135*
	12 oz = 1.5 fl cups = 2 cups of coffee	

Appendix B - Preliminary Power Calculations

C_p of H_2O

@ $25°C = 4.1813 \frac{J}{gK}$

@ $100°C = 2.080 \frac{J}{gK}$

Optimal Brew Temp

$T_{0,Brew} = 200°F = 366.48\ K$

$T_{start} \cong 25°C = 298\ K$ (Room Temperature)

$\rho_{H_2O} = 1 \frac{g}{cm^3} = 1000 \frac{g}{L}$

1 cup (Volumetric) = .236588 L

2 cups (Volumetric) = .473176 L = 473.176 g of H_2O

Using average C_p,

$$C_p = 3.131 \frac{J}{gK}$$

$$\Delta T = (366.48 - 298)K = 68.48\ K$$

$$\text{Work (2 cups)} = 3.131 \left[\frac{J}{gK}\right] 68.48 [K] (473.176) g$$

Δt = Brew time

$$W = 101454.18\ J$$

$P_{\Delta t = 1min} = 1690.9\ W$

$P_{\Delta t = 2min} = 845.45\ W$

$P_{\Delta t = 3min\ 52sec} = \frac{W}{232 sec} = 437.3\ W$

$P_{\Delta t = 5 min} = \frac{W}{300 sec} = 338.2\ W$

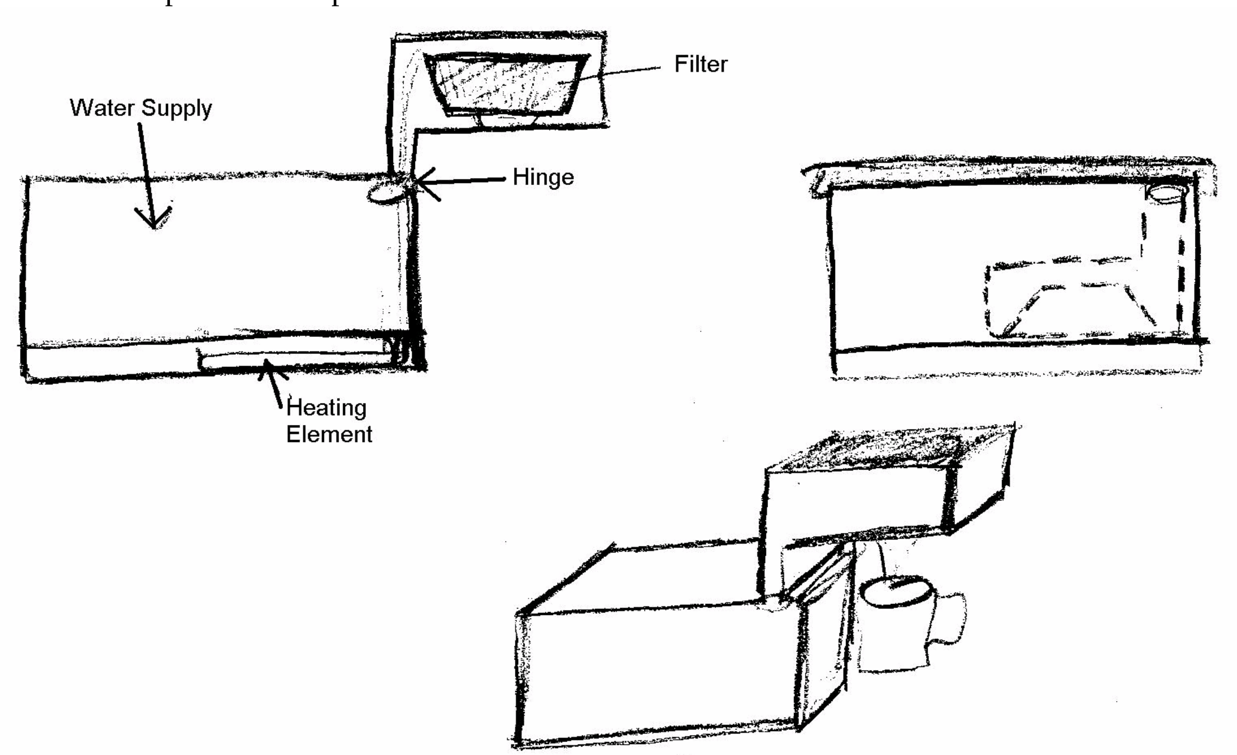
Appendix C - Gantt Chart

ME 450 Portable Coffee Maker Project Gantt Chart

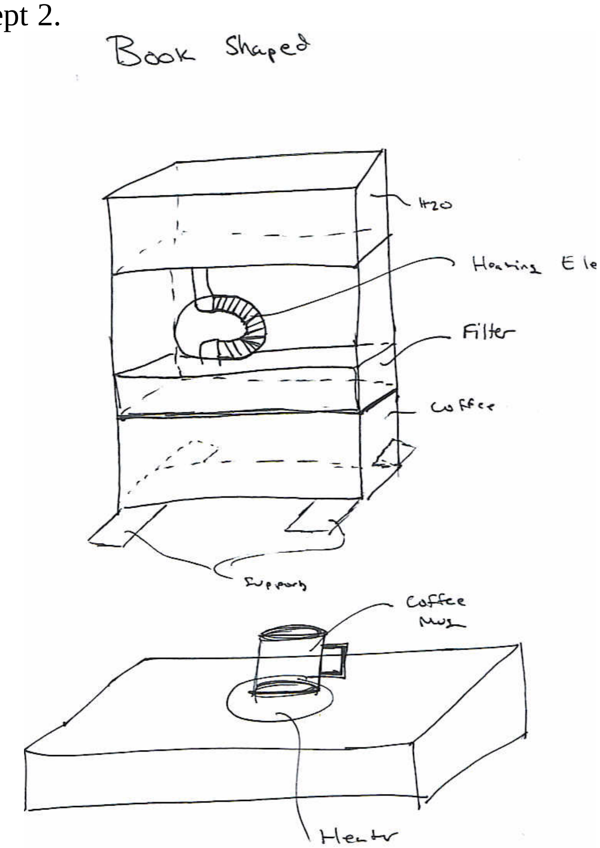
Items						Fall Break 15th & 16th						Thanksgiving Break 22nd and 23rd			
	Week of Sept 9	Week of Sept 16	Week of Sept 23	Week of Sept 30	Week of Oct 7	Week of Oct 14	Week of Oct 21	Week of Oct 28	Week of Nov 4	Week of Nov 11	Week of Nov 18	Week of Nov 25	Week of Dec 2nd	Week of Dec 9th	Week of Dec 16
Research Literature/Patents															
Benchmark Competition															
Product Dissection															
Survey Customer															
Preliminary Design Sketches															
Develop Customer Req.															
Develop Engineering Specs.															
Complete QFD															
Complete Gantt															
Write Design Review #1 Report															
Design Review #1															
Functional Decomposition															
Evaluate Preliminary Designs															
Select Conceptual Design															
Write Design Review #2 Report															
Design Review #2															
Create Engineering Drawings															
Finalize Design															
Select Materials															
Write Design Review #3 Report															
Design Review #3															
Create Machining Plans															
Create Prototype															
Write Design Review #4 Report															
Design Review #4															
Create Design Expo Poster															
Design Expo Presentation															
Final Report															
Matt's Exams						1								2	
Kurt's Exams						2								2	
Kyle's Exams						3						1		3	2
Tylers Exams						3						1		3	2

Appendix D – All Conceptual Designs

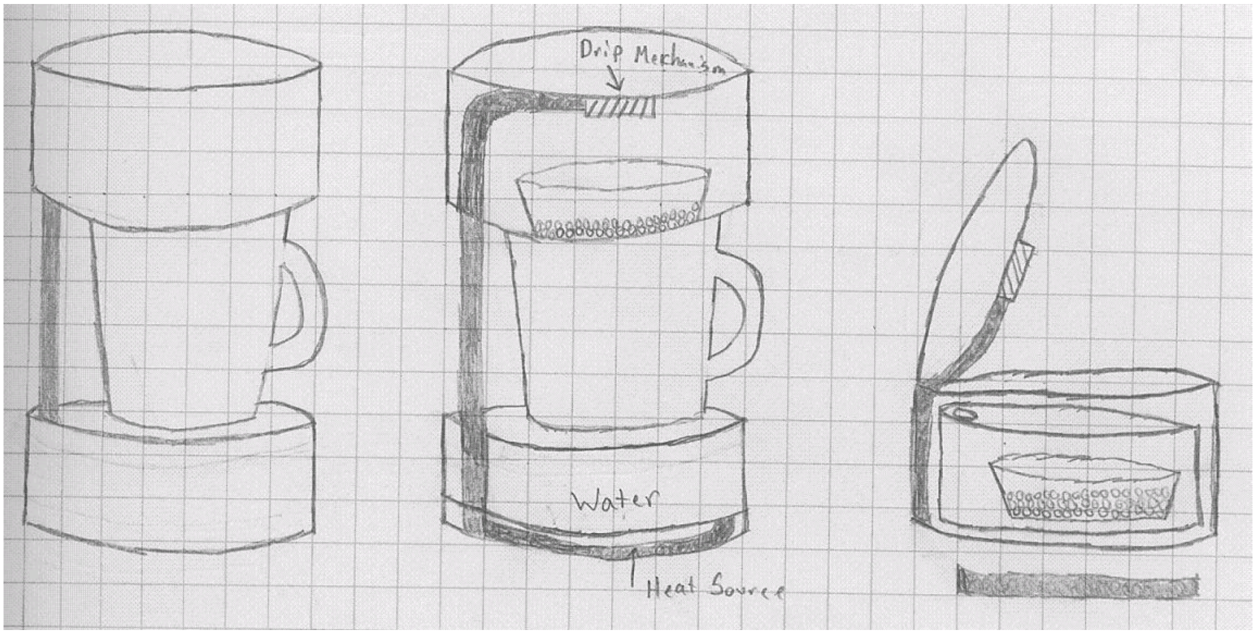
Collapsible Concept 1.



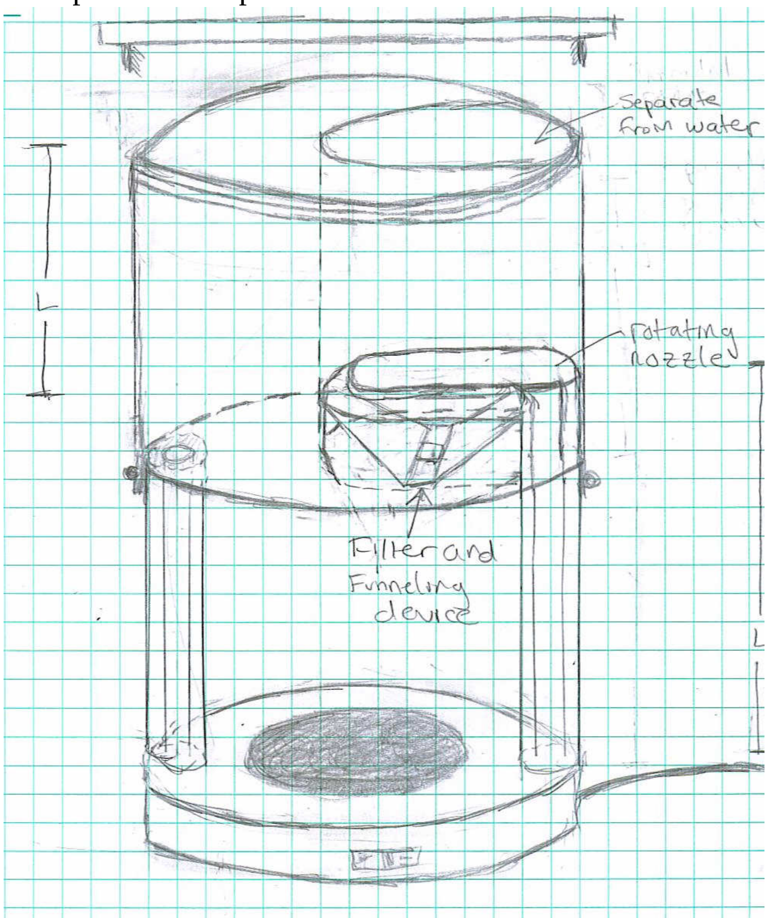
Collapsible Concept 2.



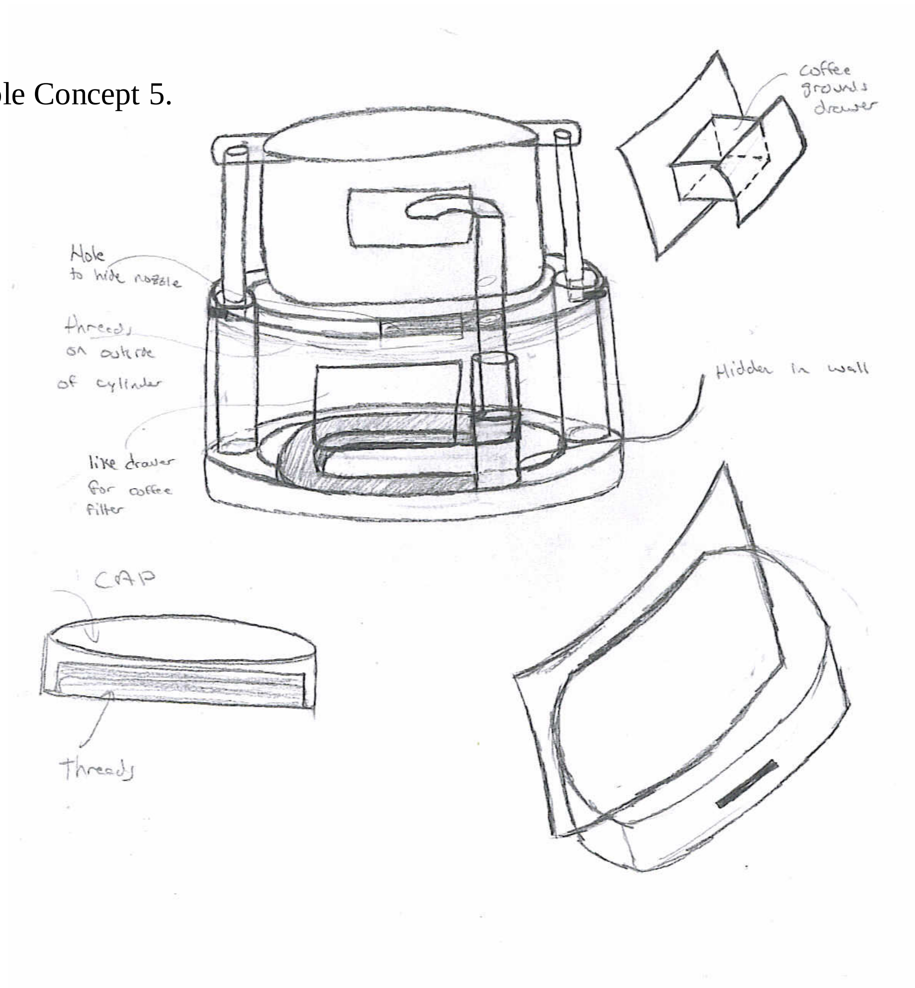
Collapsible Concept 3.



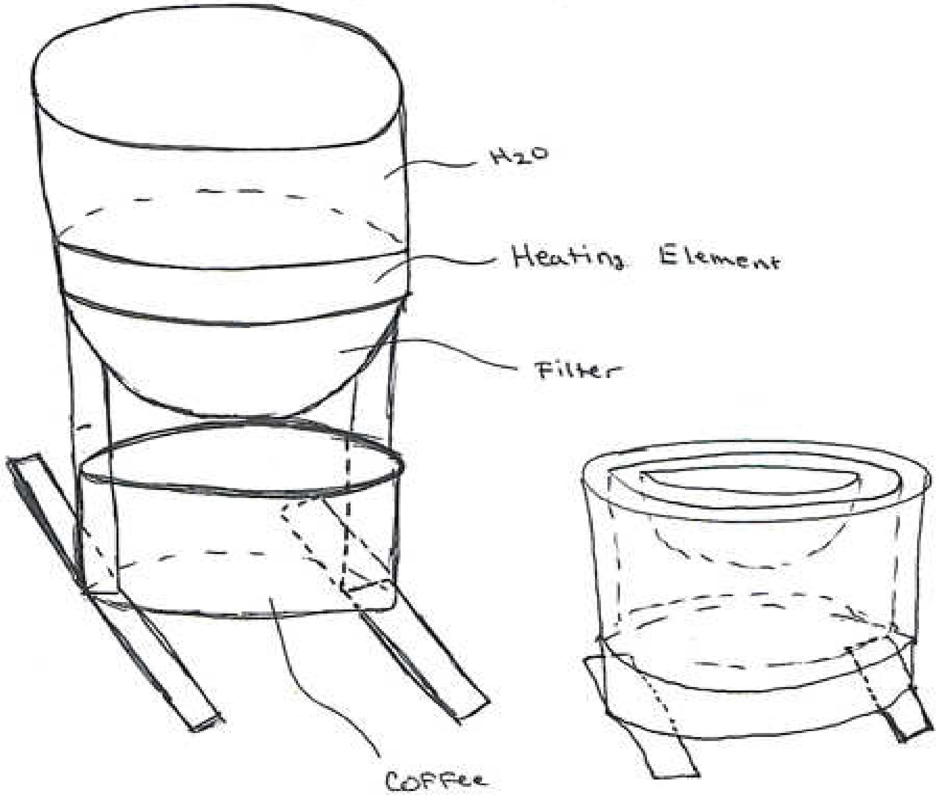
Collapsible Concept 4.



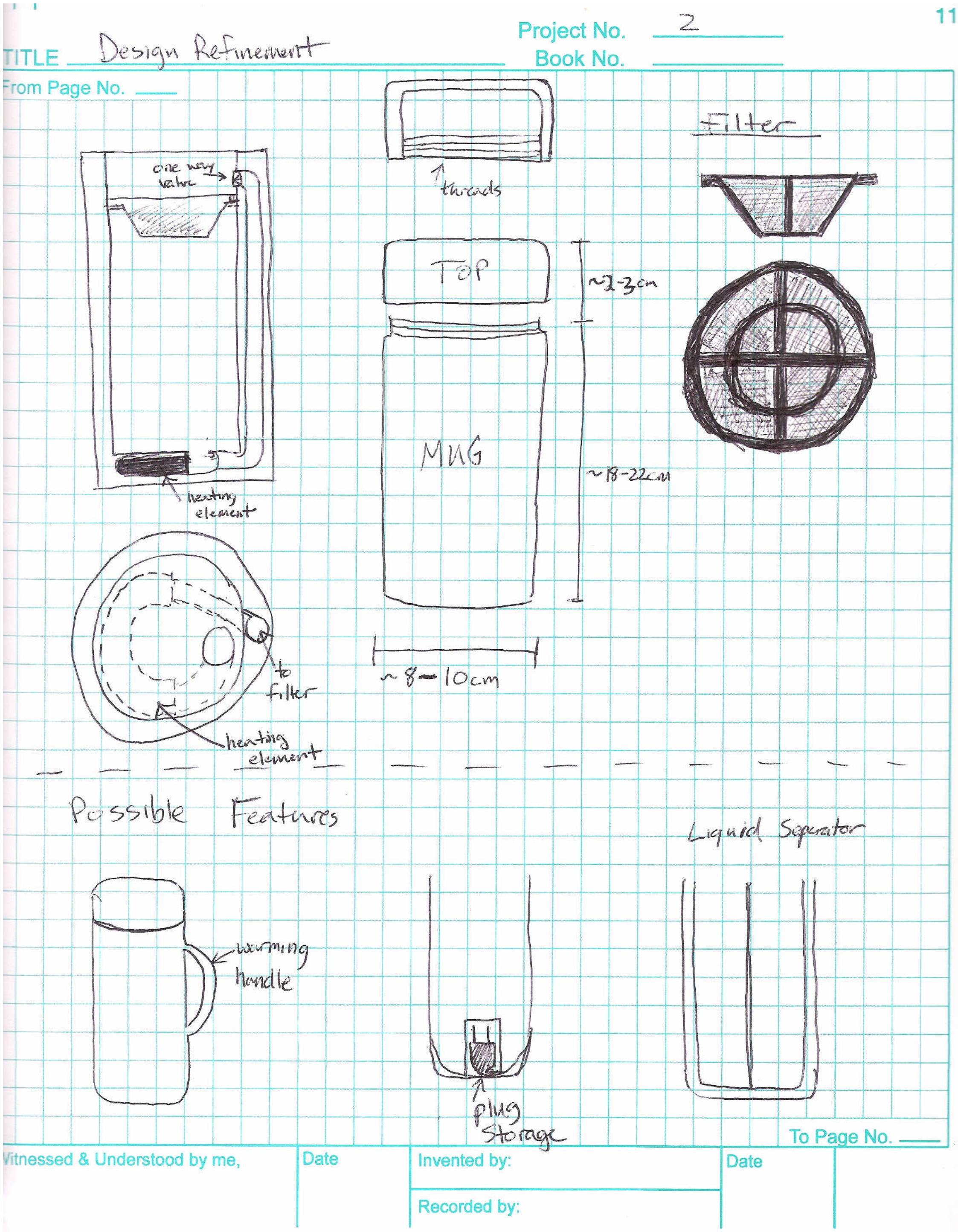
Collapsible Concept 5.



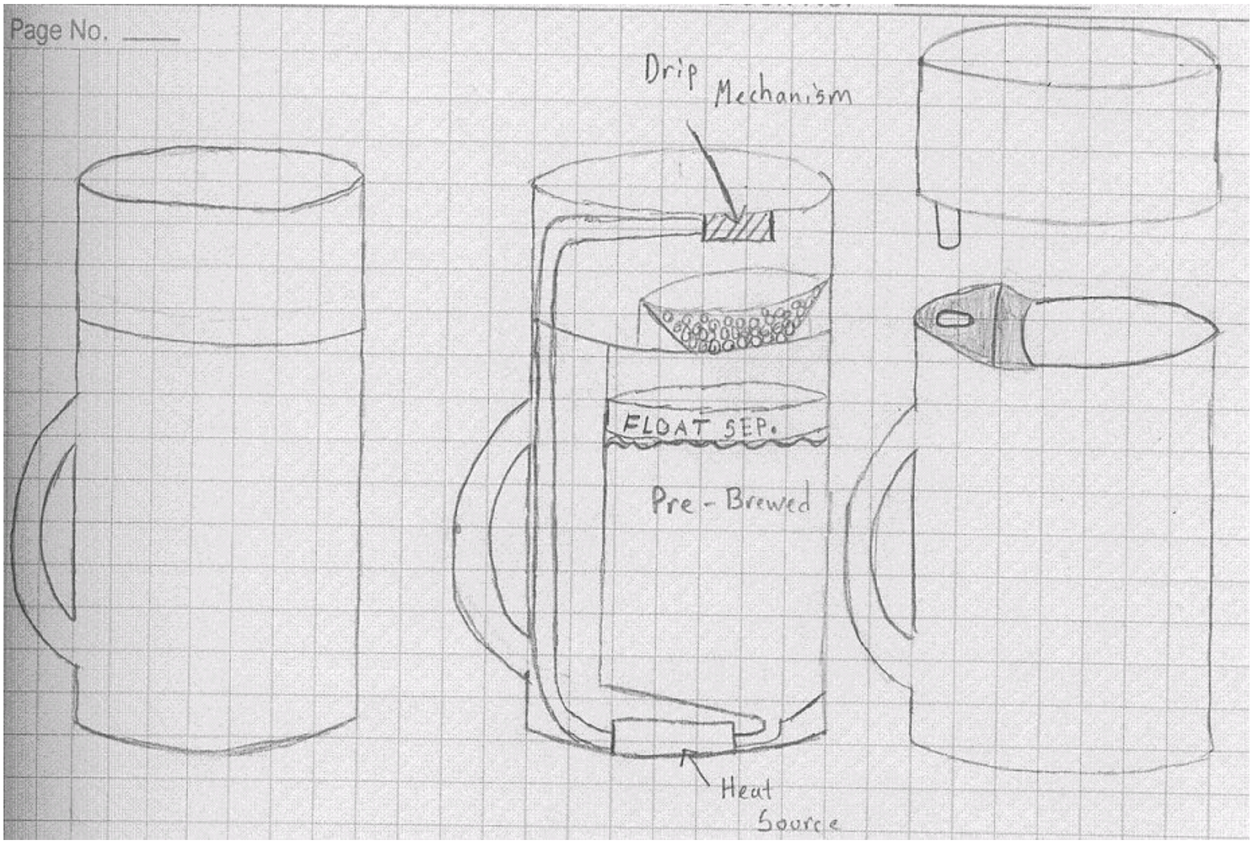
Collapsible Concept 6.



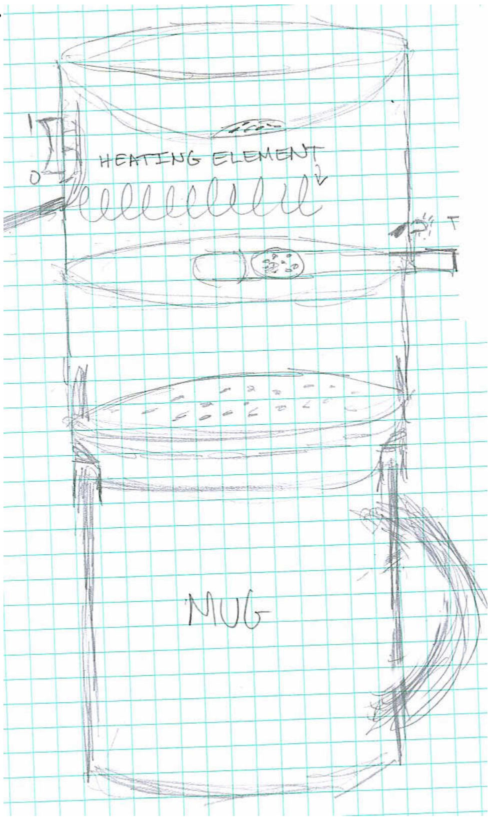
Non-collapsible Concept 1.



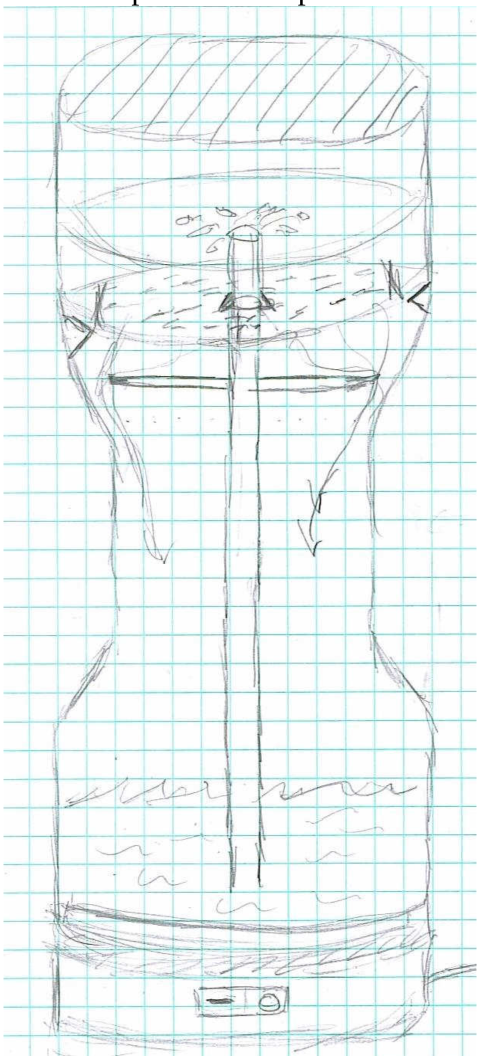
Non-collapsible Concept 2.



Non-collapsible Concept 3.



Non-collapsible Concept 4.



Appendix E - Survey

1. How often do you drink coffee?

   < 1 cup day   1-2 cups/day   3-4 cups/day   5+ cups/day

2. How much do you spend per week buying coffee from coffee shops?

   < $10 $10 - $25 $25 - $40 $40+

3. How many times per week do you want coffee when coffee shops are unavailable?

   < 1   1-2   3-4   5+

4. If a portable coffee maker existed would you consider purchasing it?

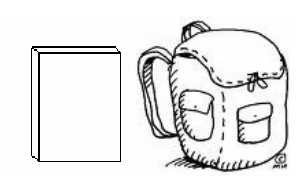
   Yes   No

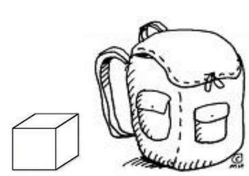
5. Please rank the following coffee maker features according to their importance to you:

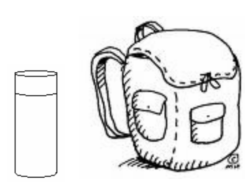
   (1=Very Important 2=Important 3=No Opinion 4=Not Important 5=Care Less)

-Brewing Time	1 2 3 4 5
-Maintenance	1 2 3 4 5
-Number of Cups Made	1 2 3 4 5
-Reheat Option	1 2 3 4 5
-Price	1 2 3 4 5
-Size	1 2 3 4 5
-Weight	1 2 3 4 5
-Noise	1 2 3 4 5
-Aesthetics	1 2 3 4 5
-Other ___________________	1 2 3 4 5

6. If a functioning coffee maker could fit into the following forms, which shape would you be most likely to carry with you (Rank: 1=Most Likely .. 3=Least Likely).





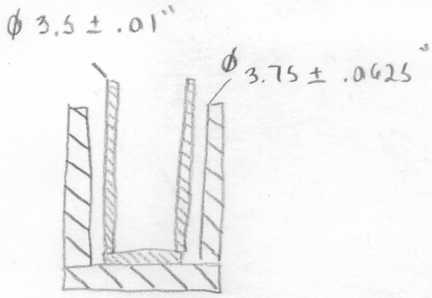


Appendix F – Survey Results

Respondents **52**

1	**How often do you drink coffee?**				
	"<1"	*"1-2"*	*"3-4"*	*"5+"*	
	20	23	6	3	
2	**How much do you spend per week buying coffee from coffee shops?**				
	"<10$"	*"10-25$"*	*"25-40$"*	*"40$+"*	
	29	21	1	1	
3	**How many times per week do you want coffee when coffee shops are unavailable?**				
	"<1"	*"1-2"*	*"3-4"*	*"5+"*	
	23	22	6	1	
4	**If a portable coffee maker existed would you consider purchasing it?**				
	YES	*NO*			
	32	20			
5	*Very Important*	*Important*	*Indifferent*	*Not Important*	*Care Less*
Brew Time	11	17	5	3	2
Maintenance	13	15	9	1	0
Number of Cups	3	15	11	6	2
Reheat	4	4	7	18	4
Price	13	19	4	1	2
Size	15	17	5	2	1
Weight	9	15	7	5	2
Noise	5	19	6	6	4
Aesthetics	5	4	7	13	2
	Most Prefered Shape				
6	*Book Shape*	*Cube*	*Cylinder*		
	9	2	41		

Appendix G – Tolerance Stack Up



Water Tank / Coffee Cup

Worse Case

3.6875 - 3.51

= .1775"

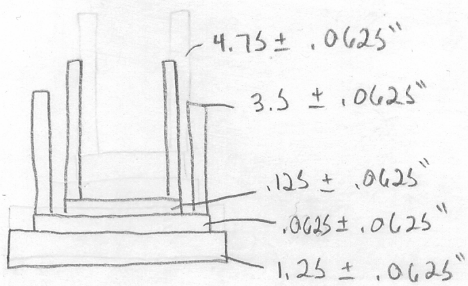
leaves .08875 radial clearance ≈ 1/16"

RMS

$\sqrt{.0625^2 + .01^2}$

= .0633"

leaves .0934" clearance



Height Clearance

Worse Case (Water Tank)

Height above casing + .125" = .875"

Given clearance = 1"

RMS is not necessary

Worse Case (Inside Casing)

Only Coffee Cup base and body: .125 + 3.5625 = 3.6875

max clearance = 3.625"

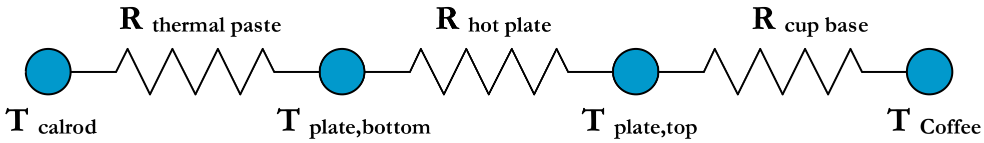
RMS

$.0625 + 3.5 + \sqrt{.0625^2 + .0625^2}$

= 3.625"

Sanding will likely be necessary

Appendix H - Original Hotplate Heat Analysis



$$R = L \,/\, (k \times A)$$

k – thermal conductivity
L – thickness
A – contact area

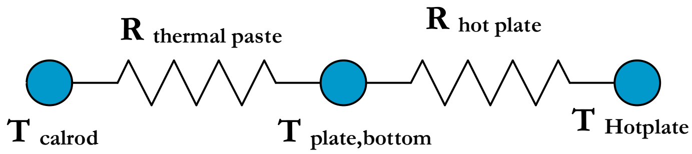
$$R_{eq} = R_{\text{thermal paste}} + R_{\text{hot plate}} + R_{\text{cup base}}$$

$$Q = (T_{\text{calrod}} - T_{\text{coffee}}) \,/\, R_{eq}$$

	Thickness	Thermal Conductivity	Area	Resistance	
	(m)	*(W/m/k)*	*(m^2)*	*(K/W)*	
Cup Base	0.003175	237	0.006207167	0.002158251	
Hot Plate	0.003175	237	0.006207167	0.002158251	
Thermal Paste	0.0004	0.7542	0.002177415	0.243574743	
T calrod	160	*degree C*	**Req**	0.247891245	*(K/W)*
T coffee	60	*degree C*			
Calrod Power	600	*W*	**Q=(T calrod-T coffee)/Req**		
Assumes Efficiency	0.6723378	%	**Q**	403.4027096	*W*

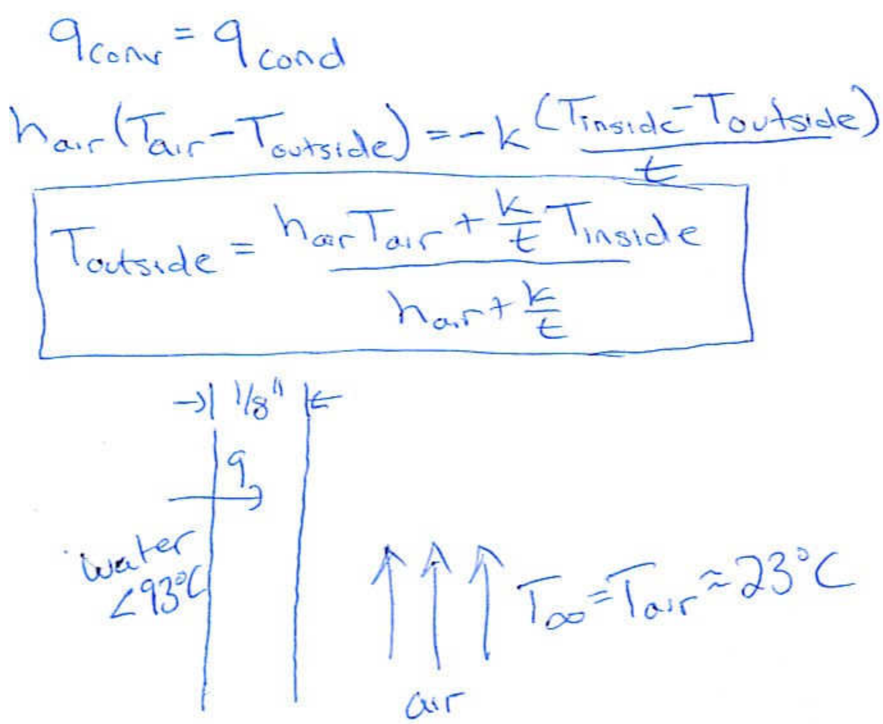
(Assumes negligible contact resistance between cup base and hotplate)

Appendix I - Modified Hotplate Heat Analysis



	Thickness	Thermal Conductivity	Area	Resistance	
	(m)	(W/m/k)	(m^2)	(K/W)	
Hot Plate	0.003175	15	0.006207167	0.034100368	
Thermal Paste	0.0004	0.7542	0.002177415	0.243574743	
T calrod	160	*degree C*	**Req**	0.277675111	*(K/W)*
T Hotplate	47.985108	*degree C*	**T Hotplate=T calrod - Q*Req**		
Calrod Power	600	*W*	**Q=CalrodPower*Efficiency**		
Assumes Efficiency	0.6723378	%	**Q**	403.4027096	*W*

Appendix J - Cool-down Heat Analysis

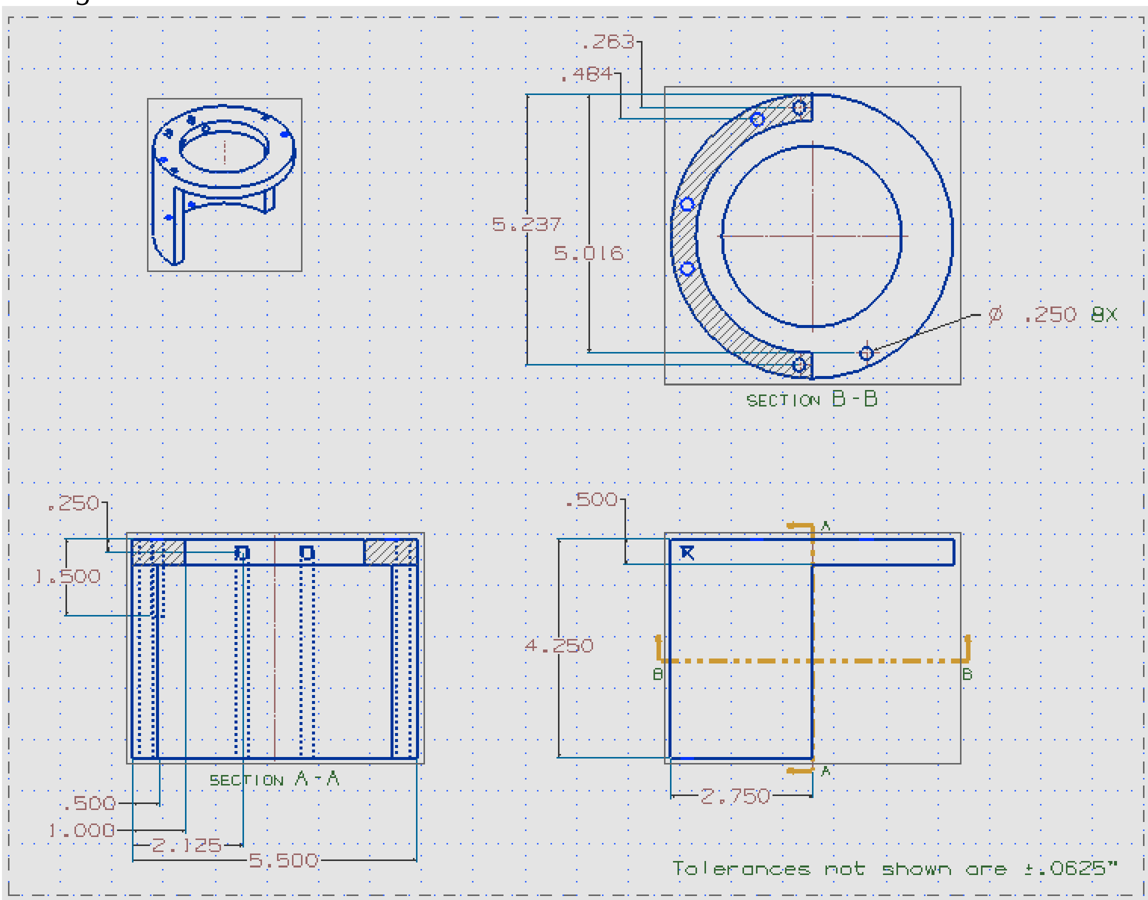


	Thickness	Thermal Conductivity	T outside
	(m)	*(W/m/k)*	*degree C*
Polypropylene	0.003175	0.4	37.08805031
Polycarbonate	0.003175	0.21	31.17802503
T inside	93	*degree C*	
h air	500	*W / m^2*K*	
T air	23	*degree C*	

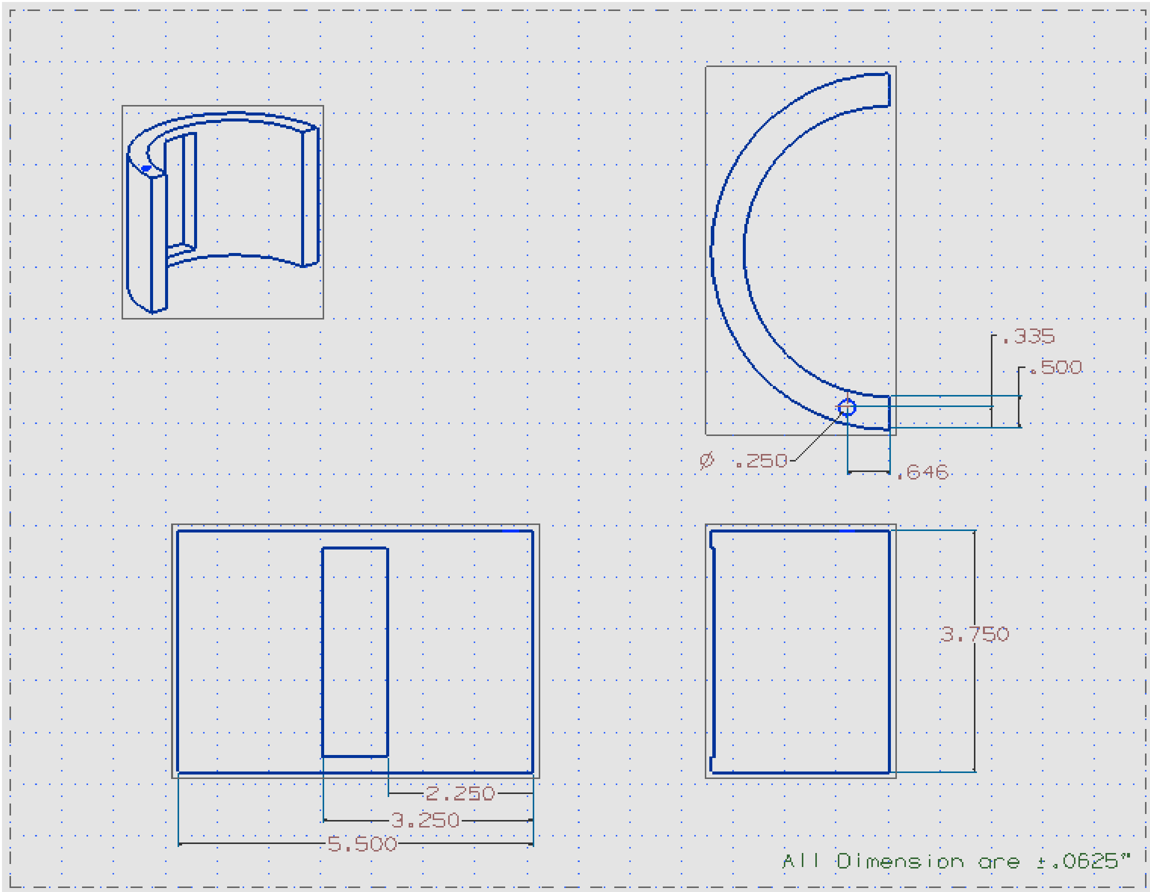
Temperature of air assumed to be room temperature (23 ºC)
Convection Coefficient of air assumed to be 500 W/m^2/K
Temperature of inside of tank assumed to be the hottest the water can get (93 ºC)
Thermal Conductivities taken as the upper-bound from www.matweb.com

Appendix K – Engineering Drawings

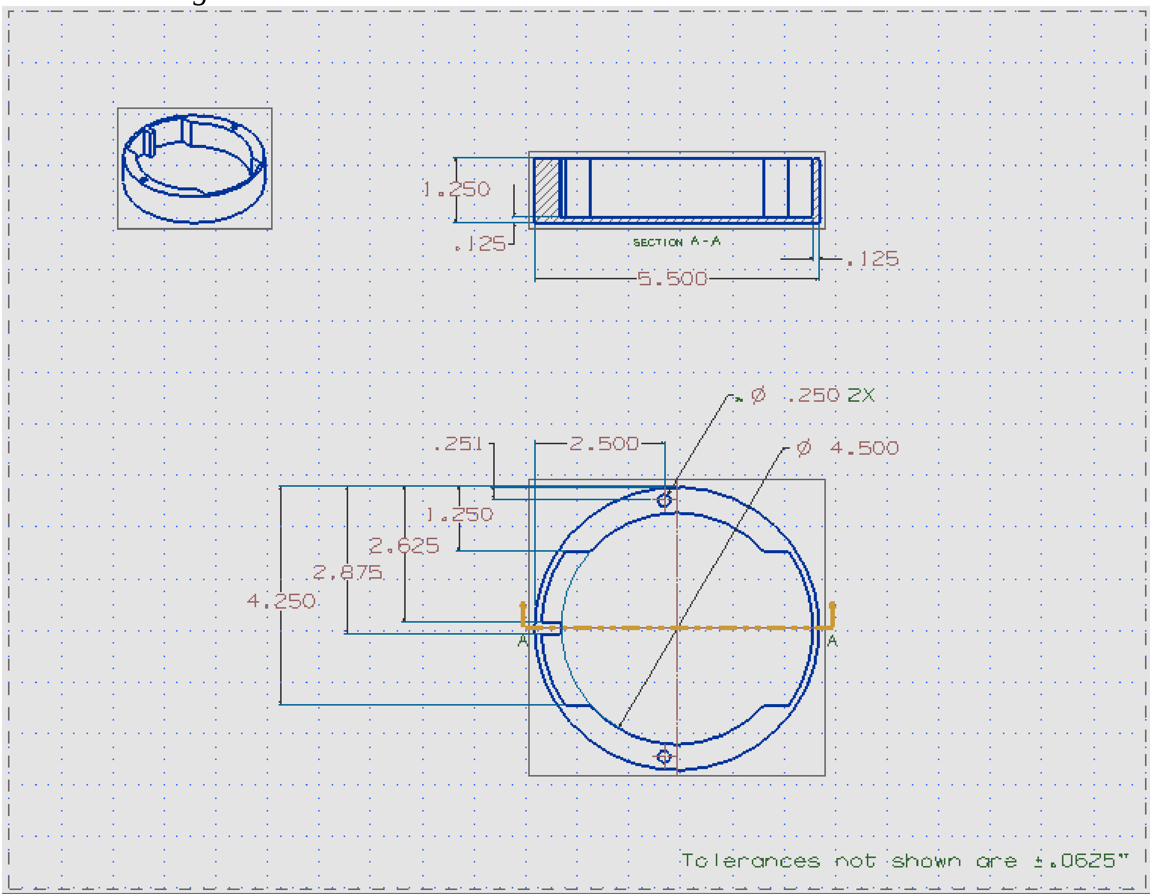
Casing



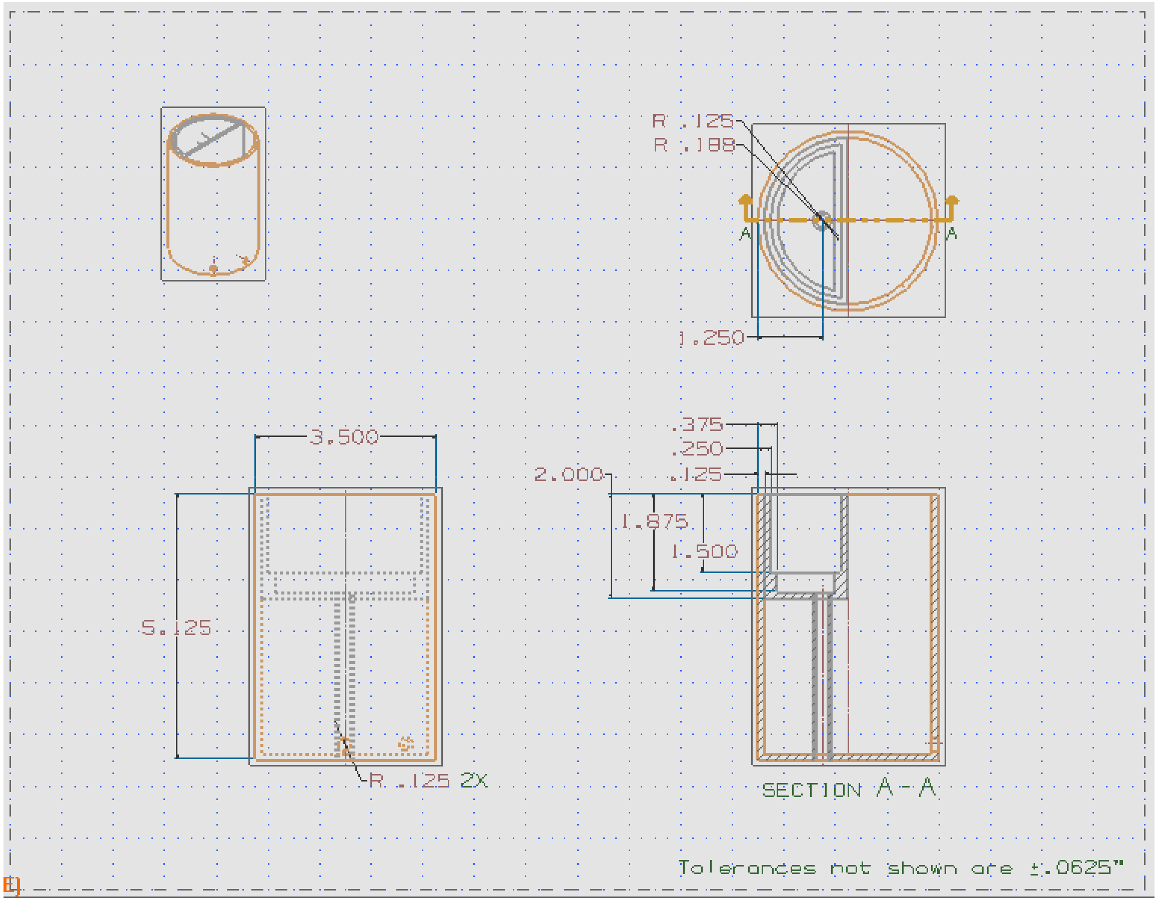
Door



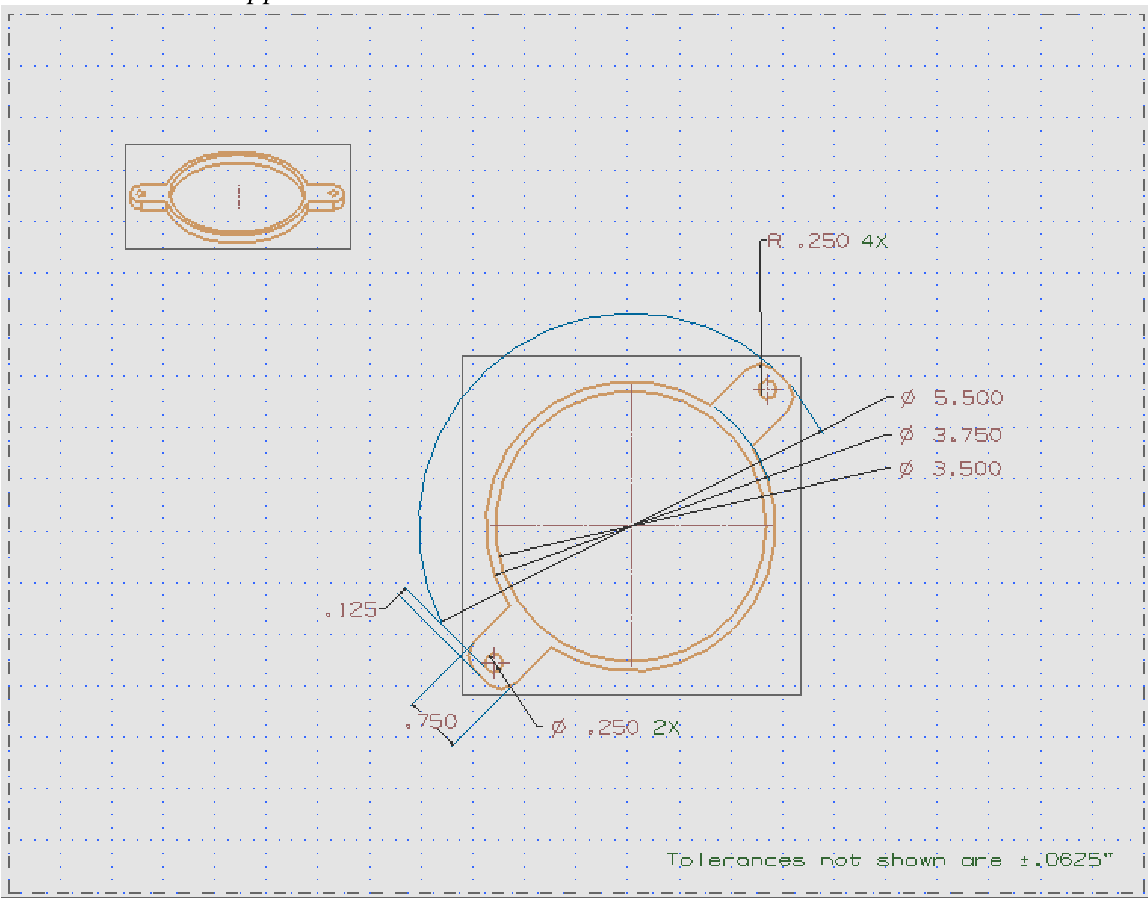
Calrod Housing



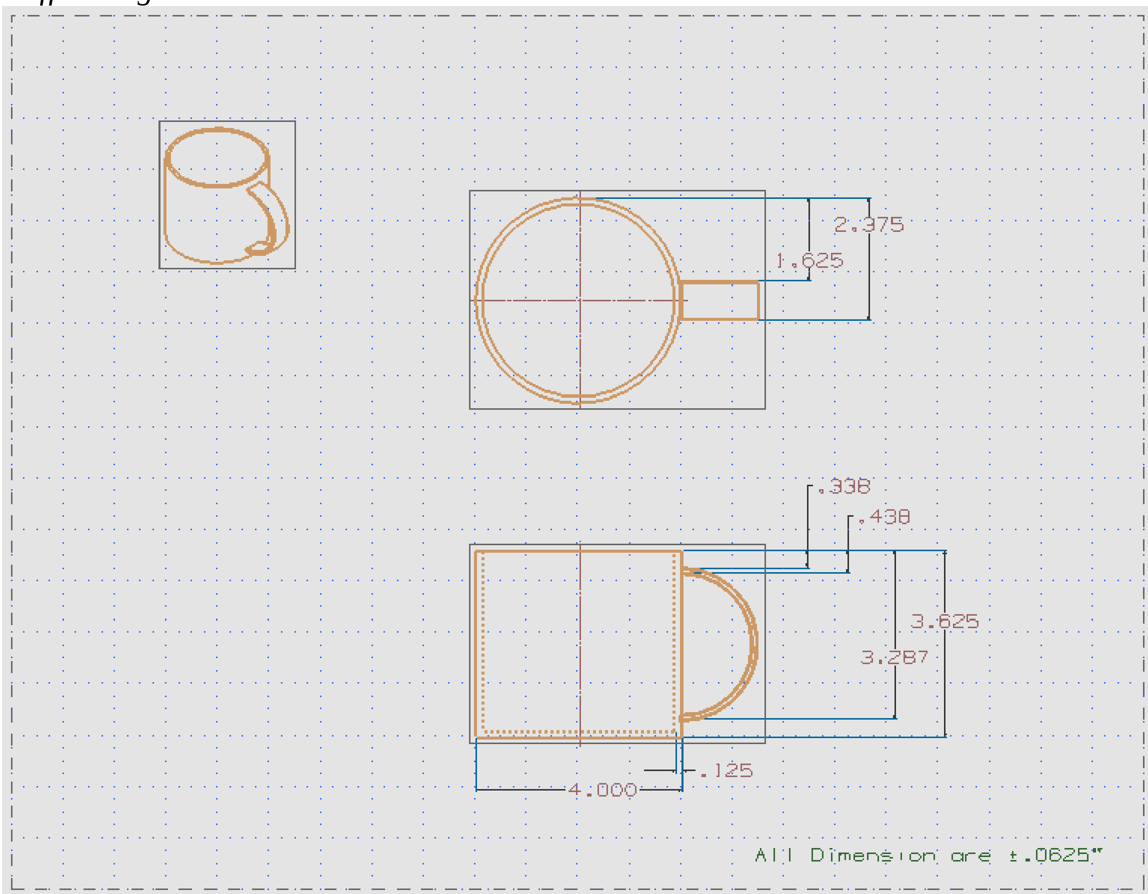
Water Tank and Filter



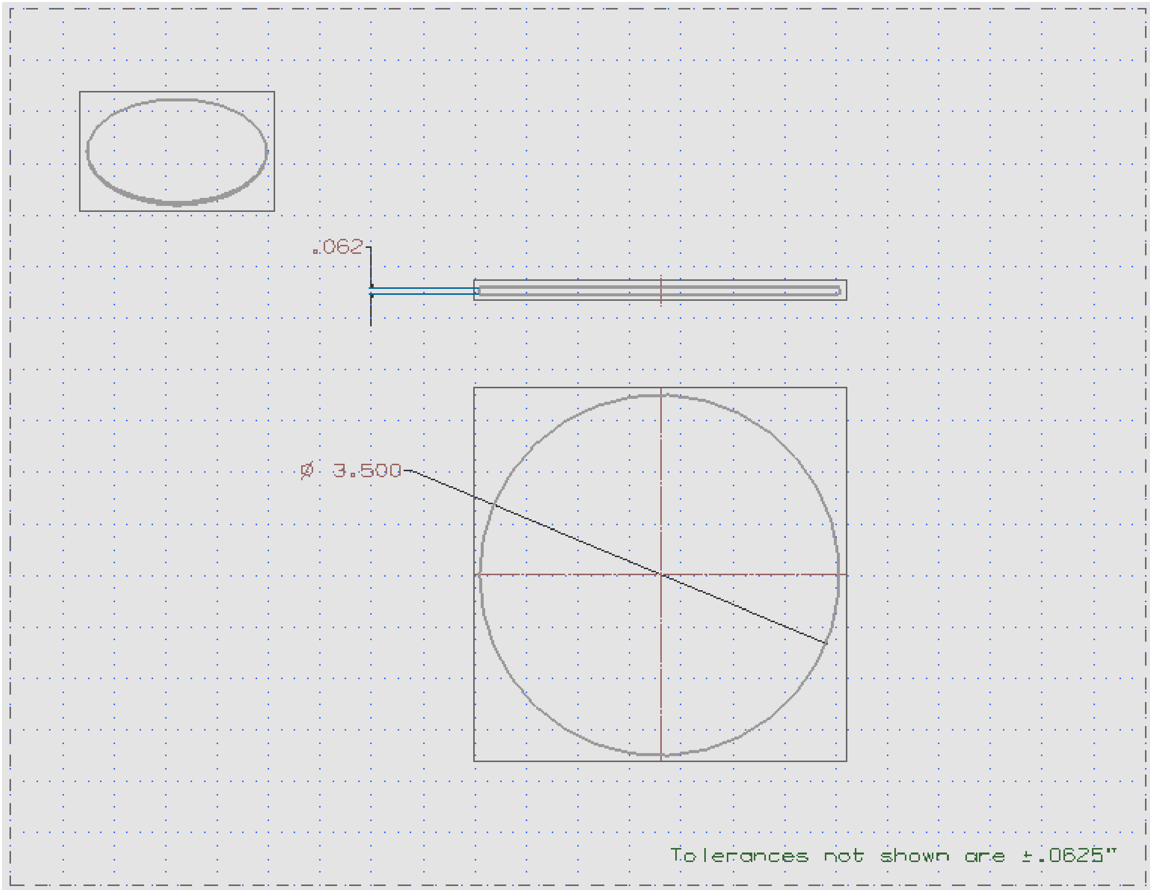
Guide Rods and Support



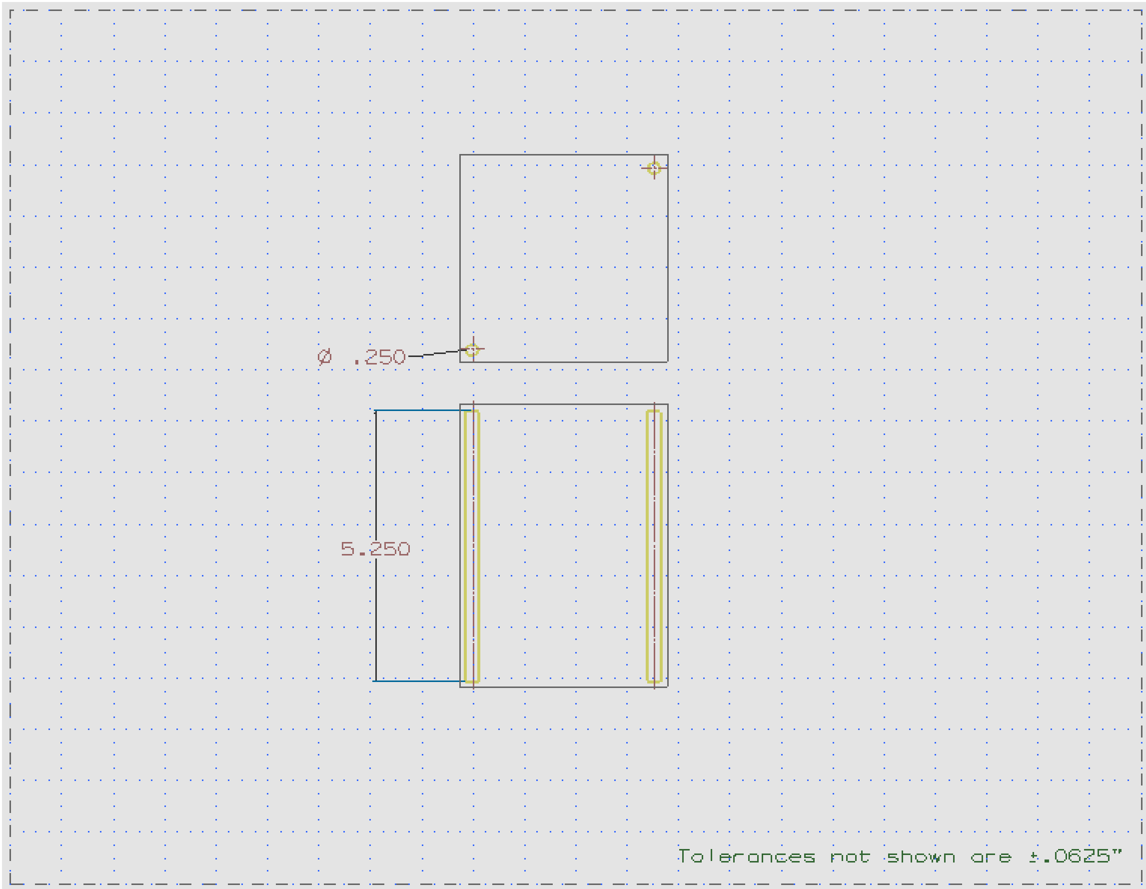
Coffee Mug



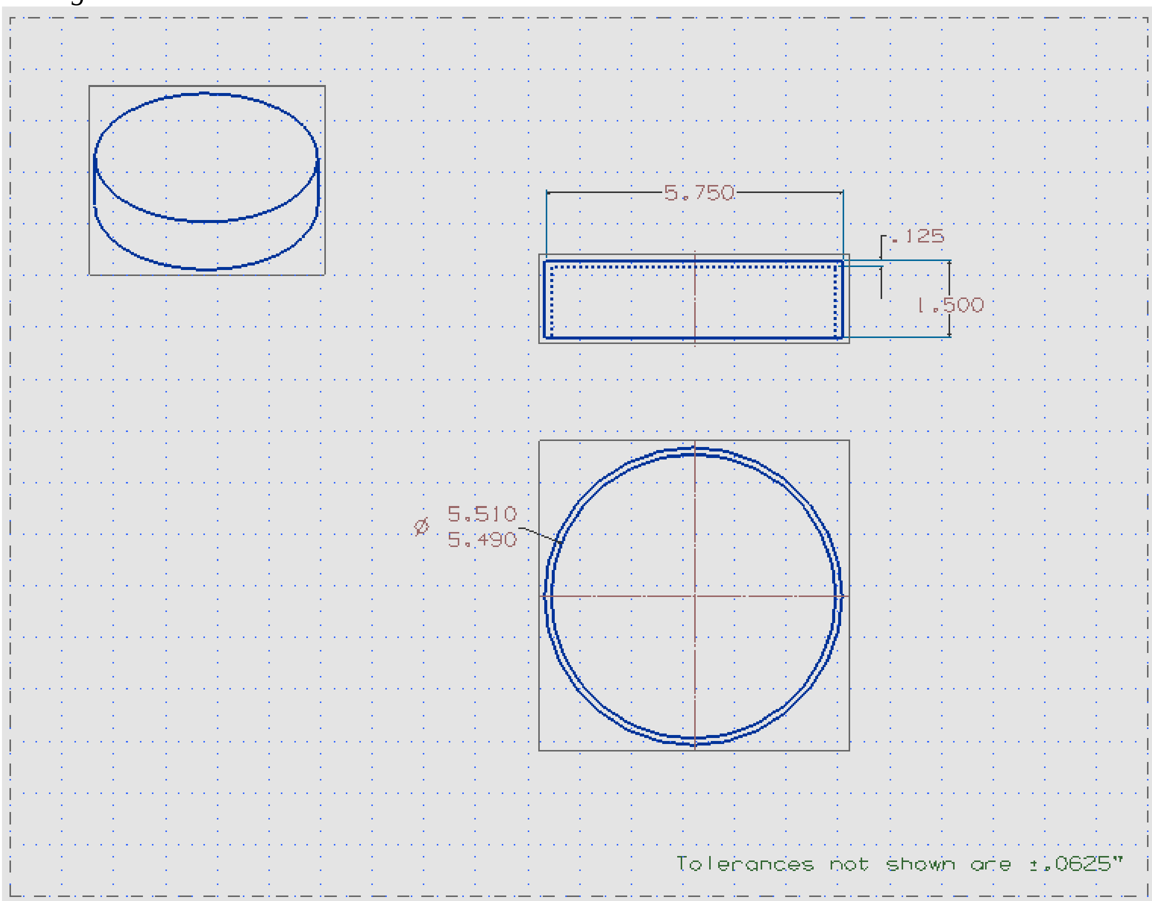
Water Tank Lid



Guide Rods



Casing Lid



Appendix L – Process Plan Sheets

Part: Main Housing
Purchased Components: Polypropelene rod stock- 6" Dia.

#	Machine or Device	Activity or Tool	Fixture	Parameters	Feed/Speed Rate	Time (hr)
1	Horinzontal band saw		Vice	Cut rod to 7" length	400 ft/s	0.25
2	Lathe	Cutting tool	Cross slide	Face end of rod	600 RPM	0.25
3	Lathe	Center drill	Tail stock	Drill center hole in end of rod for live center	600 RPM	0.25
4	Lathe	Cutting tool	Cross slide	Turn rod to 5.5" outer diameter (OD), with steps of 0.05"	600 RPM 0.05" depth/cut	2
5	Lathe	Drill bit	Tail stock	Drill 1" diameter hole in center of rod to 4.5" depth	600 RPM	0.25
6	Lathe	Boring bar	Cross slide	From top, bore 3.5" diameter hole to 0.5" depth	600 RPM 0.05" depth/cut	
7	Lathe	Boring bar	Cross slide	From bottom, bore 4.5" diameter hole to 3.75" depth	600 RPM 0.05" depth/cut	0.50
8	Drill press	Drill bit	Vice	From top, drill two 0.25"diameter holes centered on cylinder wall, 1" deep, located +90° and -90° from reference 1*	600 RPM	0.5
9	Drill press	Drill bit	Vice	From top, drill two 0.25"diameter holes centered on cylinder wall, 4" deep, located +105° and -75° from reference 1*	600 RPM	0.5
10	Drill press	Drill bit	Vice	From bottom, drill two 0.25" diameter holes centered on cylinder wall, 4" deep, located +15° and -15° from reference 1*	600 RPM	0.5
11	Band saw		Vice	Cut cylinder from top to bottom, tangent and offset 3" from reference 1*	400 ft/s	0.25
12	Drill press	Drill bit	Vice	Drill two 0.25" diameter holes, perpendicular to cylinder wall, to connect to holes drilled in step #10	600 RPM	0.5
13	Mill	End mill	Vice	In smaller cyclinder piece (main housing door) mill through slot centered on workpiece	600 RPM	0.25

Part: Water tank
Purchased Components: Polycarbonate tube, 3.5" OD w/ 0.25" wall thickness
Polypropylene rod, 3.5" OD
Polycarbonate sheet, 0.25"

#	Machine or Device	Activity or Tool	Fixture	Parameters	Feed/Speed Rate	Time (hr)
1	Horinzontal band saw		Vice	Cut tube to 4.75" length	400 ft/s	0.25
2	Lathe	Cutting tool	Cross slide	Face end of rod	600 RPM	0.25
3	Lathe	Cutting tool	Cross slide	Turn rod to 3.5" OD	600 RPM 0.05" depth/cut	0.5
4	Lathe	Parting tool	Cross slide	Cut rod to 0.125" length	600 RPM	0.5
5	Assembly	Epoxy	Vice	Attach 0.125" rod to end of tube with epoxy		0.5
6	Drill press	Drill bit	Vice	Drill two 0.25" diameter holes, located on bottom of water tank wall, 30° apart aligned with main housing interface holes	600 RPM	0.5
7	Drill press	Drill bit	Vice	On water tank floor, drill 0.25" diamter hole, located 0.75" from inner wall aligned with filter compartment output	600 RPM	0.25
8	Assembly	Epoxy	Vice	Attach filter compartment to water tank wall, located flush with top of water tank, aligned with water tank output		0.5
9	Assembly	Epoxy	Vice	Attach tubing from water tank input hole to filter compartment input hole		0.5
10	Laser cutter			Cut guide rod supports		0.25
11	Horinzontal band saw		Vice	Cut 0.25" OD Polycarbonate rod to 5" length	400 ft/s	0.25

Part: Filter Compartment
Purchased Components: Polypropylene rod, 3.5" OD
Polycarbonate tube, 0.5" OD 0.25" ID

#	Machine or Device	Activity or Tool	Fixture	Parameters	Feed/Speed Rate
1	Horinzontal band saw		Vice	Cut 3.5" OD rod to 3" length	400 ft/sec
2	Horinzontal band saw		Vice	Cut rod in half lengthwise	400 ft/sec
3	Mill	End mill	Vice	Face end of workpiece	600 RPM
4	Mill	End mill	Vice	Mill workpiece to 2.5" width, leaving small arc	600 RPM
5	Mill	End mill	Vice	Mill cavity in workpiece, leaving wall thickness of 0.125"	600 RPM
6	Mill	End mill	Vice	Face workpiece to 2.5" length	600 RPM
7	Drill press	Drill bit	Vice	On filter compartment floor, drill 0.25" diameter hole, offset 0.75" from curved wall and centered horizontally	600 RPM
8	Band saw			Cut tubing to 2.125" length	600 RPM

Part: Calrod Housing
Purchased Components: Polypropylene rod, 6" OD , 0.030" sheet steel

#	Machine or Device	Activity or Tool	Fixture	Parameters	Feed/Speed Rate	Time (hr)
1	Horinzontal band saw		Vice	Cut rod to 3" length	400 ft/s	0.25
2	Lathe	Cutting tool	Cross slide	Face end of rod	600 RPM	0.25
3	Lathe	Cutting tool	Cross slide	Turn rod to 5.5" OD	600 RPM 0.05" depth/cut	1
4	Lathe	Drill bit	Tailstock	Drill 1" diameter center hole, 2.5" deep	600 RPM	0.25
5	Lathe	Boring bar	Cross slide	Bore to 4.25" diameter, 1" deep	600 RPM 0.05" depth/cut	1
6	Lathe	Parting tool	Cross slide	Cut rod to 1.25" length	600 RPM	0.5
7	Shear	Shear		Cut heating element heat shields to shape of heating element		1.5
8	Shear	Shear		Cut hot plate to shape of Calrod housing opening		1

Part: Cup
Purchased Components: Polycarbonate tube, 4.5" OD w/ 0.25" wall thickness
Polypropylene rod, 4.5" OD

#	Machine or Device	Activity or Tool	Fixture	Parameters	Feed/Speed Rate	Time (hr)
1	Horinzontal band saw		Vice	Cut tube to 3.625" length	400 ft/s	0.25
2	Horinzontal band saw		Vice	Cut rod to 0.125" length	400 ft/s	0.25

Part: Main Cap
Purchased Components: Polycarbonate tube, 6" OD

#	Machine or Device	Activity or Tool	Fixture	Parameters	Feed/Speed Rate	Time (hr)
1	Horinzontal band saw		Vice	Cut rod to 3" length	400 ft/s	0.25
2	Lathe	Cutting tool	Cross slide	Face end of rod	600 RPM	0.25
3	Lathe	Drill bit	Tailstock	Drill 1" center hole, 2" deep	600 RPM	0.25
4	Lathe	Boring tool	Cross slide	Bore to 5.5" diameter, 1.125" deep	600 RPM 0.05" depth/cut	1
5	Lathe	Parting tool	Cross slide	Cut rod to 1.5" length	600 RPM	0.5

Appendix M – Assembly Plan Sheets

Part: Main Housing
Additional Parts: Calrod Housing, Main Housing door, tubing

#	Process	Tools	Hardware	Time (hr)
1	Attach heating element tubing to Main housing	Adehisive		0.5
2	Attach Calrod Housing to Main Housing	Screwdriver	Machine screws	0.25
3	Attach Main Housing door to Main Housing	Screwdriver	Hinge, hinge hardware	1
4	Attach latch to Main Housing & door	Screwdriver, hammer	Latch, latch hardware	0.5

Part: Water Tank
Additional Parts: Guide rods, guide rod support, filter comparment, tubing

#	Process	Tools	Hardware	Time (hr)
1	Attach tubing to hot water return hole	Adhesive	Plastic fitting	1
2	Attach filter compartment to water tank	Adhesive		1
3	Attach guide rod support to water tank	Adhesive		1
4	Attach guide rods to guide rod supports	Adhesive		1
5	Attach hot watrer tubing to filter compartment	Adhesive		1

Part: Filter compartment
Additional Parts: Tubing

#	Process	Tools	Hardware	Time (hr)
1	Attach tubing to filter compartment drain	Adhesive	Plastic fitting	1

Part: Calrod housing
Additional Parts: Heating element shields, on/off switch, heating element

#	Process	Tools	Hardware	Time (hr)
1	Attach on/off switch to Calrod housing		Switch hardware	0.5
2	Wire on/switch and power to heating element	Soldering iron, wire crimps	Solder	1
3	Attach heating element heat shields to heating element	Adhesive	Clamp	1
4	Attach tubing from Main housing to heating element			0.5
5	Attach hotplate to Calrod housing	Adhesive		0.25

Part: Cup
Additional Parts: Cup handle

#	Process	Tools	Hardware	Time (hr)
1	Attach cup handle to cup	Adhesive	Clamp	0.5