Whirlpool Front Loading Washing Machine
Water Reduction Project
Final Report

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ABSTRACT

Our sponsor, Whirlpool, has tasked us with developing an eco-efficient washing machine with a goal of reducing wash cycle water usage by 75%. In order to meet this goal, we are researching new technologies in the fields of alternative washing fluid, system mechanics, and recirculation of water. Our team will be working on the first portion of a two semester project and will perform the tasks of brainstorming potential designs and deciding on the best design as defined by Whirlpool's criteria. Contents of this report include concept generation, evaluation, and selection.

INTRODUCTION

The Whirlpool Corporation, our project sponsor, is currently the largest home appliance manufacturer in the world. They continuously strive to minimize the amount of energy used by their appliances and design their products to operate in a more environmentally friendly manner. The Fabric Care department of Whirlpool has asked our team of engineers to design a system that reduces the amount of water used in the wash cycle of their front loading Duet washing machine by 75%. We researched possible technologies such as alternative washing fluids, system mechanics, and water recirculation to achieve this desired goal. As part of the design process, we were asked to undergo concept generation, concept evaluation, and ultimately select a final design. Our design must meet the technical specifications set forth by Whirlpool and maintain the exceptional wash performance and strict safety guidelines. The final design is a washer addition consisting of a water recirculation system and filtration device. The project concluded with a design proposal that may be used to prepare a working prototype by a future engineering team.

INFORMATION AND RESEARCH

Front loading washing machines are an environmentally friendly way to wash clothes. Sales of these washers still lag the traditional top loading washer, presumably due to the high price for the front loader. The benefits of a front-loading washer include less water used during each cycle, more clothes fit per load, and higher spin speeds during the rinse cycle causing clothes to dry more quickly. There is no central agitator and therefore, the drum can hold 20-30% more clothes. Energy star front loaders use around 18 to 25 gallons per load, which is 40 to 50 percent less water than top loaders. This reduction is possible because top loaders fill the drum with water to the highest level of clothes, whereas front loaders fill only the lower third of the drum.

Special High Efficiency (HE) detergents are recommended for front loading washers because suds are left in the machine after the rinse cycle has completed if regular detergent is used. HE detergents use a lower sudsing formula which release different soap agents depending on water temperature.

For our project, we are studying the Duet HT washing machine. This washer uses 20 gallons of water per load which includes the wash and rinse cycle. The stainless steel interior is 4.0 cubic feet and reaches a maximum spin speed of 1000-1200 rpm. There are fourteen different cycles and includes a Catalyst cleaning action. This front loading washer uses 173 kilowatt hours per year.

Some competitors to the Duet HT washing machine include Samsung SilverCare, LG Tromm SteamWasher, Kenmore Elite He 5t, LG WM1814CW, LG WM0642HW, Frigidaire Gallery GLTF2940E, Frigidaire Affinity ATF7000EP, Maytag Epic, Bosch Nexxt 500, and Bosch Axxis WFT2460UC.

PATENTS

To better understand what Whirlpool's competitors are doing, and what intellectual property (IP) is already owned by others, a patent search was conducted. Patents of interest are described below.

Patent application number 08/406,424 was filed in 1995 by General Electric employees and describes an inertia based method to control the amount of water added into the washing machine. Most washers supply a certain amount of water to each load depending on a manual control which includes small, medium, or large loads. More water is often used to ensure that clothes are fully clean. This patent describes a way to provide a specific amount of water by utilizing an advanced motor controls such as a Switched Reluctance Motor or an electronically commutated motor to measure the torque and determine the inertia of clothes in the tub. The amount of water added to the washing machine is proportionate to the weight of the clothes.

Granted to LG Electronics 2003, patent application number 10/717,668 depicts a filter assembly that separates dirt and particles from used wash water. More specifically, a filter which contains a filter case with an opening that communicates between an inlet and outlet placed along the circumference of the filter. At the opening, a plate prevents dirt and particles to pass through. If the filter does not happen, used water is released outside using a drain pump and therefore particles are imbedded into the pump or motor causing the capacity of the machine to lower, ruining the drain pump, and increasing the noise level.

A patent developed by employees of Shell Oil Company in 2001, application 09/949,746 describes a method to wash successive loads of laundry using partially recycled wash water from at lease one previous wash cycle. A filter is used to form wash retentate and wash permeate water. The wash permeate helps in water recovery and reduces the production of gray water. Also, chemicals are recovered during the process. Water recovery is around 60-90% and overall surfactant recovery is 10-30%. The preferred filter contains polyacrylonitrile and is about 0.01 to 0.2 microns in size which will remove dirt, viruses, and bacteria and will keep cleaning agents in. The patent also describes reverse osmosis that rejects species on an ionic scale with weight between 200 and 500.

Another patent, application number 10/877,549, by Procter & Gamble Company has found to treat microbes in non-aqueous laundering process in 2004. Since fabric articles are at risk of dye transfer and shrinkage during laundry cycles, non-aqueous washing technologies are now emerging for home use. This process uses a cleaning composition which is made of decamethylcyclopentasiloxane and mixes it with 4'-Dichloro-2-hydroxydiphenyl ether amtimicrobial agent in a lipophilic fluid. Some examples of lipophilic fluid materials include siloxanes, silicones, hydrocarbons, glycol ethers, glycerine ethers, and hydrofluoroether solvents. The cleaning solution then passes through a filter with a size of 0.1-100 .mu.m which removes the microbes.

FUTURE DEVELOPMENT

The Aqua AWD-AQ1 washing machine by Sanyo uses oxygen from the air and converts it to ozone which is then sprayed on clothes during the cycle. The ozone destroys and disassembles bacteria cell walls and eliminates odors. This washing machine also has a wash cycle that utilizes recycled water from the rinse cycle and ozone. The water is taken from the tank where it is stored and ozone microbubbles are added which purifies the water. The wash cycle uses around 13 gallons of water.

EcoSafe has also developed a washing machine that uses less water than existing washers. The company has created a cleaning resin and delivery system that the user places into a compartment on the machine. The resin can be used for 40 to 50 loads until it needs to be replaced. After the resin comes in contact with water, the oxygen and pH level increase. The machine does not use hot water and will decrease the amount of water used by 30 to 40 percent. Hydromaid is in the process of purchasing EcoSafe.

CUSTOMER REQUIREMENTS AND ENGINERING SPECIFICATIONS

The Whirlpool Corporation has tasked us with decreasing the water consumption in their Duet washing machine by 75%. They stated very explicitly that it was an open-ended assignment and we were encouraged to think outside the box. However, there were several restraints that could not be violated. They are listed as follows:

Maintain High Washer Performance: It was made very clear that in reducing water consumption, we were not to sacrifice wash performance. In Europe, wash performance scores are posted on the front of show room units, and in most countries appliances without the highest ratings simply don’t sell. Thus, we gave maintaining high wash performance a 10 for importance.

Reduce Water Usage: This is the main goal of the project and thus was deemed a 10 for importance.

Reduce Energy Consumption: Energy reduction is also important in an eco-efficiency project, although it is not our top priority, and thus was given a 4.

Maintain Price Point: Consumers generally expect high efficiency, but won’t pay extra for it. However, an innovative new idea with considerable water savings could demand a slightly higher price. We rated the importance at a 6.

Maintain Washer Outside Dimensions: Washer dimensions have been standard for several years, and any additions we make need to fit in this cavity. Its importance is rated as a 10.

Ease of Manufacturability: Whatever modifications we make to the current washer design need to be manufacturable. The importance of this is ranked as a 7.

Ease of Serviceability: Any design modifications or additions we incorporate need to be serviceable by the repair person. This is ranked at a 5.

Reliability: It is imperative that our design be robust and will outlast the life of the washer. A washer that requires regular maintenance will reflect poorly on Whirlpool. We gave this an 8 for importance.

Marketability: Our design must appeal to consumers, and the importance of this is ranked 8.

IP Issues: We need a design that will not be subject to patent infringement suits. Better yet, we would like to come up with a new patentable design to lock competitors out of the market. This is ranked at a 4.

Since we are in the very early stages of the design process, and not yet sure what design we will be pursuing, we choose very general design parameters for our modification/addition. Our hope is that this QFD will enlighten us as to what design attributes are important when considering potential designs. (See Appendix A.1) The engineering specifications are listed as follows:

Size of Addition: What should the physical size be of our addition?

Cost of Design: How much will the new design cost?

Complexity of Addition: How complicated are the new parts or design modifications? How much development will they require?

Amount of New Tooling Needed: Will the design require new parts? Can we design to use off the shelf parts to reduce cost for new tooling dies?

Amount of Tooling Modification Needed: Are we modifying existing parts? What are the costs associated with this in terms of both tooling modifications and lost productivity while this change is made?

Resistance of Parts to Vibration: Due to the nature of the washer spin cycle, parts need to be very robust to vibrations at nearly all frequencies.

Resistance of Parts to Heat: Will parts be damaged over time by hot wash cycle?

Resistance of Parts to Humidity: Will humidity damage the parts over time?

Serviceability of Parts: Will individual parts be able to be changed out or will an entire need to be swapped?

Sustainability of Parts: Will the user need to do anything to maintain the machine over time- i.e. change filters, empty lint traps, etc.

Safety: The design modification should have no risk of harming the consumer. Hazards to be aware of include fire, chemical, bacteria contamination, and excessive vibrations. We rated this at a 10.

When the associations between the design parameters and customer needs were rated and the results tabulated, we found that certain design specification are critical to designing a successful product. The results of the QFD are summarized in the Table A.1 below.

Table A.1

Design Parameter	**Score**	**Percent of Total Points**
Complexity of Addition	389	27%
Size of Addition	161	11%
Cost of Addition	158	11%
Resistance of Part to Heat	132	9%
Resistance of Parts to Moisture	132	9%
Resistance of Parts to Vibrations	122	8%
Amount of New Tooling Needed	106	7%
Amount of Tooling Modifications Needed	96	7%
Serviceability of Parts	90	6%
Sustainability of Parts	50	3%

We found that the three critical design parameters are the complexity, cost and size of any addition to the current product, and we would like to minimize all three. However, all other proposed idea parameters proved to be consequential to the final product performance and cannot be ignored.

To provide a frame of reference, we compared the Duet to the Asko W6022. The Asko is a Swedish appliance manufacturer known for their highly efficient products, and the W6022 was listed by E-Star as most water efficient washer on the market. In talking with Whirlpool, we would like to set very high goals to push ourselves to perfection and thus we would like to have this washer as our benchmark.

CONCEPT GENERATION

In investigating ways to meet our design goal, we came up with various conceptual ideas focused entirely on reducing the amount of water in the wash cycle. To do so, we explored the logistics of the wash cycle, and divided the concepts into distinct categories describing the subsidiary functions of the design. These functions are outlined in following Morphological Chart shown in Figure A.1. Note that this Morphological Chart has been adapted from their traditional purpose to fit the needs of our team. Rather than using it to define various subsystems, we plan to use it to generate potential ideas and designs. This chart provided a broad representation of all the feasible design options available for integration into the washer system.

Figure A.1: Morphological Chart outlining our design concepts.

Water from Alternate Sources	Capture Air Humidity	Use Condensed Water from the Dryer Air Output	Reuse Household Water	
Utilize Unconventional Fluids	Low Sudsing Detergent	Advanced Enzyme Detergents		
Recycle Water	Recirculation Looped System	Reverse Osmosis Water Filtration	Surfactant Water Filtration	Incorporate Holding Tank
Decrease Water Intake	Decrease Water Per Cycle	Decrease Wash Cycle Time	Improved Sensors	
Better Utilize Water in the Wash Cycle	Incorporate Spray Jets	Heat Water to a Higher Temperature	Incorporate Steam Cleaning	
Redesign Conventional Mechanical Components	Redesign Agitator			

Note that this Morphological Chart has been adapted from their traditional purpose to fit the needs of our team. Rather than using it to define various subsystems, we plan to use it to generate potential ideas and designs. This chart provided a broad representation of all the feasible design options available for integration into the washer system.

We first explored the possibility of utilizing water from alternate sources of water within the household. Implementing a system that could integrate this water into the wash cycle would not only reduce the water usage within the washer, but would also minimize the amount of wasted water throughout the home. To be more specific, we explored the possibility of capturing the moist air leaving the dryer, condensing it, and extracting the moisture to be used as water in the wash cycle. Implementing this type of system seems feasible, however, after some research and analysis we came up with the conclusion that the amount of water reduced by obtaining it from a 'wasted' external source is miniscule compared to our design goal of 75% reduction. Therefore, this general concept category was deemed inadequate.

Based on our research of external water supply, we determined that in order to achieve our water reduction goal, we needed to generate solutions from within the washer system or wash cycle. We then deducted that the wash performance depends on both the mechanical and chemical aspects of the wash cycle. First, we came up with concepts aimed at minimizing the water used in the cycle by modifying the detergents used in the process. Our research shows that incorporating low sudsing and advanced enzyme based detergents into the wash cycle allows for some potential water savings. Although this was an appropriate solution to our design problem, we determined that implementing it would be considered more of an external influence to the washer performance, which places more focus on the detergent design which could also be utilized by Whirlpool's competitors. Also, our lack of chemical expertise steered us away from taking this approach to our design solution.

Our third design concept involved recycling the wash water within the cycle. Because clean water is a main component in achieving the desired wash quality, we simply decided that finding a way to continuously reuse the water through filtration would be a desirable way to achieve the water reduction goal. Implementing a in-line filtration system is an obvious way to do this, and we plan on pursuing such a path. The criteria for determining the final design is explained further in the concept evaluation section.

Furthermore, we explored the possibility of lessening the water intake of the washer as a whole. This involves further improving the load controls to better accommodate for the size of the load and adjust the water usage accordingly. This could also be achieved by incorporating more accurate sensors within the washer to properly determine the load size, maintain water temperature, and measure water usage.

The next two categories of ideas involved completely redesigning the conventional washing methods. We brainstormed a design concept that better utilizes the water in the wash cycle. This consisted of incorporating spray jets and harnessing the power of steam cleaning instead of the agitator. We also considered remodeling the agitator and its components, thus changing the physical design of the system. However, after comparing out design ideas, we eliminated this idea due to its complexity and questionable impact on the wash system of the washer.

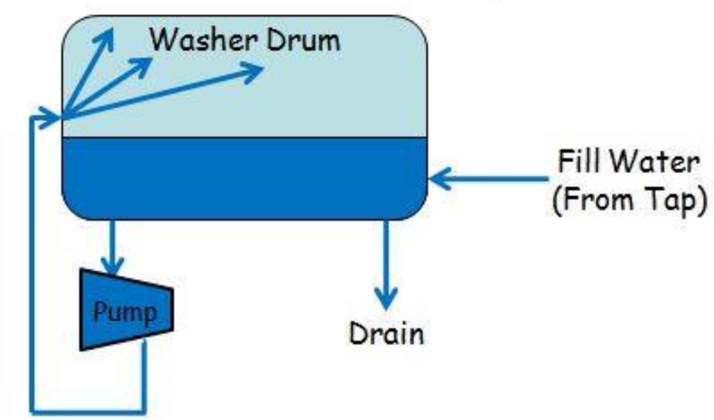
CONCEPT EVALUATION AND SELECTION

Using the aforementioned Morphological Chart (See Fig. A.1) as a guide, we have conceptualized five water reducing designs/modifications to the Duet washing machine. To determine which design is best for our application, we utilized a Pugh matrix to compares the different designs against customer requirements, and uses an arbitrary weighting scale is used to give favor to those requirement that are most important. The customer requirement used were the same as in the QFD discussed earlier with a few modifications per Whirlpool's request.

We were able to determine the circulation pump with a filter was the best design. This and other potential designs are described below. See Appendix A.3 for the final Pugh matrix.

Recirculation Loop

Fig B.1: Design Concept 1- Recirculation Loop

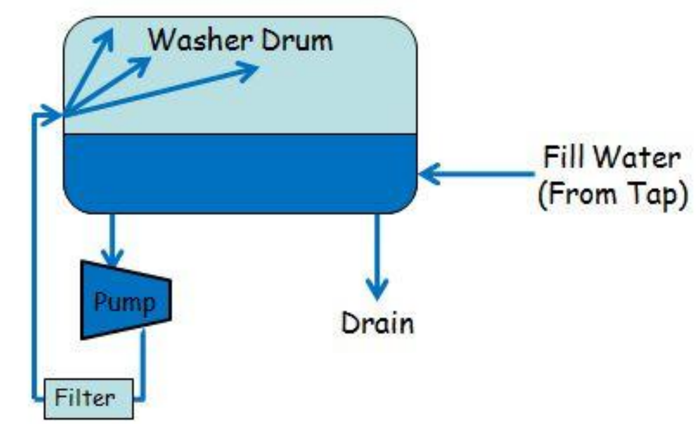


This design utilizes a pump and additional plumbing in the washer to recirculated water during wash and rinse cycles. The goal would be to create high pressure water jets to spray the clothes and increase wash performance. The amount of water used could then be scaled back until the original wash performance is met. We would also investigate pumping air through the jets during the spin cycles to increase drying and thus reducing the amount of energy the dryer will use. This design concept is shown in Figure B.1.

This design is favorable because of its relative simplicity and low cost. However, extensive research would be required to confirm high fabric care would be maintained and to find an adequate pump that will perform satisfactorily throughout the life of the washer.

Filtration System

Figure B.2: Design Concept 2- Filtration System

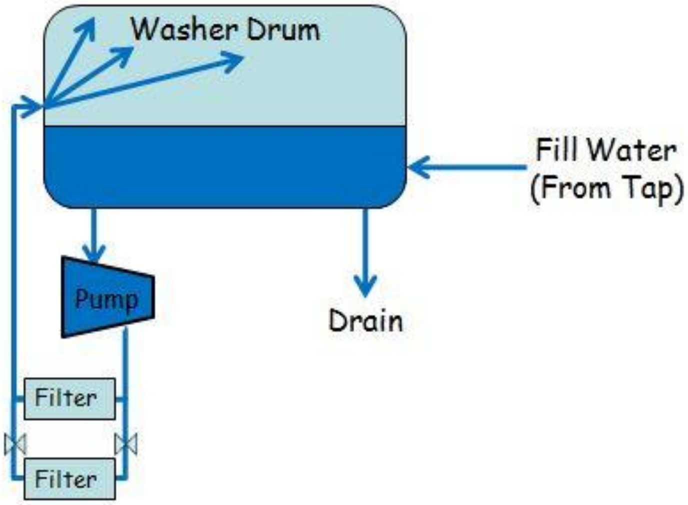


This design is similar to the recirculation loop with the addition of a filter in the recirculation loop. This will provide two benefits- increased wash performance and elimination of a second wash fill. Continuously filtering the wash water will mean the clothes will always be washed in clean water as opposed to the current arrangement where the wash water may become dirty towards the end of the wash cycle. The existing wash cycle actually drains and refills the wash water once during the wash cycle to counter this phenomenon. The addition of a filter would eliminate this additional fill, decreasing water usage by about one third. This design concept is shown in Figure B.2.

A filtration system is advantageous because of its potential to decrease water usage significantly while increasing wash performance. An ancillary benefit would be decreased energy consumption in warm or hot water wash cycles because the elimination of the second fill also eliminates the energy used to heat that water. The key to making this modification feasible is to find a filter that cleans the water at a reasonable price and need not be replaced in the life of the washing machine. We would also have to investigate previously discussed patent application number 09/949,746 by Shell Oil Company to ensure we are not in violation.

Surfactant Filter Addition

Figure B.3: Design Concept 3-Surfactant Filter Addition

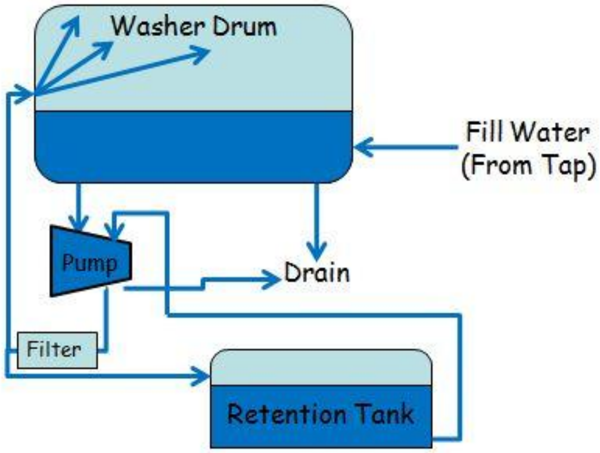


This modification again builds on the previous idea, but also incorporates a suds-eliminating (surfactant) filter in parallel with the normal filter. During the wash cycle, the water would be filtered as discussed in the previous paragraphs, but rather than draining at the end of the wash cycle, the water would be routed through a surfactant filter to eliminate the dissolved detergent, leaving clean suds-less water that can be used in the rinse cycle. Thus, the washer would only need to be filled once per load and this would decrease water usage by roughly two thirds, nearing our goal of 75% water reduction. It is plausible that the amount of water need to maintain current wash performance could be reduced since the washer is now always using clean water, and our goal could be met. This design concept is shown in Figure B.3.

The main advantage of this design is that it may actually meet our water reduction goal. However, significant risk is involved with this as there is serious question as to weather such a filter exists that can handle our pressure, flow, reliability, and monetary cost requirements.

Retention Tank

Figure B.4: Design Concept 4- Retention Tank

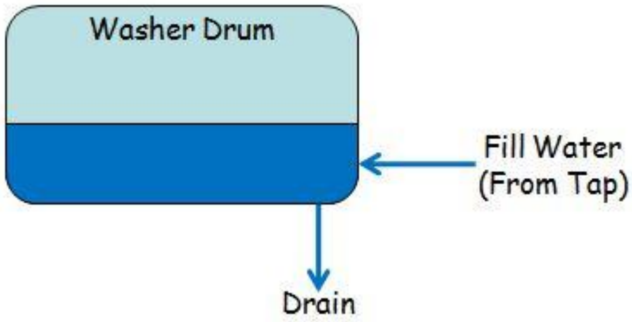


This design will offer significant water savings for those consumers who wash multiple loads of laundry in a single day. The design will incorporate the aforementioned filtration system, but rather than drain the water at the end of the wash cycle, it will store it in a retention tank incorporated within the washer. Since this water is clean, it can be reused for the wash cycle of the next load of laundry. Clean water will be still be used for the rinse cycle, since the storage wash water will still contain surfactants. Note that this design is only suitable if loads of laundry is done consecutively, otherwise concerns about bacteria growth in the water may become an issue. This design concept is shown in Figure B.4.

This design incorporates a good mix of high potential water savings with relatively low risk. If five loads of laundry are done in a single day, only six fills are necessary for this design, compared with fifteen required by the current design- a 60% water reduction. Design risks involved include the ability to fit an adequately sized retention tank in the current washer and cost and complexity issues due to the amount of additional plumbing required.

Cycle Adjustment

Figure B.5: Design Concept 5: Cycle Adjustment



This design would require no additional parts, but would only modify the cycles. The idea would be to reduce the amount of water used in each cycle, but increase the wash time in hopes of maintaining the same wash performance.

Significant research would have to be done to achieve good results with this modification, and there is question as to weather it can actually be done. In order to decrease water consumption considerably, the cycle time would have to increase greatly, coming at a high price in marketability.

By comparing all potential design in a Pugh matrix, we ranked them in the following order (with score in parenthesis): Filtration system (675), Recirculation pump (668), Surfactant filter (666), Retention tank (661), and Cycle Adjustments (656). In our future work, we will ration our time in resources according to this list so as to put the majority of our work into developing the best and most feasible designs.

SELECTED COMPONENTS

In accordance with the results of our Pugh matrix, we have created CAD drawing for the filtration system. Figure A.2 shows an isometric view of our washer with the proposed added components. The recirculation pump, illustrated as a red cube of dimensions 2"x 2" x 3", is connected to a surfactant and sedimentary filtration system shown in blue, sized to 10" x 12" x 5" to accommodate for the confined space below the drum. The tubing is 0.5 in. diameter to match with the proposed circulation pump intake valves. The evaluation process for selecting these components is discussed in more detail in 'Concept Evaluation and Selection' on page 10.

Fig A.2: Isometric of washer with additions

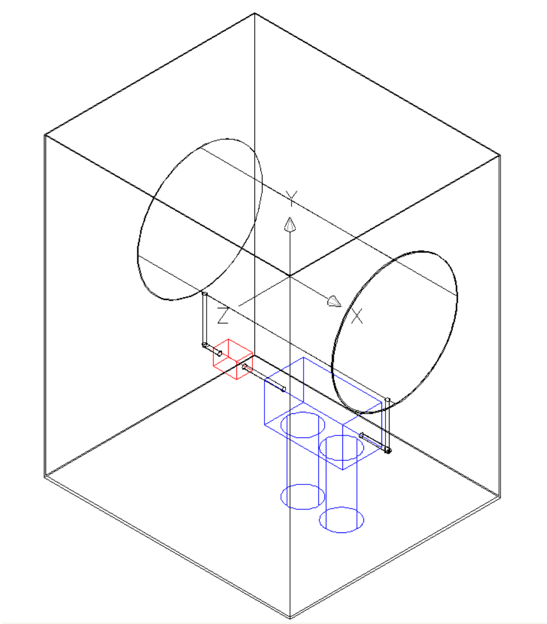
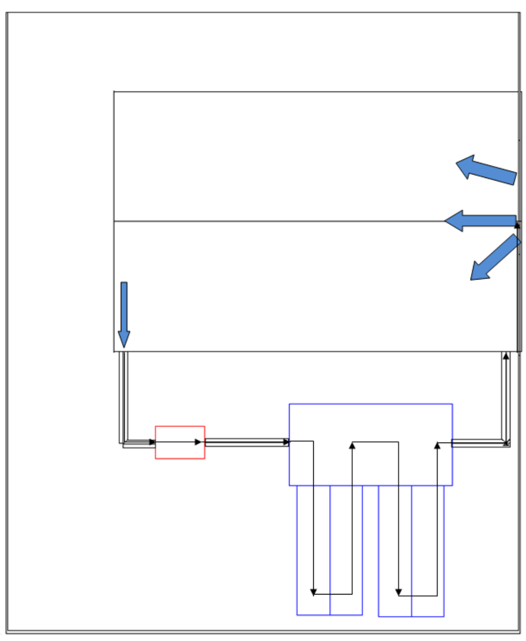


Fig A.3: Side view showing water flow

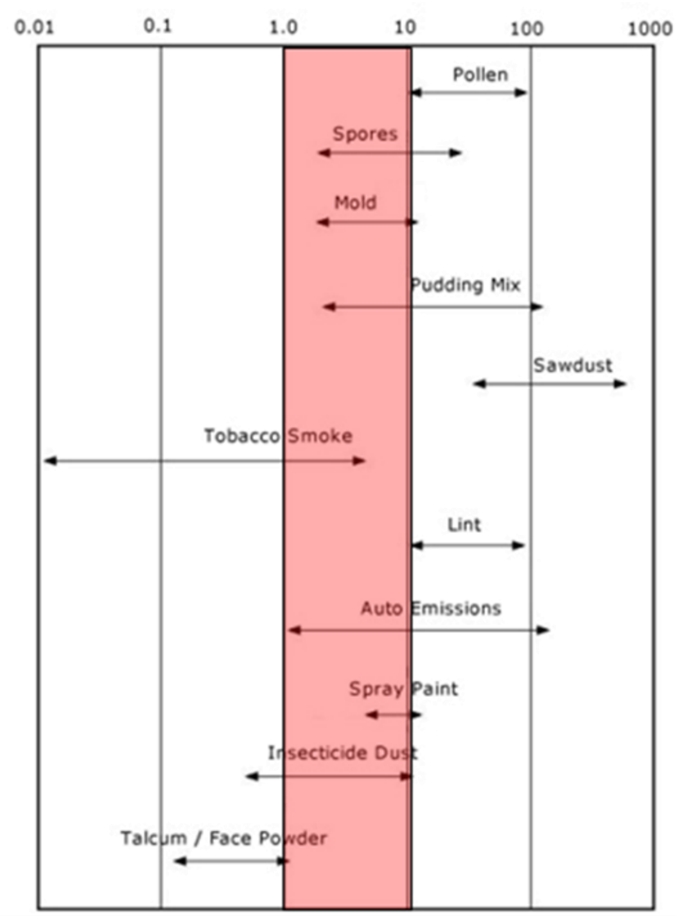


ENGINEERING ANALYSIS
Filter Selection

Our query for an acceptable filter has the following criteria: filters nearly all particulate, high maximum flow rate, low pressure drop, reliable, and long life. We found that Flowmatic produces filters that are both robust and cleanable, and come in a wide variety of shapes and sizes, making it likely that we can find one with an appropriate maximum flow and pressure drop. The Flow-Max lines of filters (made by Flowmatic) are made of a polypropylene and are reasonably priced.

When sizing a filter, we must first determine an appropriate pore size. The desirable pore size is one that is small enough to filter sediment out of dirty wash water, but no smaller. Excessively small pores will only create unwanted back pressure issues. Sizes of common particulate are shown in Figure B.1 below, and from this we can determine a 5 micron pore size would be ample to filter nearly all unwanted dirt.

Fig B.1: Diameter of common particulate

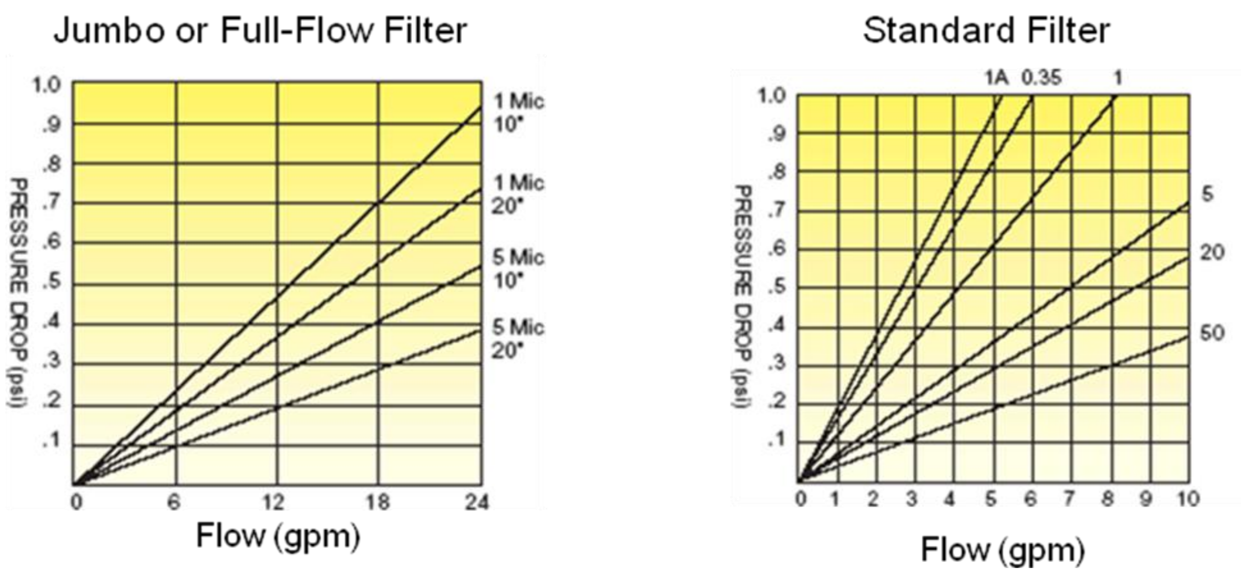


[1]

[1] Figure B.1 from Chart from http://www.askthebuilder.com/B79_Air_Filter_Particle_Size_Chart.shtml

Back pressure shares a positive correlation with the flow rate. That is, the higher the flow rate through the filter, the more back pressure is created. Figure B.2 shows back pressure- flow plots for both standard and full-flow filters with varying pore sizes. Since we plan to use a 5 micron filter, we determine that a standard filter suffices because flows less than about 14 GPM create less than 1 PSI of backpressure, which should be easily overcome with a reasonable pump.

Fig B.2: Flow- Backpressure curves for various filters[2]



Finally, a filter size must be determined. Larger filters allow larger flow rates, but come at a premium monetary price. Retail pricing and maximum flow rates are shown in figures B.3 and B.4 below.   Additionally, physical space in the washer needs to be taken into account. Upon investigation, the space available will limit us to the 10” cartridge. This merits a 7 GPM flow rate, which is ample, and an $8 retail price which presumably would be less than $5 in bulk, this too is ample.

Fig B.3: Retail prices of various filters[3]

Standard Cartridge			Full-Flow		Jumbo		
10”	20”	30”	10”	20”	40	90	170
$8	$15	$21	$20	$34	$95	$119	$159

[2] Fig 2 from: http://www.h2odistributors.com/flow-max.asp
[3] Pricing from: http://www.h2odistributors.com/sediment_cartridges.asp?gclid=CJjHxpOmvI8CFQsLIgodvTzT5w

Fig B.4: Maximum flow rates of various filters[4]

Micron Rating	Maximum Flow Rates Per Cartridge (GPM)							
	Standard Cartridge			10" Full-Flow	20" Full-Flow	Jumbo Cartridge		
	9-3/4"	20"	29-1/4"			40	90	170
1 Absolute	3	6	9	8	12	20	40	80
0.35 Micron	4	8	12	9	13	25	50	100
1 Micron	4	8	12	10	15	30	60	120
5 Micron	7	14	21	15	25	50	100	150
20 Micron	8	16	24	15	25	50	100	150
50 Micron	10	20	30	15	25	50	100	150

Note: Filter housing selection should also be considered when flow rate per cartridge is determined.

To summarize, we recommend using Flowmatic Flow-Max filter model #FM-5-975, which is a 10"x2¾" cylindrical filter with 5μ pore diameter. This will allow for a maximum 7 GPM flow and less than a 0.5 PSI back pressure. This filter retails for $8, but we hope to procure it for less than $5. The filter is rated up to 125°F and can be washed when it becomes dirty.

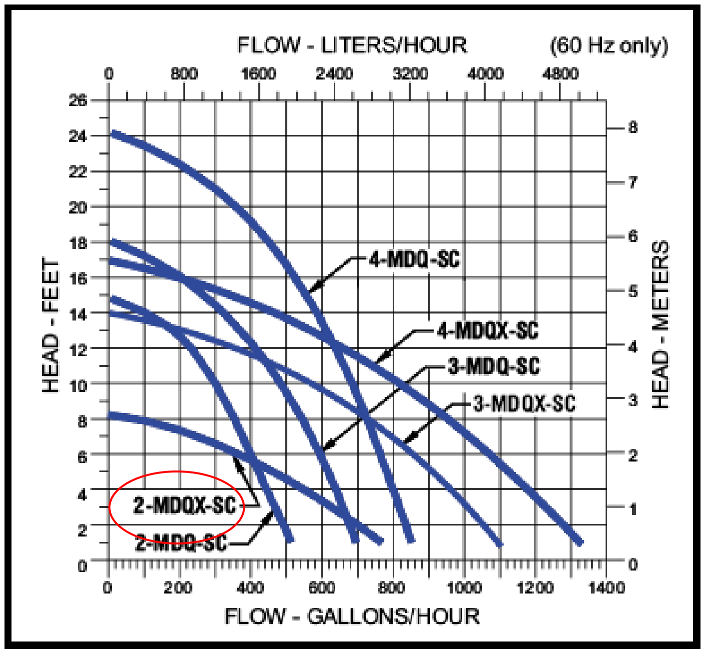
Flowmatic also offers housing custom designed for this filter. Model FW4200WW14 is a polypropelyne and acrylic sytrene housing that can withstand temperature up to 125°F. It mates with 0.25" FNPT pipe. The retail price is $24, but due to it's simplicity we expect to obtain the house in bulk for less than $10 per housing.

Pump

The pump that we have selected for our project design is the 2-MDQX-SC Magnetic Drive Aquarium Water Pump manufactured by Little Giant. The pump consists of a thermally protected motor that runs at 115V AC and 60 Hz. It consumes 110 Watts or 1/30 HP and has a maximum flow rate of 760 GPH, or 10.7 GPM. The head-flow curve of the water pump is shown in Figure B.5.

[4] Chart from: http://www.h2odistributors.com/flow-max.asp

Figure B.5: Pump performance curve showing head at various flow rates



The head is the energy imparted to a fluid by a pump and is measured in feet. Bernoulli's equation is used to find the value of head for each flow rate. This is shown in Equation 1.

$$h = z(x) + \frac{p(x)}{\rho g} + \frac{V(x)^2}{2g} \qquad \text{(Eq. 1)}$$

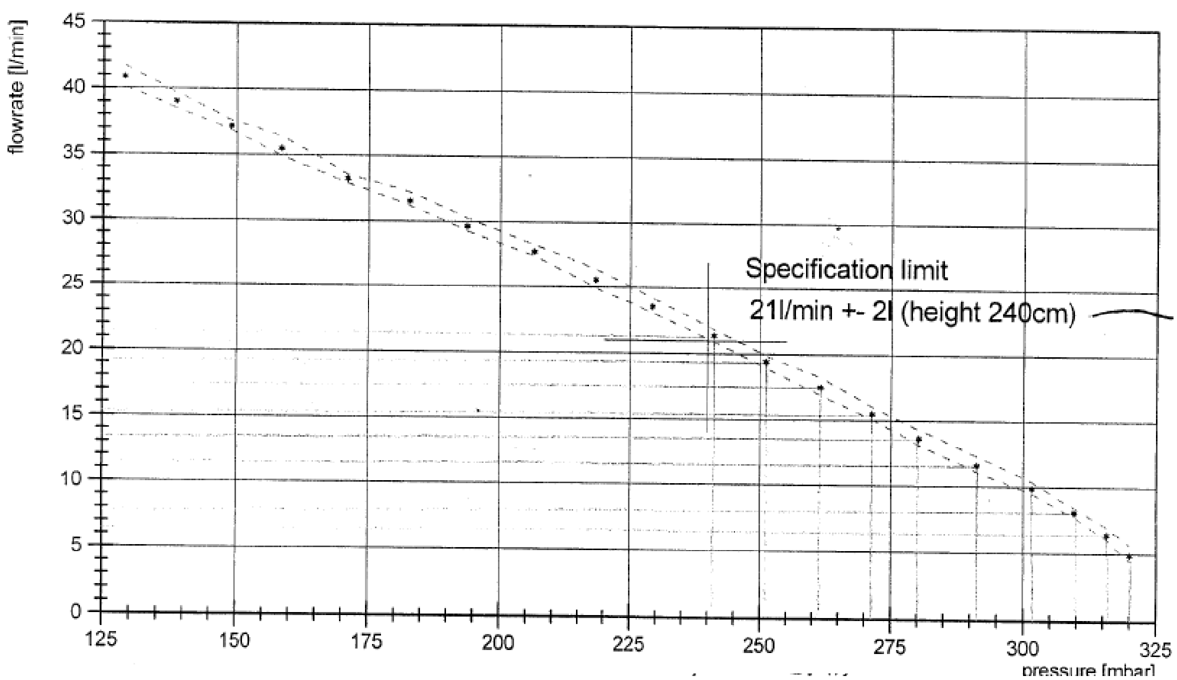
Where h is the total head, p is the pressure, V is the average fluid velocity, ρ is the fluid density, z is the pipe elevation about some datum, and g is the gravity acceleration constant.

The pump has physical dimensions of 5"x9.1"x4" allowing it to find inside the Duet. The intake contains a female and male national pipe thread of 1" which will mates with our addition plumping. Figure B.6 shows a diagram of the 2-MDQ-SC Magnetic Drive Aquarium Water Pump. The pump retails around $105 which is fairly high, but we hope to negotiate for a significant discount in bulk.

Figure B.6: 2-MDQ-SC Magnetic Drive Aquarium Water Pump

Another option our team has considered using is the current Whirlpool Drain Pump. This is a Copreci pump that runs at 127V and 60 Hz. This pump performance curve, shown in Figure B.7, shows potential for working with our recirculation system as the maximum flow rate is 41 l/min or 10.8 GPM. Reusing the drain pump as a recirculation pump would be advantageous in both cost and reliability aspects. Eliminating the implementation of a pump specifically devoted to recirculation drastically cuts costs. Furthermore, it is assumed that Whirlpool has already done all the necessary testing and qualifying to ensure their drain pump is reliable, and there tests would need not be repeated.

Figure B.7: Performance curve of pump showing head at various pressures



Surfactant Filter

Earlier in the paper we had discussed the possibility of using a surfactant filter to eliminate suds from wash water and thus reuse it as rinse water. However, after further researching this option it was deemed to be impractical for our design as current sudsing methods are not appropriate for industrial applications. Polymers can be used to remove chemicals from water by acting as positive ions that attract the negatively charged particles in the water. The difficulty with this method is that the proper polymer must be used to remove the desired chemicals. In addition, large amounts of the polymer must be used to obtain the desired affect and this method is generally used in filtration of pool and spa water. An example of a patented polymeric surfactant technology is known as MYCELX. MYCELX is currently used to filter out oil and other substances from industrial waste water.[5] This substance meets our spatial and pressure constraints, but we are uncertain if soap particles could be removed using this type of filter and cost would likely be an issue as well. Further research and development would be necessary to determine the effectiveness and cost of these polymeric substances before they could be used in our application.

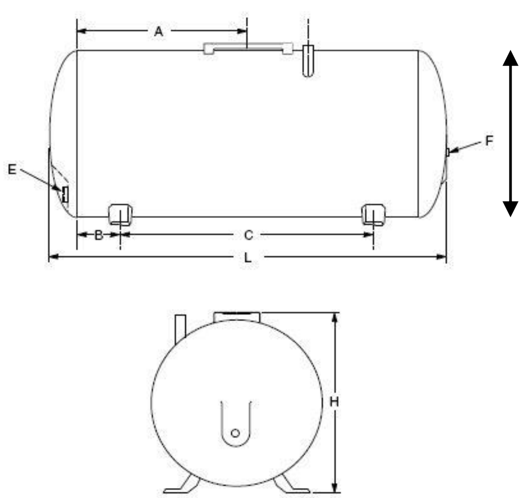
SUGGESTIONS FOR FUTURE ADDITIONS

Retention Tank

Earlier, we had discussed using a retention tank to store wash water for use in later loads. Because of concerns over bacteria reproducing, the water could only be stored for a short period of time before it would have to dumped and new fill water used. Due to the complexity of this addition and the further costs incurred by adding it, it is not part of our core design, but we wanted to include calculations pertaining to in incase Whirlpool or team handling phase two of this project decide they would like to implement it.

Dimensions

The dimensions of the retention tank were primarily determined based on the amount of available space within the washing unit. At first, we decided to incorporate the addition within the washing machine frame, however, after accounting for the sedimentary filter as well as the pump, there left no room for an appropriately sized tank. The only location available for an addition of adequate size is the pedestal bin located at the base of the washer. Although Whirlpool recently developed this storage bin as a new feature of their washer lines, market research and customer feedback have concluded that the bin is uncomfortably low, and is difficult to access. Therefore, we decided to utilize this space to house the retention tank and integrated chemical feed system. The storage bin is approximately 27” Width x 26 ¼” Length x 13” Height. Based on these limits, we determined the following maximum tank dimensions shown below.



D

Length, L = 26”
Height, H= 13”
Diameter, D = 12”

The specified maximum dimensions yield a maximum volume capacity of about 12.7 gallons. A current washer cycle consists of two wash cycles and a rinse cycle, which use approximately a total of 80 gallons a water total (25 per wash cycle and 30 for rinse). The addition of a recirculation filtration loop will eliminate one of the wash cycles and the retention tank will reduce the amount of tap water consumed in the remaining cycle by 12.7 gallons. Thus, rather than using 50 gallons of fresh wash water per load, only 12.3 gallons are being used, representing a 75% reduction.

Material Selection

Corrosion Resistance

The retention tank is broken up into two layers of material. The inside shell layer will consist of a High Density Polypropylene.

Corrosion was the primary factor that we aimed to design against for the inner lining. Because the inside surface of the retention tank will continuously be exposed to water, the interior lining of the tank must be of a material that is resistant to the corrosive effects of water. Therefore, we determined that the inner lining must consist of more of a polymer based material, completely ruling out the possibility of using common metals which are easily susceptible to moisture corrosion. Also, the water entering the tank is filtered for sediments, but there still may be different types of bacteria in the water. To remedy this, we can either hold the drain the tank after a certain amount of time to eliminate bacteria growth, or have the tank contain certain disinfectants such as chlorine to eliminate this bacterium. Presence of chlorine in the water also accelerates the corrosive effects.

Microbial Corrosion is also another type of corrosion which we needed to consider. This is a type of corrosion that is caused or promoted by the various types of bacteria within the environment. Although disinfectants within the tank eliminate bacteria and micro organisms, this process takes time (Chlorine Contact Time); therefore a material needs to be chosen that will be resistant to this deteriorating effect on the tank. Generally, materials that resist the corrosive effects of moisture also prove to be resistant to this type of corrosion as well.

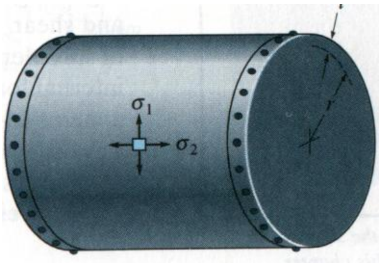
We also considered the possibility of corrosion caused by high temperatures. Often, steel coming into contact with steam or other high temperature liquids can have an adverse effect on the carbon level of the steel and even oxidize iron, which produces extensive corrosion. This type of corrosion is non existent with the polymer material choice. Under normal operating conditions the temperature of the water rarely exceeds 80 degrees Fahrenheit, therefore eliminating any potential design problems.

Material Strength

Because the vessel will be under constant loading due to the pressure throughout the system, we need to consider the yield properties of the material. To do this, we performed a stress analysis under a prescribed thickness.

We first determined the thickness of the tank to be 0.25”. It was then necessary to perform the Von-Mises Criteria stress analysis to determine if the thin walled cylindrical pressure vessel (Retention Tank) would yield under the maximum operating pressure of 75 psi (5.17E5 Pa).

The longitudinal and hoop stresses of the cylinder were determined using the following equations.



$$\sigma_a = \frac{p\,r}{2t}$$

$$\sigma_h = \frac{pr}{t}$$

After determining these principal stresses, we substituted them into the Von-Mises Yield Stress Equation shown below.

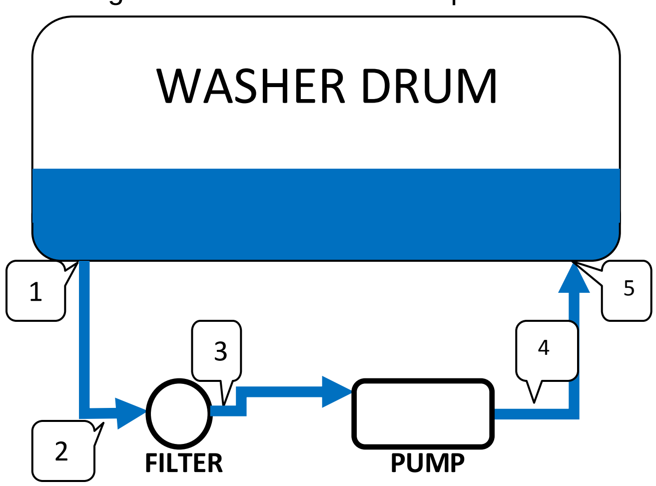
$$\sigma_1^2 - \sigma_1\sigma_2 + \sigma_2^2 \leq \sigma_y^2$$

With a wall thickness of 0.25"(.64 cm), we determined the stress to be 10.75 MPa. This is approximately one-third of the yield stress of the HD Polypropylene, which is equal to 30.2 MPa. Thus, our prescribed wall thickness is sufficient for our design.

Engineering Analysis

It is desirable to know the flow rate and gauge pressure at various points in the recirculation loop. This can be achieved using dimensional analysis of pipe flow[5]. Head is lost through the filter, friction in the piping, elbows in the piping, and flow against gravity. It is gained through the pump and flow with gravity. Figure C.1 below shows a schematic of the recirculation system with call-outs where pressure and flow will be calculated.

Figure C.1: Recirculation loop



[5] All fluid mechanics formulas and principals from Munson, Bruce, Theodore Okiishi, Fundamentals of Fluid Mechanics, 5th Ed. Hoboken, NJ: John Wiley & Sons, Inc., 2006.

Water will be assumed to be incompressible for this process. Combining this assumption with conservation of mass flow allows us to consider volume flow constant, and thus average water velocity will be constant. Equation 2, below, expresses the average velocity in terms of flow rate, Q, and pipe radius, R. We will be using a 1" diameter pipe to mate with the pump inlet (and have adapters to mate with the filter and pump outlet), and a flow rate of 5 GPM, or 1150 in^3/min. This yield V_{avg}, is found to be 1464 inches/minute, or 2.03 ft/second. This equation assumes non viscous flow which may be a weak assumption with is deemed adequate for these calculations.

$$V_{avg} = \frac{Q}{\pi R^2} \quad \text{(Eq. 2)}$$

The reference pressure reading will be taken at point 1. Moving to point 2 involves a six inch vertical drop, creating the same amount of head. However, there will be loses from pipe friction and pipe geometry. Routing the water through a 90° elbow will result in head loss as determined by Equation 3 below, where g is the acceleration due to gravity, 32.2 ft/second. Plugging in this and the average velocity determined above, we find a 0.032" head loss, which can be considered negligible. Furthermore, all elbows in this system will have this same head loss and thus can all be considered inconsequential to flow dynamics.

$$h_L = \frac{0.5V^2}{2g} \quad \text{(Eq. 3)}$$

To determine head loss due to friction in piping, we must first determine the Reynolds number of the flow as given below in Equation 4 below, where Re is the Reynolds number, ρ is the density of water 1.94 slugs/ft3, D is the pipe diameter, 0.0833", and μ is the dynamic viscosity, 2.34×10^{-5} lb s/ft^3. Plugging these numbers yields a Reynold's number of 14025.

$$\mathrm{Re} = \frac{\rho VD}{\mu} \quad \text{(Eq. 4)}$$

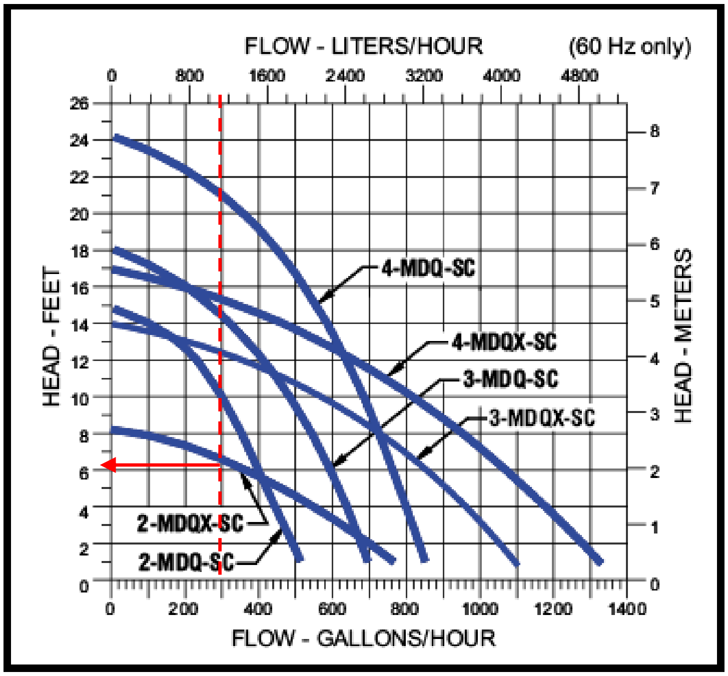
Knowing the Reynolds number allows us to determine the f value in Equation 5. The value associated with a smooth pipe and Reynolds number of about 15000 is 0.0155. Plugging in values allows us to determine a flow loss of 0.012 inches of head loss per inch of tube traveled. This again will be negligible when compared to head gains and losses from other sources.

$$hL = \frac{flV^2}{2gD} \quad \text{(Eq. 5)}$$

According to documentation provided by the manufacturer, a 5 GPM flow through the filter will result in 0.35 PSI back pressure, or a 9.7" head loss.

In order to operate the pump at the appropriate spot on the flow-head curve (see reprint of Figure B.5 below), we need to purposefully create back pressure after the pump. This can be done by creating a section of pipe of much smaller radius. The change in pressure and flow rate can be described by Equation 6 below. As shown on the reprint of Figure B.5, we need 7 feet, or 84 inches of back pressure to have the pump operate at 5 GPM

Figure B.5:



In order to achieve this, we will create a section of pipe 1/8" in diameter; Equation 5 can be used to determine the necessary length of this section. Using Equations 1 and 3 to determine average velocity and Reynolds number, we find them to be 10.7 ft/sec and 9241 respectively, indicating turbulent flow. The Reynolds number can be translated into an f value of 0.031 for a smooth pipe, and plugging these values in to Equation 6 yield a result of 0.44 ft of head loss per inch of pipe. An eleven inch section of vertical pipe will thus create 4.84 feet of back head due to friction and an additional 0.92 feet due to the movement of fluid against gravity. The final value of 5.76 feet of head is less than the 7 feet dictated by the head-flow curve which is desirable to ensure flow and account for discrepancies between assumptions made in computations and actual real world conditions.

$$h_L = f(\frac{l}{D})(\frac{V^2}{2g}) \qquad \text{(Eqn 6)}$$

These calculations and findings are summarized in Table C.1 below.

Table C.1:

Location (See Figure C.1)	Head (in inches)
1	0 (Reference)
2	6
3	-3.7
4	80.3
5	11.1

FLUENT

In order to confirm our calculations for the choked flow, we created a 2-dimensional model of the pipe in the program Gambit. The model was created with a 2" length of the 1" diameter pipe, a necking region, and a 1/8" diameter region measuring 11" in length. This model was then meshed and imported into the flow analysis program Fluent. Inlet pressure was set to 80.3" of head (20 kPa) and all other operating conditions such as gravity and fluid properties were set to the appropriate values. Flow was analyzed as a second order turbulent flow with an incompressible fluid. Figures B.6 and B.7 show the pressure plot and pressure gradient respectively. Both figures show that our analysis confirms our calculated pressure drop over the length of the choked tubing.

Figure B.6: Pressure drop through choke piping

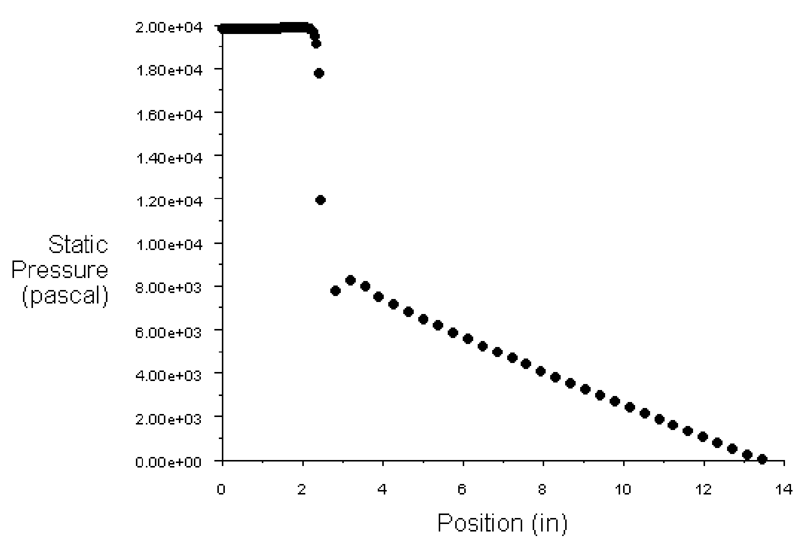
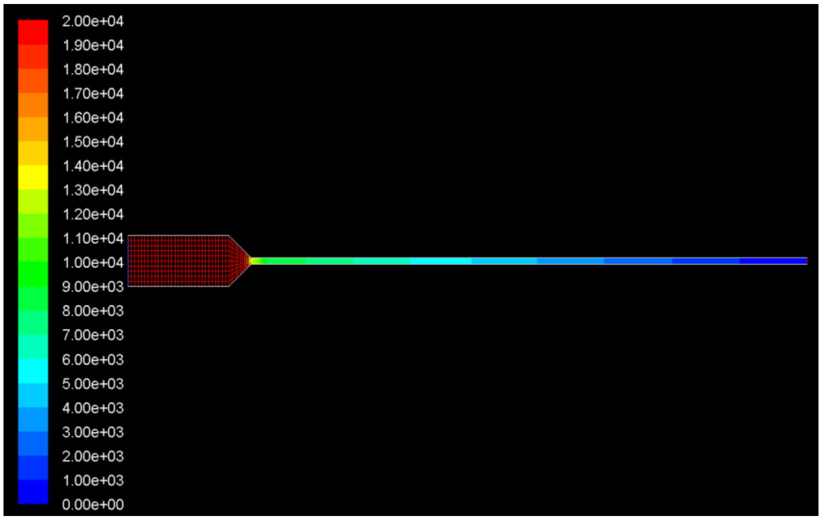


Figure B.7: Pressure gradient through choke piping



FINAL DESIGN

CAD drawing

Fig C.2: Isometric view of washer

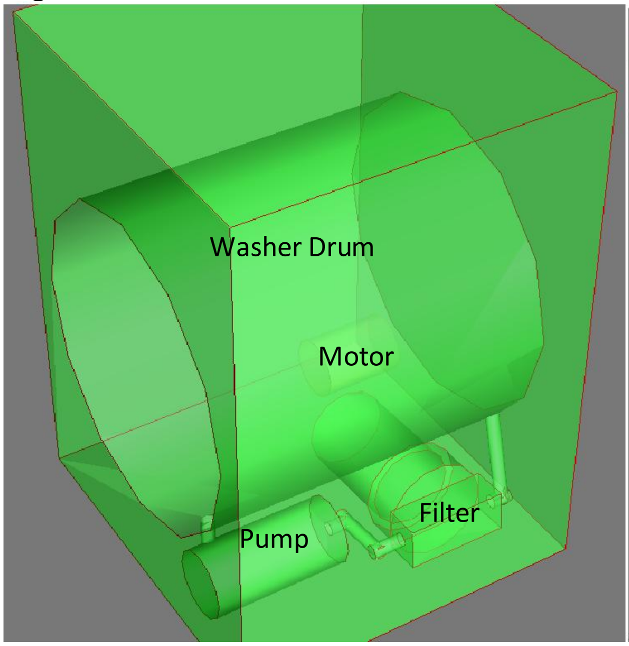
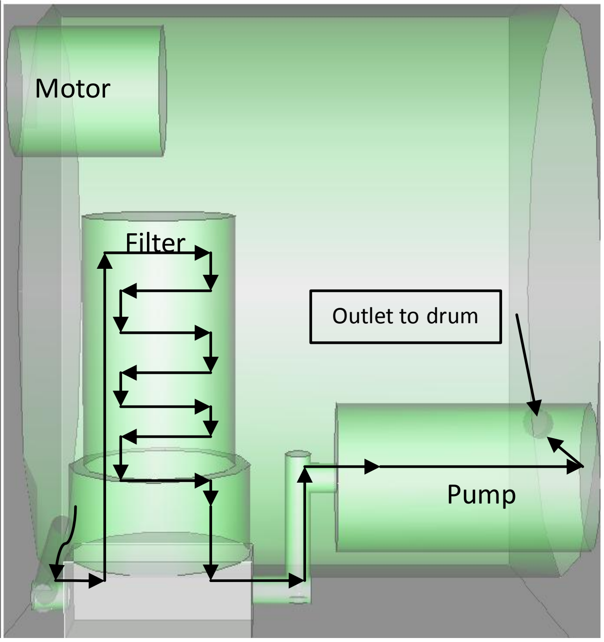


Fig C.3: Top View- cross sectional flow



Figures C.2 and C.3 show isometric and side views of our CAD drawing representing the washing machine with some internal components along with our proposed additions. In Figure C.2, the motor driving the clothing drum is represented by a red cylinder 4½" in diameter and 6" long. Damping supports are represented as four cylinders attaching the clothing drum to the outer frame in both figures. Piping is represented as 1" diameter cylinders connecting all components. The sediment filter is modeled in blue to the specifications of the selected 10" filter and casing. Finally, the water pump is modeled as a cylinder of 5" diameter and 10" length. On the side view, Figure C.3, the path of water is shown dropping from the clothing drum, into the filter, through the pump, and then back in to the drum.

Bill of Materials is shown in Appendix 4. Specific information and prices are given for our selected components. Mountings, fittings, and other assembly materials will be determined in phase 2 of this project during the manufacturing plan.

ENERGY ANALYSIS

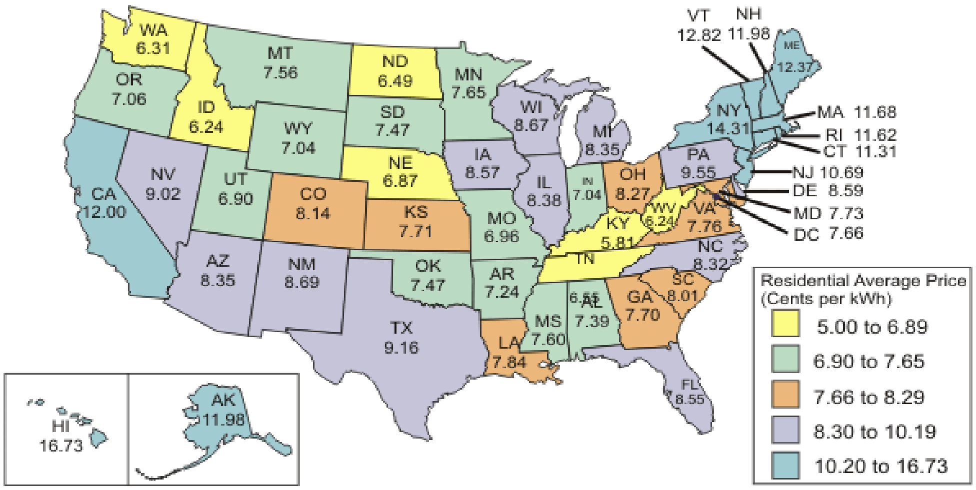
Table C.2 shows the energy analysis of our redesigned washing machine. The data depicts the savings for use in the United States where the average cost of electricity is around $0.0986 per kW hour [8] and the average cost of water is $0.002032 per gallon [9]. We also included the density of water, 3.79 kg/gallon [6], and specific heat, 4.18 kJ/kg K [7], into our calculations. Currently, the Duet washing machine uses around 13-15 gallons of water per load. With our addition, the machine will save 5 gallons of water per load which will in turn save on energy during warm and hot washes as less water needs to be heated. During a warm wash cycle, 2138.7 kJ of energy will be conserved which saves an average of $0.05 per load. For each hot wash cycle, 3802.1 kJ of energy will be conserved which will save the consumer $0.09 per load. Cold, warm, and hot washes will all save around $0.01 due to the reduction in water. Over the course of a year, the consumer will save around $0.25 for cold wash cycles only, $21.23 for warm wash cycles, and $37.55 for hot wash cycles. This is based off of the average household loads per year of 358 [10].

Table C.2: Washing machine energy analysis

	Cold Wash	Warm Wash	Hot Wash
Water Temperature (°C)	18	45	66
Water Savings (gallons)	5	5	5
Mass of Water Savings (kg)	19.0	19.0	19.0
Energy Savings (kJ)	0.0	2138.7	3802.1
Energy Added from Pump (kJ)	345.6	345.6	345.6
Monetary Savings from Energy per Load	-$0.01	$0.05	$0.09
Monetary Savings from Water per Load	$0.01	$0.01	$0.01
Total Monetary Savings per Load	$0.00	$0.06	$0.10
Total Monetary Savings per Year	$0.25	$21.23	$37.55

The amount of monetary savings increases with the temperature of the water. If the user runs mostly hot wash cycles, then the savings will be higher. These calculations assume that the water is efficiently being heated. If in heating the water, some heat escapes to the atmosphere, even more energy will be saved in the redesigned washer. The amount of savings will increase in Hawaii, Alaska, California, and other countries where the average price of water per load is higher. Figure C.4, shows the price of water in different states throughout the USA [8].

Figure C.4: Energy costs by state



Source: Energy Information Administration, Form EIA-861, "Annual Electric Power Industry Report."

The cost for implementing our design cannot be detailed to the exact amount because we do not know the exact cost of additional parts when purchased in bulk. However, we can confidently predict the proposed additions will add less than $100 to the cost of the washer. The user will then start saving money after 2 to 5 years of using the washer with the new additions. The average lifespan of a front load washing machine is over 10 years.

We understand that the total monetary savings for the customer is not a high selling point, however, the purpose of this project was to develop a system that will decrease the amount of water used for the Duet washing machine and we have therefore achieved our goal. As previously mentioned, we recommend marketing the washer where energy and water come at a premium, or consumers are concerned for the environment.

Manufacturing and Testing Plan

Testing Plan

In order to ensure top quality and reliability to the consumer, our redesigned washer will be tested at the component and system level. Whirlpool has existing testing and qualification procedures and in the event their evaluation plan calls for a test similar to one described below, their test will be performed instead of ours. In all tests, we will assume the washer needs to be able to accommodate 5 loads per week for 15 years.

At the component level, we will run forty pumps continuously at 125 VAC in 100°F, 95% RH humidity against 90" back pressure until failure. We will then find the mean pump life and standard deviation. The pump will be considered acceptable if it can be proved with 95% confidence that the pump will last longer than 4000 hours in the described conditions.

A second pump test will be to switch the motor on and off at ten second intervals. This test will be conducted on a group of forty pumps 4000 times each. The test will be passed if no pumps fail.

A group of forty filters will be fed 180°F water in the same conditions as described for the pump. After 4500 hours, each filter will be fed sand mixed with water. Only if each filter is still adequately able to filter particulate will the Flowmax filter is incorporated into the final design.

On the system level, we will run the washing machine through a barrage of tests. The first will be to run the forty washers 4000 times each at 125 VAC in 100°F, 95% RH humidity. To pass the test, the washers must still run with no leaks after the evaluation has ended.

To ensure the filter need not be cleaned more than once a year, the system will be ran with a full load of clean clothes and a cup of sand. If the washer still functions after 260 cycles, it will be considered sufficient.

Due to the recirculation loop, new flow patterns will emerge inside the washer. To make sure overloading the washer doesn't interfere with this, a king size comforter will be washed while monitoring the unit to ensure there is flow through the recirculation loop.

Manufacturing Plan

As previously mentioned, all additional parts will be purchased. We assume Whirlpool already has a system in place for procuring purchased parts, and ensuring they are properly stored until use.

The only part of the current production washing machine that needs modification is the washer drum. It will require two holes to be made so that dirty water may be taken from the drum and clean water returned. Rather than creating an entirely separate part with a dedicated mold, we plan to modify existing drums. This can be done by drilling and taping two holes.

All additional parts need to be mounted to the base of the washer. Exactly how this is done will depend on the mounting brackets designed by phase two design team. However, we recommend using self tapping metal screws.

We foresee these implementations creating need for five more manufacturing jobs: one to drill and tap each hole in the washer drum, one to mount the pump, one to mount the filter, and one to connect the plumbing. More specific information as to the manufacturing plan would require more in-depth knowledge of the current manufacturing process and this more within the scope of phase two.

PROJECT PLAN

While reading this section, note that a detailed Gantt chart can be found in Appendix A.2.

As a critical first step in the design process, we familiarized ourselves with the general function of the Duet HT washing machine. To gain a proper understanding of components of the machine, we visited Whirlpool's world headquarters to observe a teardown of one of their models and to establish relationships with the team members within the research and development department. Furthermore, our sponsors have provided us with a Duet washer and pedestal to assist with our design.

The next step we performed was to conduct market research by exploring the current energy and water saving technologies used by Whirlpool's various competitors. This market research is vital because it enlightens us as to what IP rights we need to design around. Various washer fluid types and the washing cycle in general were analyzed and dissected in hopes of improving the eco-efficiency of the product line.

After all the research is completed, we compiled a list of all the possible design solutions along with their respectable strengths and weaknesses. Because our segment of the project deals primarily with the research and preliminary design of washer components, there is a large amount of time dedicated to the divergence and transition aspects of the design process. Our group will not be constructing a physical prototype. However, we will be determining, through extensive market research of emerging home appliance technologies, the most cost and economically effective designs and additions to the washer brand.

Through extensive research and collaboration with our sponsors, we recently completed an evaluation of all our concepts, and determined a suitable combination of additions that will fulfill our water reduction goal. For the next few weeks, we will be determining an objective and accurate way of measuring water reduction, performing cost analysis, outlining manufacturing objectives, and providing detailed specifications on our selected system components.

In general, the tasks at hand consist of a combination of extensive research and practical application. Our recommendations for the designed components of the washer will be passed along to the second phase of student groups to be applied and developed in the second half of the project.

Throughout the phases of the project we will be meeting with specialized engineers in the Whirlpool Fabric Care department. The function of these meetings will primarily be to ensure that the design and technology recommendations we have considered are feasible options for washer improvement and meet their design criteria.

Because we will not be creating a prototype, our project costs will most likely only consist of travel cost reimbursement, and extensive budget planning will not be necessary.

CONCLUSION

Our project sponsor, Whirlpool Corporation, has asked us to reduce the water usage of their Duet HT washing machine by 75%. To obtain a greater knowledge of the industry we have researched water reduction patents and future developments including inertia based water control, water filtration methods, water recycling, and alternative washing fluids. We also evaluated all of our customer requirements and project constraints and organized them using a QFD. From this QFD, we were able to determine that our most important design constraints would be to maintain the cleaning performance and outside washer dimensions while still accomplishing our primary goal of a 75% water reduction.

We then used to a Morphological Chart to brainstorm potential water saving techniques and then generated actual design modification based on our Morph Chart. Once we have completed our research, we will pursue a number of different design options and ultimately decide on a final design recommendation. Currently our two best potential designs are a water recirculation scheme and a water filtration system. This recommendation will then be passed on to a future group who will complete the second half of the project.

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GROUP MEMBER BIOGRAPHIES

Jennifer Sutherland is a senior in Mechanical Engineering and will be graduating in December. She has completed two co-op rotations at Toyota Technical Center. Her most recent rotation was in Vehicle Performance Development and her previous rotation was in Engineering Design Interior Trim. She has also held two internships at Siegel-Robert Automotive where she worked on component design and manufacturing. After graduation, she is seeking a full time position in the automotive industry or related field.

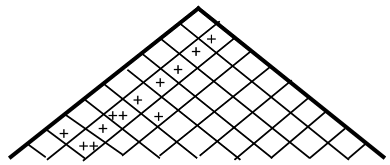
Kaveh Dabiran is a senior in Mechanical Engineering and will be graduating in May of 2008. He has held two internships throughout his college career, working as an environmental engineering consultant for Nova Environmental, and a project management intern for Structural Group. After graduating, he plans on pursuing a permanent position in Project Management and Construction Consulting.

Chris Brooks is a senior and will be graduating in December with a degree in Mechanical Engineering. For the past two years, Chris has worked part and full time at University of Michigan-ITCS as a Campus Computing Sites senior rover. After graduating from Saline High School, Chris chose Mechanical Engineering for the flexibility to work in different areas of industry. After graduating, Chris will seek a full time position in the Ann Arbor area to remain near friends and family. Chris is a huge sports fan and enjoys playing golf, bowling, basketball, and various other sports.

Marty Austin is a senior in the Mechanical Engineering department at the University of Michigan. In addition to his studies, he has enjoyed two part time research positions. One job involves touring factories and making recommendation on how they can reduce their energy consumption, and a second involved writing a computer program for a reconfigurable factory CNC machine. In his free time, Marty enjoys boating, golf, bowling, and watching Michigan football.

APPENDIX A.1

Quality Function Development (QFD)



Relationships

++ Strong Positive
\+ Medium Positive
\- Medium Negative
\- - Strong Negative

(+) => more is better
(-) => less is better

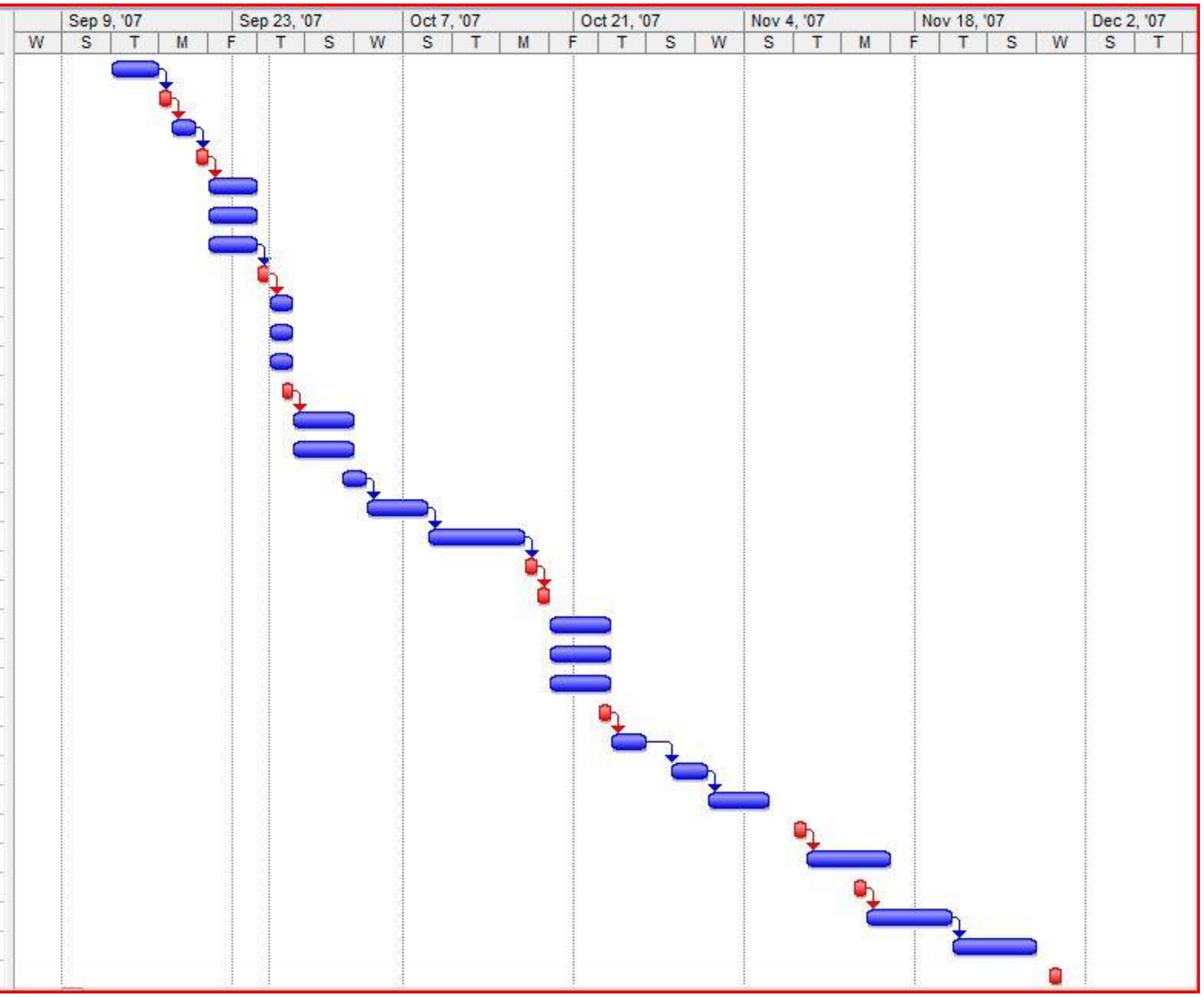
	Weight*	Size of addition (-)	Cost of addition (-)	Complexity of addition (-)	Amount of new tooling needed (-)	Amount of tooling modification needed (-)	Resistance of parts to vibrations (+)	Resistance of parts to heat (+)	Resistance of parts to moisture (+)	Servicability of parts (+)	Sustainability of parts (+)		Benchmarks: Asko W6022		
Maintain High Wash Performance	10	1	5	5	1			1	1				4		
Reduce Water Usage	10	1	5	9	1	1							5		
Use Less Energy	4		1	5									2		
Maintain Price Point	6	1	9	5	9	9							3		
Maintain washer outside dimesions	10	9		5									5		
Ease of manufacturability	7	5		9	1	1							?		
Ease of servicability	5				5	5				9	1		?		
Relability	8						9	9	9				?		
Marketability	5									9	9		?		
IP Issues	4			9									?		
Saftey	10	1		5			5	5	5						
Measurement Unit			ft3					C	RH						
Target Value			~2					100	100						
Importance Rating															
Total		161	158	389	106	96	122	132	132	90	50				
Normalized		11%	11%	27%	7%	7%	8%	9%	9%	6%	3%				

Key:
9 => Strong Relationship
3 => Medium Relationship
1 => Small Relationship
(blank) => Not Related

***Weights are figured on a scale of 1 to 10**

APPENDIX A.2

	Task Name
1	Get background information on Whirlpool
2	Conference Call with Sponsor
3	Collect wash cycle information
4	Visit Corporate Headquarters for project breakdown and washer teardown
5	Compile engineering and marketing information
6	Explore current washer technology
7	Prepare Presentation stating project objectives
8	Short Presentation #1
9	Research washer fluid types
10	Research mechanics of the wash cycle
11	Research water filtration system
12	Design Review #1
13	Analyze current technologies used in Whirlpool washers
14	Analyze competing washer technologies
15	Select technologies to be included in final product design
16	Receive Washer Model & Dissect
17	Determine design components and parameters
18	Conference Call with Sponsor
19	Short Presentation # 2
20	Qualitatively measure energy conservation
21	Qualitatively measure water conservation
22	Perform cost analysis
23	Design Review #2
24	Detailed Configuration Analysis
25	Manufacturing Planning
26	Variable Testing and Feedback
27	Short Presentation # 3
28	Design Improvements
29	Design Review #3
30	Prototype Planning
31	Project Overview and Pass Off
32	Design Review #4



APPENDIX A.3

		Design Criteria													
		Maintain High Cleaning Performance	Maintain High Fabric Care	Reduce Water Usage	Reduce Energy Usage	Maintain Price Point	Maintain Washer Outer Dimensions	Ease of Manufacturability	Ease of Serviceability	Reliability	Marketability	IP Issues	Safety		
	Importance Weighting:	**10**	**10**	**10**	**4**	**6**	**10**	**7**	**5**	**8**	**5**	**4**	**10**	**Total Score**	**Rank**
Design Ideas	Recirculation Pump	6	6	5	4	8	10	9	8	8	7	8	10	668	2
	Filter	8	6	7	8	7	10	7	6	6	8	6	10	675	1
	Surfactant Filter	8	6	8	8	5	10	6	5	6	9	6	10	666	3
	Retension Tank	8	6	9	8	7	6	6	6	7	9	6	10	661	4
	Adjust Wash Cycles	4	6	3	4	10	10	10	10	10	2	10	10	656	5

Appendix A.4

Quantity	Part Description	Purchased From	Part Number	Retail Price(each)	Anticipated Bulk Price(ea)
1	10” cylindrical filter w/5μ pore diameter	Flowmatic*	FM-5-975	$8	$5
1	Polypropelyne and acrylic sytrene filter housing	Flowmatic*	FW4200WW14	$24	$10
1	2-MDQ-SC Magnetic Drive Aquarium Water Pump	Little Giant**	580506	$105	$75
TBD	Mounts, fittings, etc.	TBD	TBD	TBD	TBD
			Total =	$137	$90

*http://www.flowmatic.com
**http://www.lgpc.com