Final Engineering Report

Automatic Water-Level Detecting Bilge Pump for a Whitewater Canoe

Michael Bauer

Ian McGray

Paul Roman

Table of Contents

1.0 Introduction

3.0 Implementation

Abstract

Team Bilge Pump consists of Michael Bauer, Ian McGray, and Paul Roman, all of whom are mechanical engineering students. Our advisor is Timothy Whitmoyer. Our consultants consist of Dr. Timothy Whitmoyer, Dr. Donald Pratt, Steve Frank, and John Meyer.

The problem addressed is a dilemma found in the world of canoeing; what to do when a canoe is taking in water. Water splashes into the canoe often, whether it is from paddle-strokes, rapids, or waves. Excess water in the canoe is undesirable as it significantly reduces the performance of the canoe and gets the canoeist's gear wet.
We propose the design and prototyping of an automatic water-level detection bilge pump that can be installed into a canoe to monitor water level and sustain a minimal depth within the canoe.

Description

No matter how good the canoeist is, water cannot be prevented from splashing into the canoe. Sometimes, when going over falls, the nose of the canoe dives completely under water. Other times, in rapidly moving water, a wave can wash completely over the canoe The point is, when canoeing a rough river, water always finds its way into a canoe. This is a problem for two reasons: the canoeist's supplies get wet and, more importantly, the canoe's weight increases. The more weight, the lower the canoe sits in the water, and the more the chance of taking in water increases. The added weight decreases the canoe's maneuverability and increases the canoe's chances of colliding with objects that would be better avoided. Periodically, the canoeist is forced to bail (moving water out of the canoe via some sort of bailing device, usually a hand-held scoop) in order to maintain optimal steering capabilities. In whitewater canoeing, the canoeist is often forced to pull over to the bank of the river and completely overturn the canoe to rid it of water. There is a desire in this field to create an alternative to the physically laborious and time-consuming task of manually bailing a canoe while attempting to navigate through the body of water.

An automated bilge pump is a legitimate solution to the problem at hand. When the water reaches a specified level, the pump system will automatically activate to rid the canoe of excess water. This will save the canoeist undue stressful panic, enable he/she to maintain control of the canoe at all times, and also substantially increasing situational awareness. Since water level is strictly based on weight distribution, the pump should be located where the majority of the weight exists. Usually the weight is more concentrated near the back of two-seater because canoes perform better when the majority of the weight is distributed toward the stern. In a one-seat canoe, the seat is placed in the middle of the canoe and the weight is obviously concentrated around that seat. With this in consideration, the pump will be located under the seat (the back seat in a two-seater), where the greatest amount of weight will be present and where the device will be out of the way of the canoeist.

Also, our system would be a valuable development currently because, according to our Literature Review, this type of system has not been made for canoes. We have talked to 4 individuals who are experienced in whitewater canoeing and who have all agreed that the problem of manual bailing is something that needs to be addressed, especially in the world of whitewater canoeing. Once again, our system could potentially revolutionize the whitewater canoeing experience by allowing the canoeist to focus on the actual canoeing, without being hassled with the task of bailing.

Literature Review

We found a great deal of bilge pumps for large and medium sized boats. Nothing for canoes or kayaks (that we can find) has been commercialized. However, we did find one independent project that developed a solar powered bilge pump for a canoe.

The following are some pumps we are looked at.

Attwood-V-Series Bilge Pump:

This is a submersible 12V pump which draws only 3.3 amps. This pump will produce 3.3 Amps running on 12V. One model has a 1250 gallon per hour flowrate or 950 gallon per hour flowrate with 3' head. Designed for small boats, around 20' in length. The other model we looked at and are going to use is the Attwood 1700 Heavy Duty bilge pump. This pump outputs 1700 gallons per hour with 3' head.

Sahara S500 gallon per hour 12-Volt

This is a submersible 12V pump which draws only 1.5 amps of current while running on 12V. Has a 500 gph flowrate or a 350 gph flowrate at 3.3' head. Designed for 17' boats.

Attwood 24" Hand-Operated Bilge Pump

This product is specifically designed for a canoe to replace hand-bailing scoops. This is a hand-powered pump which outputs one gallon of water per six hand strokes.

Rapid Runner Bilge Systems

The day before we presented our project, Dr. Ray Norman sent us some information that was new to us. This information was on Rapid Runner Bilge Systems. We looked up their website and found that they produced three different types of battery-operated bilge pumps for canoes and kayaks. The systems range in cost from $200-400 depending on the type; the types differ according to what kind of battery used – lead acid, nickel metal hydride, or lithium polymer batteries. The three systems all produce a flowrate of about 16 gallons per minute. Most importantly, the systems are not automated, they must be activated and deactivated by the canoeist.

The importance of our literature review was that it established the current state-of-the-art. The only products we found designed specifically for canoeing were manual bailers such as hand scoops/hand pumps and the rapid runner battery powered systems. We were able to conclude from our literature review that an automated bilge system would indeed be state-of-the-art. Through the Literature Review we have established desirability for our system and credibility for our design proposal.

Solution

The pump that we originally chose to use was the Attwood 1250V series. We thought that this pump would meet our needs by pumping out 20 GPM while having a moderately cheap price of about 30 dollars. This pump was also lightweight and small enough to fit under the back seat of the canoe. We purchased two of these pumps so that if anything went wrong with one of them, we would have a backup. We originally purchased the two pumps with an idea of possibly using both of them in our system to generate a greater flow rate. However, after doing flowrate tests and our required amp-hour battery calculations, we decided to only use one pump. A major factor in our decision to use only one pump was cost. Using two pumps would achieve a much better flowrate, but we would probably not be able to meet our most important objective/specification which is keeping the cost of our final system under $100. With the new pumps (which cost a little over $60), using two would definitely put us over our cost objective. Another major factor in our decision to use one pump was weight. Any additional weight in a whitewater racing canoe is extremely undesirable and best avoided. Since the pump is one of the heaviest components in our system, having two pumps present would significantly increase our system's weight.

After conducting two sets of flowrate tests on both pumps, executed in a simulated environment much like that which the system would be performing in, we were faced with a major problem. Instead of the specified 20 gallons per minute flowrate designated by the manufacturer, we were getting around 14 gallons per minute. At first, we figured that the shoddy performance was due to a combination of not providing enough electrical power and the presence of a variable called head loss (degradation of the pump due to the friction through the hose and the force of gravity). The lack of electrical power was due to the fact that we were using a portable power supply provided by Steve Frank of the engineering department that could only output 2 amps of current. We knew that our optimum amperage was around 2.6 amps.

We reran our tests with a bigger power supply in the Frey engineering shop. We were able to conduct our tests at optimum voltage and amperage; 12 volts and 2.6 amps. The results were more or less the same as a first set of tests with the smaller power supply (for actual experimental results, please see Appendix B).

We contacted the manufacturer (Attwood Marine) and talked to a technician. He informed us that the specified flowrates were achieved in nearly perfect conditions and that a customer should expect around 12 gallons per minute as a "ballpark figure." He then went on to tell us that he would do us a favor and send us two of a stronger pump manufactured by Attwood. The pump we actually used is the Attwood 1700 Heavy Duty Bilge Pump. It's slightly bigger and heavier than our original pump, but it will give us a flowrate closer to our desired 20 gallons per minute. In our conditions, with the 1250 model, we were getting about 70% of the flowrate specified by the manufacturer. The 1700 Heavy Duty pumps provided an average flowrate of 23.6 gallons per minute during our flowrate tests (for actual results, please see Appendix B).

We decided to use electrical means to power our system. Both our original pumps (the Attwood 1250's) and the new pumps (the Attwood 1700 HD) run on a 12 volt battery system. We had to do quite a bit of research on batteries to find one that was suitable. The three types of batteries that we considered were nickel cadmium, nickel metal hydride, and sealed lead acid batteries. Each battery type had attractive qualities and some unattractive qualities. Nickel metal hydride batteries have the best power-density and are the lightest-weight, but are considerably more expensive than the other two choices. Nickel cadmium batteries have more power-density than sealed lead acid batteries, but are more expensive and experience voltage depression.

Voltage depression is a phenomenon in which the optimum operational voltage range of the battery is lessened due to the overcharging of the battery or discharging below its lower performance limit. Voltage depression causes permanent degradation to the battery's performance. The sealed lead acid batteries ended up being the best choice because they were the cheapest, they are resilient (they can get knocked around without being damaged), and they are waterproofed.

The battery that we originally purchased is a 12 V sealed lead acid battery. The battery has a 4 amp-hour life-rating which means that it will provide 4 amps per hour. It weighs 3.5 lbs and is small enough to suit our purposes. Unfortunately, because our original pumps did not produce a flowrate close enough to our desired flowrate output, we have purchased a new battery. The new battery is also a 12 volt sealed-lead acid battery, but it has a 7 amp-hour life-rating. It is also bigger and heavier than the original battery, weighing 6 lbs.

Using electricity to power a water pump brings about a significant design challenge. Our system needed to be fully waterproofed in order to prevent water from penetrating the electrical components and rendering them useless. The battery as well as the control circuit needed to be completely protected from water infiltration. We purchased an Otterbox 3500 waterproof container to perform this task. The battery and the circuit fit snugly inside. We drilled small holes in the front of the Otterbox to allow the power and cutoff wires to reach the cutoff device and the pump. We used a sealant called "water weld" to waterproof these wire-casing interfaces.

The automation of our system is composed of a series of electrical components and an adjustable float sensor which is installed on the side of the packaged system. The circuit is designed so that the battery cannot be discharged too far (as this can degrade the battery). For a detailed description of the functionality of the separate components of this system, please refer to the Design portion of this report. For a detailed layout of this circuit, refer to the Appendix C.

The float sensor is a major design component of our system. A small cylinder, vertically aligned, with a float contained within, is attached to the side of the battery housing platform. As the water level in the canoe increases, water enters the cylinder and raises the float. The float then trips a switch that completes the circuit and activates the pumping system. For a detailed description of the float sensor designs, please refer to the Design portion of this report.

Design

The first step in our design process was to develop a list of objectives we wanted our system to fulfill. The following is a list of our original design objectives:

a) We would like to keep the actual cost of the device under $100.

b) We want to spend no more than $250 of the $500 allotted to our team by Messiah College.

c) We would like to develop a system that generates a flowrate of at least 20 gallons per minute at peak performance.

d) We want our system to in no way interfere with the interaction between the canoe and the water. With this in mind, we would like our system to fit securely underneath the seat of the canoe and out of the way of the canoeist. We want no significant degradation in canoe performance as a result of the presence of our system.

e) We would like our entire system to weigh no more than 10 pounds.

f) We want our system to be able to run for a full hour before needing a battery change.

The foundation of our project is the pump. One of the first steps in our design process was selecting a pump to suit or flowrate objective of at least 20 gallons per minute. Our original pump was an Attwood 1250V pump of approximately 2 lbs. It is 3 inches in diameter and about 3 inches in height. The new pump is an Atwood 1700 Heavy Duty Bilge pump that weighs approximately 2.5 lbs. A tube with an inner diameter of 1 5/8" inches is secured around the outlet of the pump. This tubing needs to be about 5 feet long to fit through the rear of the canoe. The placement of the pump will be directly under the seat (or under the back seat in a two-seater) to prevent any clutter or inconvenience.

Once we had our pump selected, the next step in the design process was to choose a suitable power source. Our Atwood 1700 HD pump operated on a 12 volt battery system. We did a substantial amount of research on battery types trying to find the best type of battery to suit our needs. The types of battery that we considered included sealed-lead acid, nickel-cadmium, and nickel-metal hydride. As described in the Solution portion of this manuscript, we determined that sealed-lead acid batteries would best suit our objectives based on cost and efficiency.

Once we had our type of battery selected, we had to shop for an actual battery. We attempted to find a battery that would give us at least 60 minutes of life, was lightweight and small, and as cheap as possible. We settled on the Power Sonic 1270, a 12 volt, sealed-lead acid battery with a 7 amp-hour life. The battery has a height of 3.68 inches, a length of 5.94 inches, a width of 2.56 inches, and a weight of 6 lbs.

The decision to use a sealed-lead acid battery brought about one of our major design challenges: what to do to prevent voltage depression of the battery. As described in the Solution portion of this manuscript, sealed-lead acid batteries have a weakness known as voltage depression, a phenomenon which degrades the performance of the battery if the voltage is not kept within the optimum operating voltage range. To prevent the battery's voltage from dropping too far, we had to design a voltage control circuit. The circuit's function was to shut the system off once the battery voltage reached a designated value. We found this value to be 10.5 volts through research and some simple calculations.

We sat down with Dr. Pratt and collaborated on a circuit design that would cut the system off if the battery voltage got too low. The circuit incorporated a relay that would be activated by a pushbutton. A transistor held the relay on until the voltage to the transistor got too low, leading to the relay being shut off. We had some problems with placement of the pump and float switch with this design, and it never really took off. For a visual representation of this circuit design, please refer to the Appendix C.

We then consulted Steve Frank regarding the circuit. We reviewed the circuit design with Steve Frank who mentioned that it could work, but the ability to repeat the manufacturing of the circuit would be difficult because of tolerance ranges on all of the parts. He suggested replacing the system with an op amp design that would be much more reliable. After some calculations we developed a working prototype and this design was implemented into our system. For a visual representation of the modified circuit design, please refer to the Appendix C.

The main feature of our system is automation. Being mechanical engineers, we were naturally inclined to design a mechanically actuated automation device for our system. All of our design ideas utilized a flotation device to activate a switch. Our main ideas included a flotation device which would trigger a contact switch (we brainstormed using a pushbutton or a rolling switch) or a flotation device with a magnet contained within it which would trigger a reed switch.

The pushbutton design utilized a flotation device contained within a PVC cylinder. Mounted at the top of the cylinder was a pushbutton facing the flotation device. When the float reached the top of the cylinder, it would depress the pushbutton and activate the system. After some consideration, we discarded this design based on the fact that as soon as the system was activated (assuming no additional water was being taken on), the water-level would begin to descend, releasing the button and turning off the system. A very short pumping time would be attained using this design and little water would be pumped out.

Learning what we did after pursuing the pushbutton design, we next decided to try to implement the roller design. This design used a similar PVC cylinder with a flotation device contained within. The roller switch was oriented on the side of the PVC, with the arm penetrating through the side wall of the PVC at an angle. As the water level increased within the device, the roller would come in contact with the float and depress the arm, activating the switch. The roller switch was a good idea because it allowed the float to keep moving up the PVC cylinder, keeping the system on. The roller switch functioned as a proximity switch rather than a contact switch. This means that there was a range of water depth that the system would allow the system to be activated and running as opposed to one designated height that would activate the system (as was the case with the pushbutton device).

When we presented this idea to our advisor, Dr. Timothy Whitmoyer, he voiced some concern regarding the waterproofing of the switch-PVC interface. After some brainstorming, we decided that waterproofing the device may prove to be extremely complicated. Since we had one more float switch design (the reed switch), we decided to discard the roller switch idea and pursue the reed switch design.

The reed switch design gave us all the benefits that the roller switch design gave us. It is a proximity switch, a feature we deemed necessary after our initial pursuit of the pushbutton design, utilizing the magnetic Hall effect (as described in the solutions portion of this manuscript). It is also a waterproofed device as the switch is contained within a glass vacuum tube. This was the feature that influenced us to pursue this design rather than the roller device. It was a simpler device to construct than the roller switch design and we foresaw fewer waterproofing complications with this design.

Two other design considerations we faced in the design of our float switch was how to ensure that the system pumped out as much water as possible and also how to prevent our system from activating and deactivating sporadically as water sloshed in and out of the canoe. We decided to mechanically dampen our float switch so that the water level inside the device was not the same as the water level in the canoe. Mechanical dampening was a means by which we could confront both of the design considerations listed above. By capping the ends of the PVC and drilling small holes in either end, we allowed water to enter and exit the PVC slowly. This ensured that the system would not kick on due to water sloshing around. It also allowed the system to remain activated while the water level descended in the canoe. The flotation device, because of the small hole in the bottom end cap, would descend much slower than the water level in the canoe, allowing our system to churn out as much water as possible before shutting off.

The next design consideration we had to take into account was how our system would respond to a capsize. In the event of a capsize, all of the water would leave the canoe and, if the system was activated, our system would continue running. This would waste our system's battery life and, most importantly, run a dry pump, which can easily ruin the pump. We determined a need to incorporate an emergency capsize feature into our system.

Our original capsize cutoff design was a switch consisting of a cylinder with wiring running into either end. The wiring at the bottom of the cylinder was to be fixed into a conductive metal disk and secured at the bottom of the cylinder. The top wire was connected to a heavy conductive metal weight. When the canoe is oriented properly (not capsized), gravity would force the weight down so that it makes contact with the metal disk at the bottom of the cylinder. In the event of a capsize, the weight will be heavy enough that it will overcome the opposing force of the somewhat rigid wire and separate from the metal disk, disconnecting the circuit and shutting off the system.

However, before we began the pursuing the construction of this device, we stumbled across a switch that we found to be ideal to be used for our capsize feature. This switch used liquid mercury housed within a glass cylindrical chamber. On either end of the cylinder, metallic contact filaments fed into the cylinder. Depending on the orientation of the switch, the liquid mercury flows to the lowest end of the cylinder, making contact with one of the metallic contact filaments. Housing this switch inside a protective casing proved to be an ideal design because it did not require a canoe to fully capsize before it shut the system off. As soon as the cylinder is tilted past 90 degrees, the mercury flows to the other end of the cylinder, breaking electrical contact with our system. This quick cutoff is desirable because there is virtually no risk of running the pump dry in the event of a capsize and no battery life is wasted. Also, as long as the device is protected, it is practically 100% reliable.

The last design challenge was the packaging of our system. The pump needs to be in the open water can be drawn into the intake, but it needs to be connected to the battery and circuit so that it can receive electrical power and be switched on. The packaging also needs to be as small as possible so that it does not interfere with the canoeist's movements. Also, the system needs to be as lightweight as possible so that it does not significantly degrade the canoe's performance.

Our initial design involved a horseshoe shaped platform being placed over the pump so that the pump can draw in water and eject it out the stern of the canoe. The platform's sides were to be flush against the pump's sides to save space. The horizontal portion of the platform would run directly over the pump's top face. The pump's wires would run through two small holes in the bottom of the platform directly to the battery. The battery and circuit would sit on top of the platform (directly above the pump) in a waterproof, lightweight, plastic casing. This vertically stacked design was the most space-efficient design that we could think of. A detailed sketch of the system layout can be seen in the Appendix A.

To hold the system in place, we planned on using a vertical clamping device. This device will function similarly to a shower-curtain rod. It was to be placed on top of the housing and run in between the housing and the bottom of the canoe seat. The pole consists of two threaded pieces put together so that the canoeist can simply twist or untwist the clamp to easily install or uninstall the system.

Due to time constraints, we did not achieve our platform design. To improvise, we decided to use an industrial Velcro which was attached via a strong, waterproof adhesive to the bottom of the canoe and to the bottom of the pump. The waterproof housing was then to be placed on top of the pump and held to it by a vertically oriented ratchet strap. Then, the system is held in place underneath the seat by the extendable rod.

Construction

We began construction with our automation device, the float switch. We purchased 10 feet of 1" diameter PVC as well as two PVC end caps. We also attained three wine corks which we checked for buoyancy and absorptivity in water. We selected the most buoyant cork as our flotation device. We cut a 4" length of PVC and capped the ends. We then drilled holes in the end caps (using the smallest possible bit-size) to produce mechanical dampening within the float switch. We submerged the device in water and recorded the amount of time it took the flotation device to reach the top PVC cap and the time it took for the flotation device to reach the bottom PVC cap. We then drilled the holes a little bit bigger and repeated the submersion test. We varied the hole size in the end caps until we reached a desirable dampening effect.

Once we had selected the proper dampening hole size, we installed the reed switch on the top of the PVC. We dremmeled out a section of the top cap so that the reed switch could be housed snugly inside. We fit the reed switch into the indentation we had formed using the dremmel. We then water-welded around the reed switch to protect it from water and also to hold it in place on top of the device. Removing the bottom cap, we removed our flotation device and cut out a section from the top of it, embedding a vertically-oriented magnet within. The magnet was vertically oriented because we found the magnetic field to be stronger in that direction, allowing us to activate the reed switch sooner and giving our system a larger activation proximity. We then put the flotation device back into the PVC cylinder and replaced the bottom cap.

The construction of our voltage control circuit was an involved process. First, the designed circuit had to be bread-boarded and tested for functionality. Once this was done, the proven circuit design had to be input into a computer program called Ultiboard 9. This program was used to orient the circuit components as well as the traces into a space-efficient layout. Once the components and traces were laid out and sized, the saved file had to be exported to another computer program called Boardmaster.

Boardmaster is a computer-aided milling program which controls a robotic milling machine. After importing our file into the system, we then went through the process of giving the computer our desired geometrical constraints and insulation preferences while it controlled the milling machine. The computer-aided milling machine cut out our circuit board, the traces, and drilled the mounting holes so that we could install our circuit components onto the board. Once the board was done routing, drilling, and milling, the soldering process began. We hand-soldered all of our circuit components into their respective places on the circuit board. We then had our complete voltage control circuit. Using a power source and a voltmeter, we tested the functionality of the completed circuit board to make sure it turned on and cut off at the right voltages.

The construction of the emergency cutoff switch was simple. The mercury switch required no construction, however, it needed to be protected so that it was not broken when subjected to the rough conditions it will be facing in the canoe. To ensure that the switch does not break, we encased the mercury switch inside a small piece of PVC and fixed it in place using water-weld. We then cinch-strapped this component onto our float switch oriented vertically.

Putting together all the components of our system was relatively simple. The battery had to be hooked to the voltage control circuit. The voltage control circuit was wired to both the float switch and to the pump. The capsize switch was then installed in series with the pump and the float switch. The battery and the voltage control circuit were housed inside a waterproofing container, our Otterbox 3500. For a block diagram of the system, please refer to the Appendix A.

A second construction of our float switch was required after we performed initial tests of the system. The original reed switch we purchased was approved at a maximum of 2.2 amps of current. We were pulling about 2.6 amps through the reed switch. This resulted in the overheating of the switch which actually caused the two metal filaments to fuse together, resulting in the continuous running of our system and a ruined reed switch. We then had to purchase a higher current capacity reed switch to accommodate for our 2.6 amps of maximum current. The new reed switch was larger than the original, forcing us to produce a “top-down” redesign of the float switch.

The heavy duty reed switch required a more powerful magnet than the original. A magnet of 100 gauss capacity was neededto activate the reed switch. The magnet that we attained was significantly larger and heavier than the original magnet. Because of this, we had to procure a new flotation device that was more buoyant. We purchased some craft Styrofoam and cut it into a cylindrical piece big enough to produce the desired buoyancy required to lift the new magnet. Unfortunately, the Styrofoam was extremely porous and absorbed water quickly. To prevent this absorption from occurring, we coated the flotation device in latex. This bigger flotation device forced us to use a longer-length of PVC for the float switch. Also, the large reed switch would not fit across the top cap of the PVC. We aligned the reed switch vertically on the side of the PVC and fixed it into position just as we did with the original, using a dremmel and water-weld. We then fixed the magnet to the top of the flotation device horizontally so that it was perpendicular to the reed switch (the magnetic force was stronger in this direction). We also added a length of smaller diameter PVC on top of the magnet as a spacer. This ensured that the magnet stayed within the activation vicinity of the reed switch. See the Appendix D for detailed drawings of both float switch constructions.

Operation

Once our system was fully configured, a number of tests needed to be conducted to see if we met our objectives for flowrate, battery-life, activation/deactivation time/height, size, and weight. The first tests we conducted were flowrate and battery-life tests. These two tests could be performed at the same time. First, we submerged our system in water. Once the system activated, we then pumped water into a container with a known volume. We timed how long it took our system to fill the container, and then recorded the data. The first time we performed this test; we ran the system continuously and filled the container as often as we could, filling it, dumping it, and then refilling it as quickly as possible.

Our first test produced a dilemma. After about five minutes of testing, we realized that the temperature of our float switch was increasing dramatically The top of the device, the water welded portion containing the reed switch, became exceedingly hot. We stopped the test and disassembled the float switch to investigate the problem. What had happened was that the metallic filaments on the inside of the vacuum tube had actually fused together. The system had overheated. We quickly realized that we were drawing more current than the reed switch was approved for.

Two days later, we had found and attained a larger, heavier duty reed switch approved for 2.6 amps of current, the maximum current draw our system would be facing. We redesigned the float switch as was described in the construction portion of this manuscript. We then reran our flowrate and battery life tests in the same fashion as before. Our first test resulted in 43 minutes of continuous battery life and an average flowrate of 23.6 gallons per minute. We had met our flowrate objective, but not our battery life objective.

We believe that the 43 minutes of battery life is a very conservative value. Our system was not designed to be run continuously. Because of the high flowrate generated, we do not believe that our system will be activated for more than 5 minutes at any given time, even if it has to empty an entire whitewater canoe of water. Once the water is out of the canoe, the float switch will descend and deactivate the system. Our battery's voltage will recover a bit before the next activation. Once real-life testing is conducted, we believe that our battery-life will be much closer to our objective of 60 minute run-time.

Once our battery's voltage was depleted, we experienced a strange phenomenon. After 43 minutes of testing, the system shut off. Almost immediately, the system turned on again but with a much degraded flowrate. We recharged our battery and performed the test again. Once again, once the battery was drained, our voltage control circuit deactivated the system only to have it immediately kick back on with a significantly slower flowrate. We were baffled as to why this was.

We disassembled the system and did some tests on the control circuit using an external power source and a voltmeter. By reducing the voltage slowly from the power source, we were able to see that as the voltage approached 10.5 volts (our cutoff voltage), the system did in fact shut off. However, there was a point just above 10.5 volts where the circuit would make a loud whirring noise, as if the relay was shutting the system on and off extremely rapidly. We confronted Steve Frank about our problem. He explained that our circuit did not have hysteresis built into it. Hysteresis is a lag between a trigger and a response. In our case, the system, once the battery voltage was reduced to 10.5 volts, immediately deactivated the system, shutting off the current flow from the battery to the pump. As soon as the battery stops being used, the voltage in the battery recovers. We witnessed this phenomenon using a voltmeter and shutting our system off. We saw almost an immediate 1 volt increase in the battery followed by a slower further voltage increase.

The circuit was not designed to account for this voltage recovery. The end result is that, once the circuit deactivates the system, the battery voltage recovers immediately, the circuit recognizes this, kicks the system back on, the battery voltage descends to 10.5 volts again almost immediately, and the circuit deactivates the system. This cycle results in the rapid turning on and turning off of the system, explaining the loud whirring of the relay and also the slow flowrate produced.

Another test that we conducted was the activation time or the time it takes the flotation device to reach the activation proximity of the reed switch. We performed this test by nearly instantly fully submerging our system in water and monitoring the time it took for the system to turn on. After a number of these tests, we found an approximate activation time of 14 seconds. During this test we also were able to calculate the depth of water that would be left in the canoe once our system turned off. We drained the water out of the container until the system shut off. The depth of the leftover water was just over 2 inches. This is about as good a result as we can get because 2 inches is the minimum amount of water our pump can operate in without running dry; an occurrence that will at least degrade the performance of the pump and potentially destroy the impellor.

Schedule

Organization of tasks and objectives were crucial for this project due to the complexity and length of the endeavor. This made important to have a detailed schedule of things we needed to complete throughout the course of the school year. Our Gantt chart was a great tool for creating deadlines and time durations for all the parts of our project. This helped pace our project in a detailed and professional way. (See Appendix E for Gantt Chart)

Budget

One of our main objectives was to make this project affordable for a consumer. Budget was an integral part of this project. We were allotted 500 dollars for spending, and it was imperative that we kept track of all spending for project materials. The overall cost of all the materials we purchased for our product came to approximately 220 dollars. The spending for the amount of materials that we actually used for our project came to approximately 68 dollars. A detailed spreadsheet is attached in the Appendix E with a listing of all spending for the project over the course of the school year.

Conclusions

The following is a list of our original design objectives:

a) We would like to keep the actual cost of the device under $100.

b) We want to spend no more than $250 of the $500 allotted to our team by Messiah College.

c) We would like to develop a system that generates a flowrate of at least 20 gallons per minute at peak performance.

d) We want our system to in no way interfere with the interaction between the canoe and the water. With this in mind, we would like our system to fit securely underneath the seat of the canoe and out of the way of the canoeist. We want no significant degradation in canoe performance as a result of the presence of our system.

e) We would like our entire system to weigh no more than 10 pounds.

f) We want our system to be able to run for a full hour before needing a battery change.

The cost of our final system was $136.22. Our original objective was to keep the final cost of the system under $100. We had determined that, in comparison with the cost of a whitewater canoe, which is normally in the $1500-2000 range, any serious whitewater canoeist would front the money for our system. Also, this projected cost was based on the original pump and battery. Had we used the original pump and battery, we would have been much nearer to meeting our cost objective. Although we did not keep the system under $100, we still firmly believe that the cost of oursystem is extremely reasonable when compared to the price of a good whitewater canoe. We are convinced that any serious canoeist would consider our cost a small price to pay for the service performed by our system. We actually spent $221, meeting our objective of spending less than half our $500 allotted budge, saving Messiah College some money.

The most important objective that we set at the beginning of the year was our desired flowrate. Based on some volumetric calculations for canoe dimensions and some research on whitewater canoe water intake, we determined a flowrate of 20 gallons per minute to be adequate. We figured that, in an intense rapid, if the canoe took on 10 inches of water (with water bags installed), this translated to about 60 gallons of water. We figured 3 minutes of pumping would be a short enough amount of time to get the canoeist safely and efficiently to the next rapid. Our system exceeded our expectations producing an average flowrate of 23.6 gallons per minute.

Another objective we made was regarding size. We wanted our system to fit underneath virtually any whitewater canoeing seat, remaining out of the way of the canoeist. The dimensions of our final system are 10.75 inches in length, 8.25 inches in height, and 4.75 inches in width. We have been unable to find any whitewater canoe on the market that our system would not fit into.

We wanted our system to weigh no more than 10 lbs. When whitewater racing, weight is one of the main concerns and we needed our system to be lightweight. Our final system ended up being exactly 12 lbs. The extra 2 lbs is virtually negligible when compared with the weight of the canoe and the canoeist. However, we would have met our objectives had we been able to use our original pump and battery.

Finally, we estimated that a full hour of battery life would be more than enough to cover the bailing necessary on any given day. According to our research, the average day on a whitewater river requires about 6 bailing sessions. We estimated that an hour of battery life would be more than enough to take care of the water-to-be-bailed on a given day. We ended up with a battery life of 43 minutes when the system was continuously run. However, we have good reason to believe that this is a very conservative number due to the fact that our lab testing in no way reflects a real-life test. On the river, our system shouldn't be activated for more than 5 minutes at a time. Taking into account voltage recovery in the battery, we believe that we will be very close to meeting our battery life objective of 60 minutes once real-life testing is conducted.

References for Future Work

There are some loose ends that we would like to see tied up on this project. First, a good packaging device needs to be developed for the system. This packaging device needs to be lightweight, easy to install into the canoe, and needs to be extremely resilient. It needs to stay underneath the seat and hold all of the components firmly together.

Second, the voltage control circuit needs to be redesigned including hysteresis. The hysteresis designed into the circuit will allow the circuit to shut the system off once the battery is drained to the deactivation voltage without allowing the system to reactivate once the battery voltage recovers. This is a major issue that needs to be ironed out. Future work of the system would involve either a complete shutoff circuit or a circuit that would turn back on later as the voltage recovered. We could also incorporate an LED that would notify the user that the battery was low. A prototype of a completely electronic float switch has been designed in theory, but has not been tested yet. This would involve another voltage comparison and have two probes that when contacted with water would have the same effect as a resistor.

Third, some real-life testing needs to be conducted. Fortunately, this is going to happen. Dr. Ray Norman, Dean of the Math, Engineering, and Business School, just so happens to be an avid whitewater canoeist. He and his daughter are competing in the U.S. National Open Boat Whitewater Championships in July. They would like to use our system in their canoe.

Fourth, there are some electrical wire splices outside of the waterproofing container that we had to waterproof using a silicon caulk. We would like to either house these splices within the waterproof container or implement some waterproof connectors to eliminate these unnecessary electrical interfaces. The less waterproofing required by our system, the less likely a waterproofed interface is to fail. Also, with the use of waterproof wire connection terminals we could have a versatile system that could swap out batteries and pumps to accommodate for weight vs. performance considerations. The circuit would not have to be changed at all, and the packaging would only have to be modified slightly.

Last, we would like to create a simple recharging package for our system. This would eliminate the need to charge the system using a bulky external power source and would increase marketability of the product. This recharging unit would have to be kept simple so that the cost of the overall product was not increased substantially.

Acknowledgments

Steve Frank

John Meyer

Dr. Timothy Whitmoyer

Dr. Donald Pratt

Dr. Bob Barrett

Dr. Ray Norman

Yaskawa Electric America

Sean Koenig

Technical Support of the Attwood Co.

References

http://www.attwoodmarine.com/

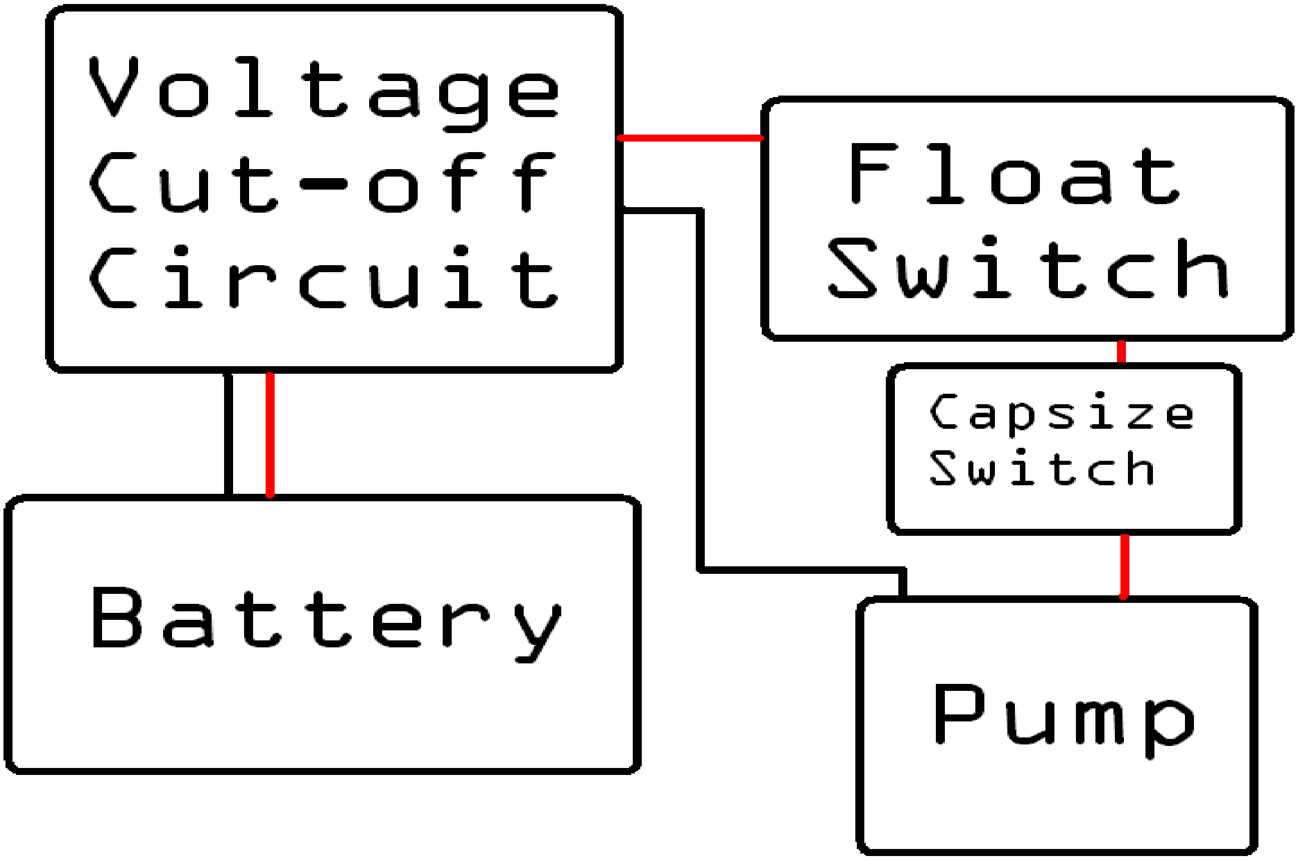
www.otterbox.com

www.power-sonic.com

http://rapidrunnerbilge.com/products.php

Appendix A – System Layout

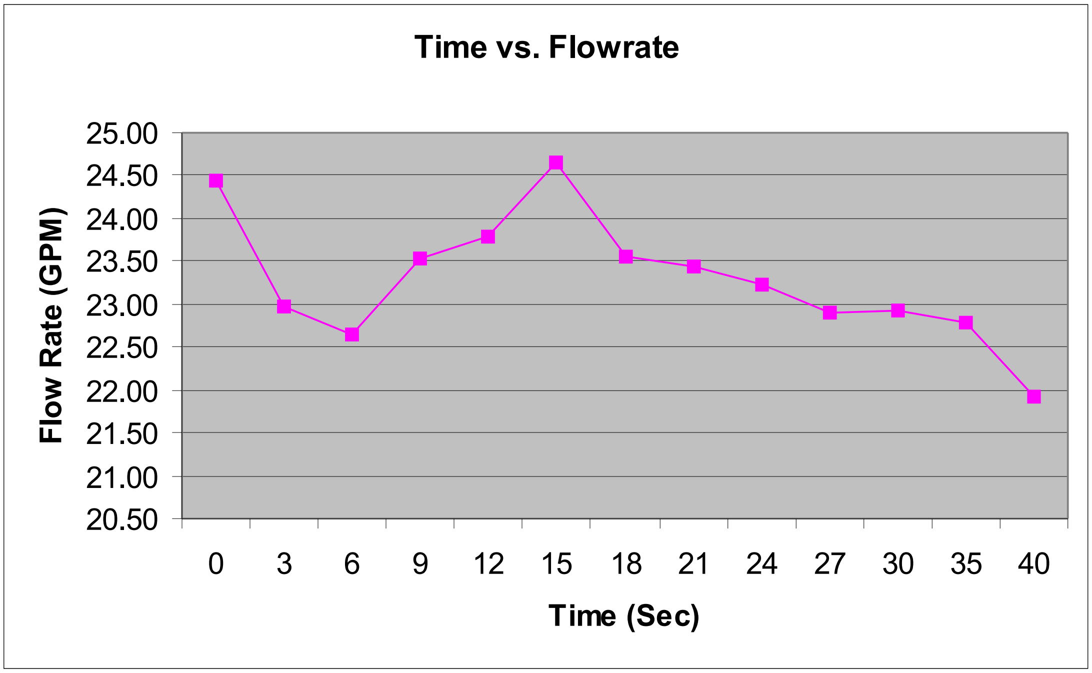
Block Diagram of System



Appendix B – Data

1st Flowrate Test:

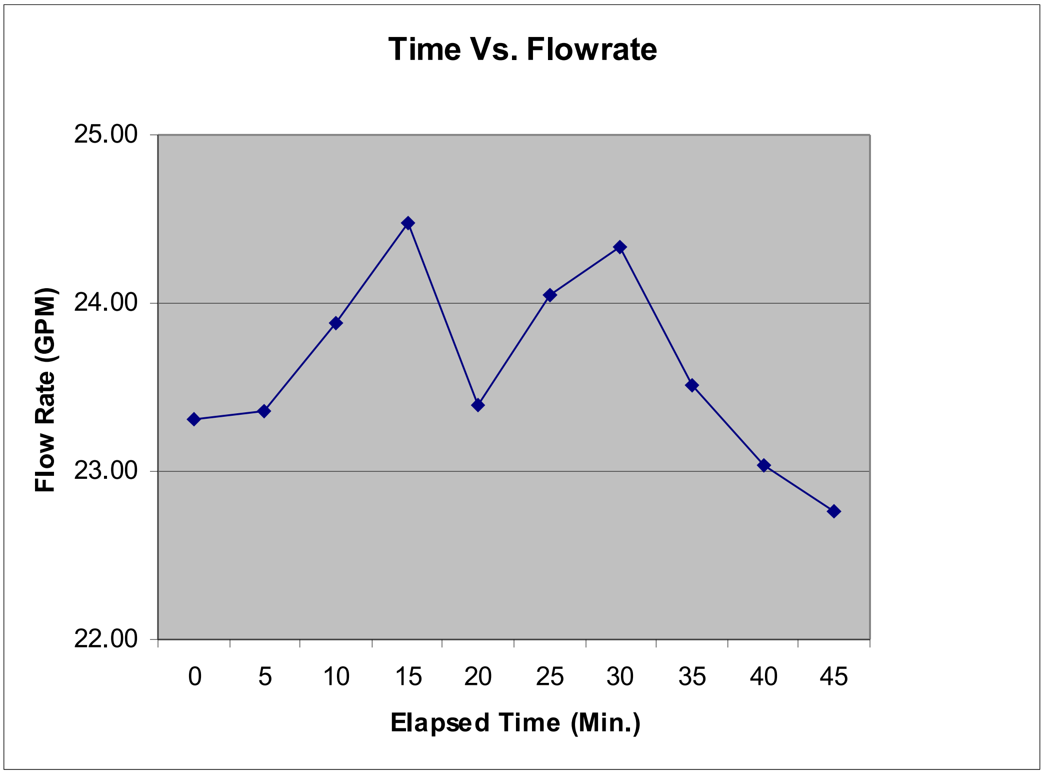
Starting Voltage (V)	Volume (Gal)	
13.25	13.06	
Ending Voltage (V)		
12.3		
Time Increments (Min.)	Pumping Time (Sec.)	Flow Rate (GPM)
0	0.53	24.44
3	0.57	22.98
6	0.58	22.65
9	0.55	23.54
12	0.55	23.78
15	0.53	24.65
18	0.55	23.56
21	0.56	23.43
24	0.56	23.23
27	0.57	22.90
30	0.57	22.91
35	0.57	22.78
40	0.60	21.91
	Avg. Flowrate:	23.29



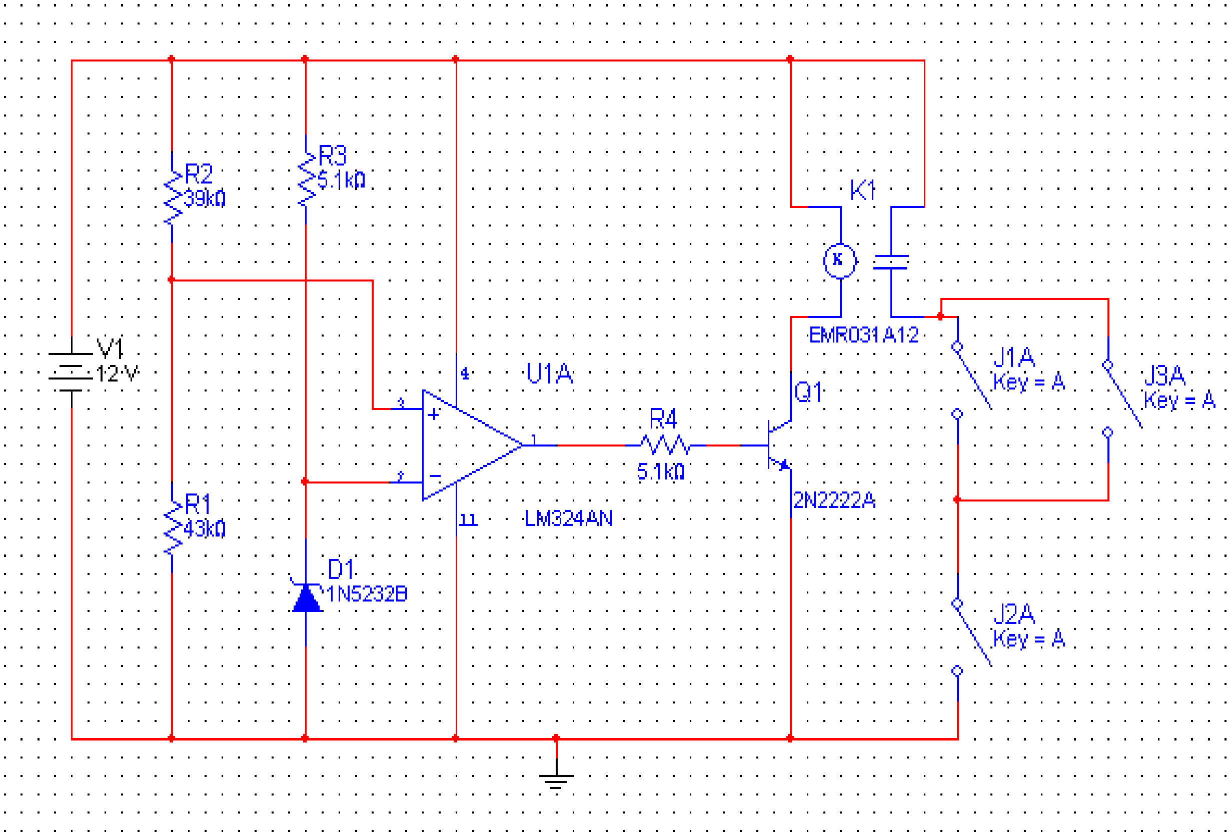
Second Flow Rate Test

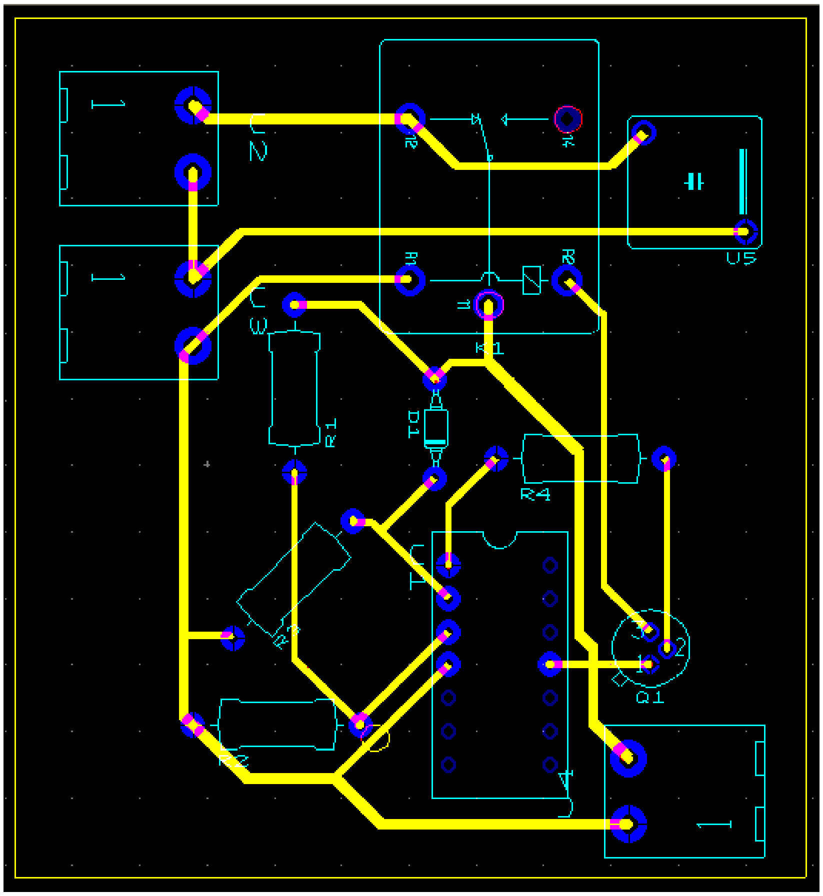
Starting Voltage: (V)
13.4
Stopping Voltage: (V)
12
Volume: (Gal)
13.06

Time Increments (Min.)	Pumping Time (Min.)	Flow Rate (GPM)
0	0.56	23.31
5	0.56	23.36
10	0.55	23.88
15	0.53	24.47
20	0.56	23.40
25	0.54	24.05
30	0.54	24.34
35	0.56	23.51
40	0.57	23.03
45	0.57	22.76
50.28		
Average:	0.55	23.61



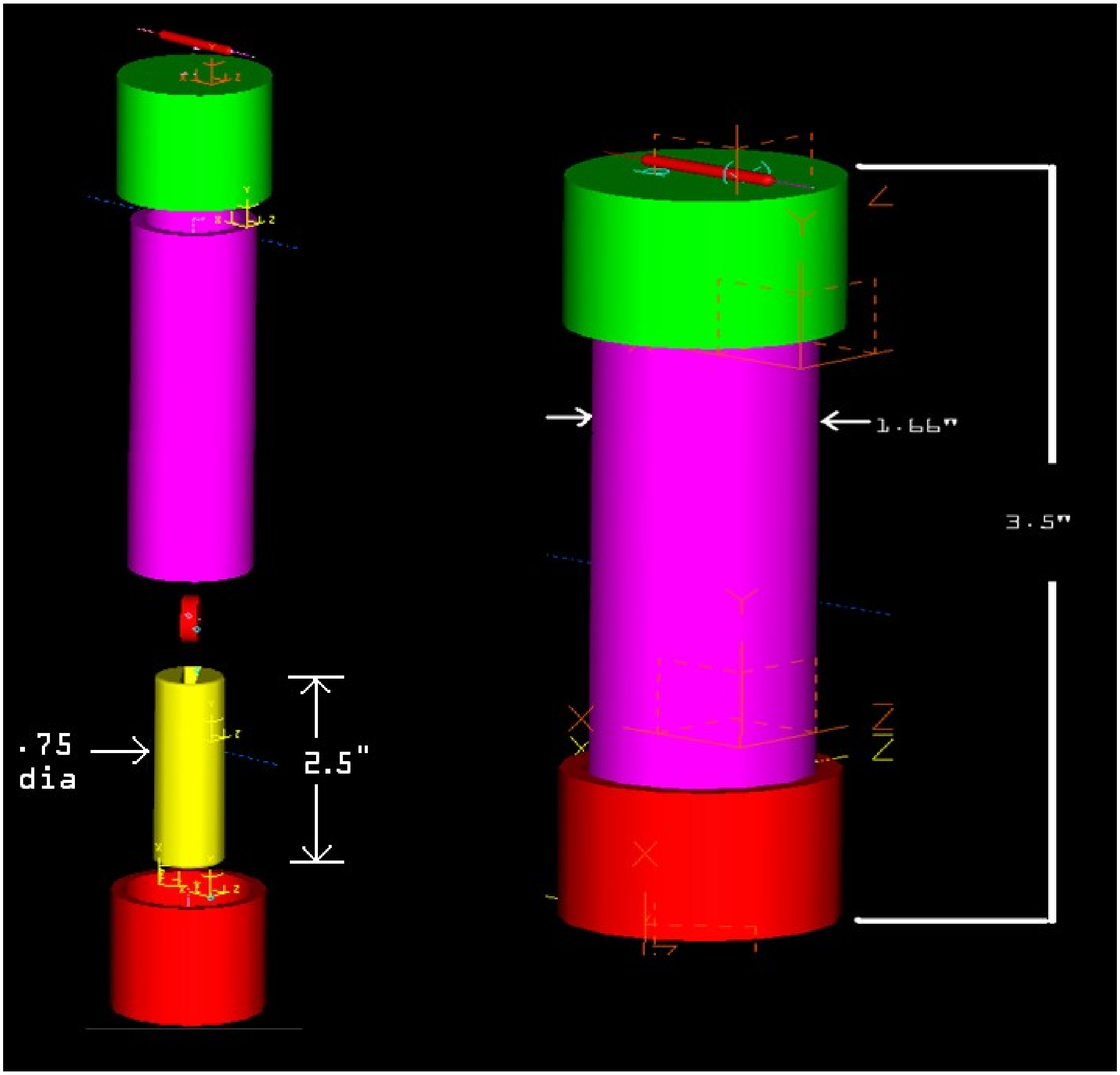
Appendix C - Circuit Design



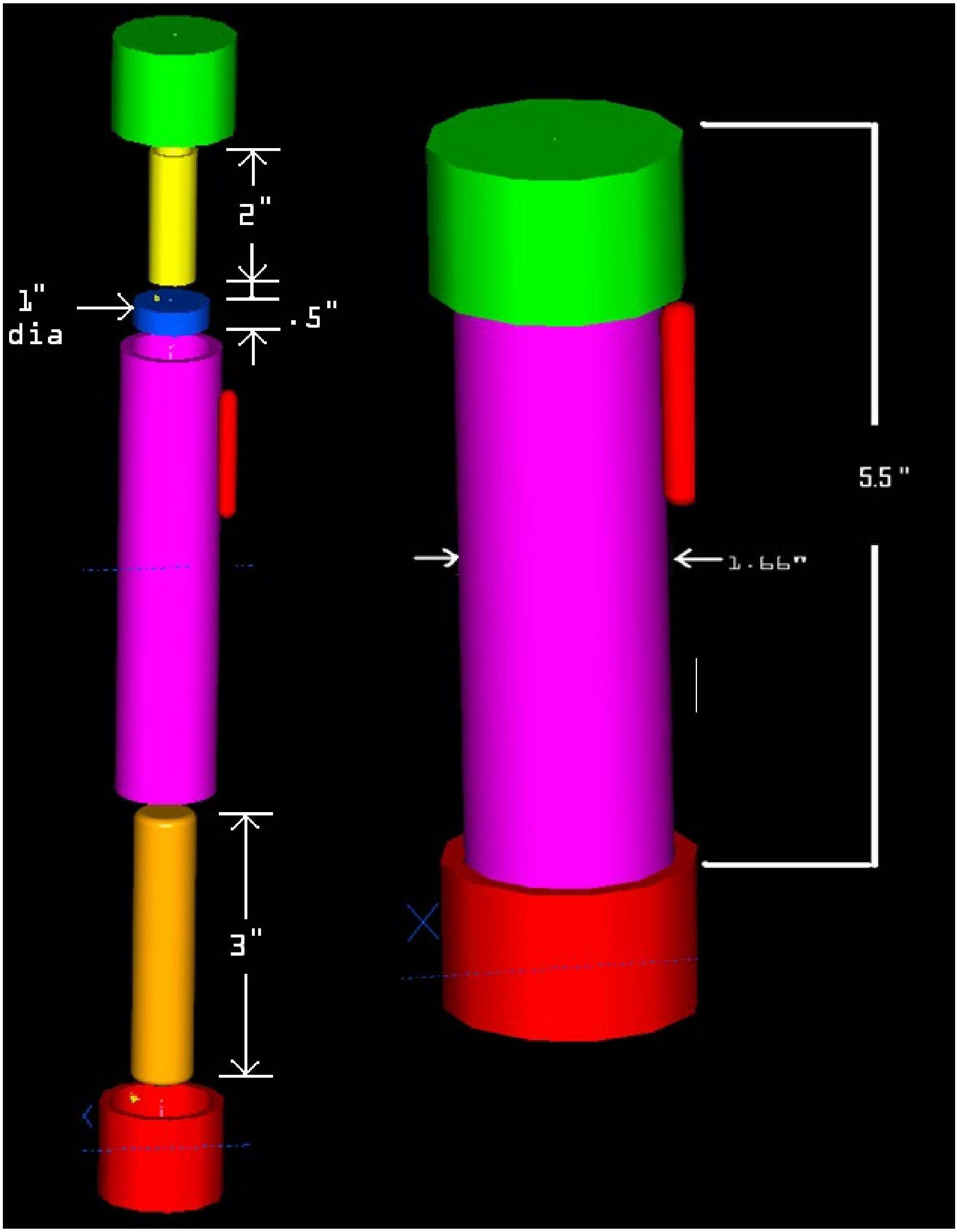


Appendix D - Automation

Float Switch Prototype 1



Float Switch Prototype 2



Appendix E - Cost Analysis (Budget) and Schedule

Total Items	**Cost paid**	**Actual Cost**	**Names of GIK**
Attwood V1250 (2)	$83.25	$83.25	
Attwood 1700HD (2)	**GIK**	$125.98	**Attwood**
Sealed Lead Acid Battery 5AH	$14.98	$14.98	
Sealed Lead Acid Battery 7AH	$18.08	$18.08	
Otterbox 3500	$22.95	$22.95	
Miscellaneous Items	$24.26	$24.26	
PVC Parts	$13.05	$13.05	
Magnets	$2.39	$2.39	
Float	$1.02	$1.02	
Rubber Pads	$9.94	$9.94	
Tubing	$26.86	$26.86	
Milling	$4.43	$4.43	
Electrical Components	**GIK**	$8.00	**Messiah College/Yaskawa**
Total Cost	**$221.21**	**$355.19**	
Items Used	**Cost Paid**	**Actual Cost**	
Attwood 1700HD	**GIK**	$62.99	
Sealed Lead Acid Battery 7AH	$18.08	$18.08	
Otterbox 3500	$22.95	$22.95	
Rack Tie Down	$8.47	$8.47	
PVC Parts	$2.50	$2.50	
Magnets	$0.96	$0.96	
Milling	$4.43	$4.43	
Electrical Components	**GIK**	$5.00	
Tubing	$10.72	$10.72	
Float	$0.13	$0.13	
Total Cost	**$68.23**	**$136.22**	