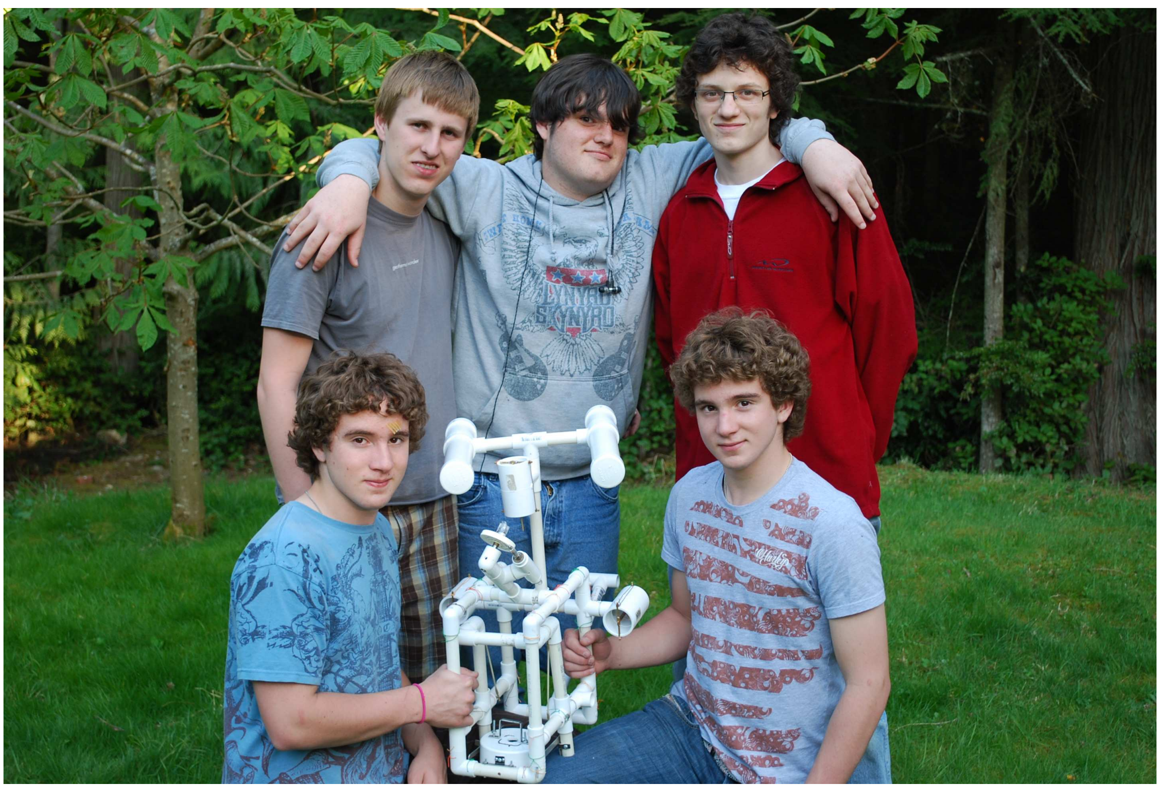
Technical Report

Ranger Class

APIA Submersible Team

South Whidbey High School



Team Members:

(Top row) Kip Hacking 17, Kimmer Webb 16, Geoffrey Wilson 17
(Bottom row) Evan Mattens 16, and Aren Mattens 16

Team Leader:

Eric Wilson
(not shown)

Table of Contents

Abstract......1

Amazing New Submarine Rescue Vehicle......1

Electrical Schematic and CAD Drawings......3

Expense Report......6

Design Rational......6

- Propulsion System......7
- Motors......7
- Frame......8
- Cameras......8
- Tether......8
- Pod Hooks......9
- Mating Skirt......9
- Airline Holster and Lever Turner......9
- Control Panel......10

Challenges Overcome......10

Troubleshooting Techniques......11

Skills Gained......12

Future Improvements......12

Reflections......13

Acknowledgments......15

Abstract

APIA Submersible Team is a group of high school students from Whidbey Island, WA. We thoroughly enjoyed our experience this year learning about real life submarine rescue vehicles, designing, and building an ROV. Our design focus of "simple, light, and inexpensive as possible" guided most of our decisions and kept us brainstorming until we had solutions we were excited about. Our craft is unique in that our motors are on shore, our propellers are homemade, our frame is PVC pipe, our cameras were waterproofed by us, our tether contains drive lines for the propellers, our pod hooks retract when pressure is applied, our mating skirt is a PVC pipe cap and camera combination, our airline holster is a cutout from a drain pipe, and our lever turner operates via a worm gear removed from a windshield wiper unit. Our control panel uses joy sticks to control the craft, a huge improvement over the cumbersome switches we used last year. Our design challenges were overcome largely with the help of our replica of the challenge submarine. This replica allowed us to "walk" through the challenges and easily test our design. We are grateful for the many skills this challenge helped us build. These organization, communication, and shop equipment skills will be useful throughout our lives and make this experience very memorable and invaluable.

Amazing New Submarine Rescue Vehicle

Ever since the world wars, submarines have become increasingly prevalent. The risks of being on these fascinating contraptions have been known, and for the most part, accepted by the sailors who lived on them. Though it may have been scary, sailors probably took comfort in the fact that submarines were only sunk during wartime. That illusion was sunk, literally, when the USS Thresher sank on April 9, 1963. Because of the sinking, people called for submersibles that could rescue the passengers on downed submarines.

The DSRV-1 was the first submarine rescue vehicle, and it has been in operation for about 40 years. Like the space shuttles, the DSRV-1, and its successors are based on "old technology". Now, a newer, more versatile submarine rescue vehicle is desired. Enter the SRV1.

The SRV1 was developed cooperatively by Britain, Norway, and France. Because it successfully completed most of its task during the test phase, the developers were elated. It weighs 24.5 metric tons and is 9.45 meters long. It costs $95 million to build and $150 million to maintain over a 30 year period.

The SRV1 renders other submarine rescue vehicles obsolete for five main reasons. First, it can be deployed anywhere in the world in 72 hours via airlift. It's mating skirt connects with almost any submarine at up to a 60 degree angle. Amazingly, 15 people can be rescued at a time. Power is supplied by sodium nickel batteries. Finally, it is able to operate at depths of 914.4 meters. This is the maximum depth most submarines can reach.

As the SRV1 is still in the final stages of completion, the DSRV-1, Scorpio, and other rescue vehicles will remain in service.

Mystic (DSRV-1) [Internet]. Unofficial US Navy Site; Maintained by Thoralf Doehring; 2009.[1]

1 http://navysite.de/ships/mystic.htm

NATO's Submarine Rescue System [Internet]. Defense Industry Daily, 26 Mar 2008[2]

NOAA Photo Library [Internet]. Credit for photo: OAR/National Undersea Research Program (NURP); U.S. Navy.[3]

NATO Submarine Rescue System Takes Shape [Internet]. Analox, 23 May 2007.[4]

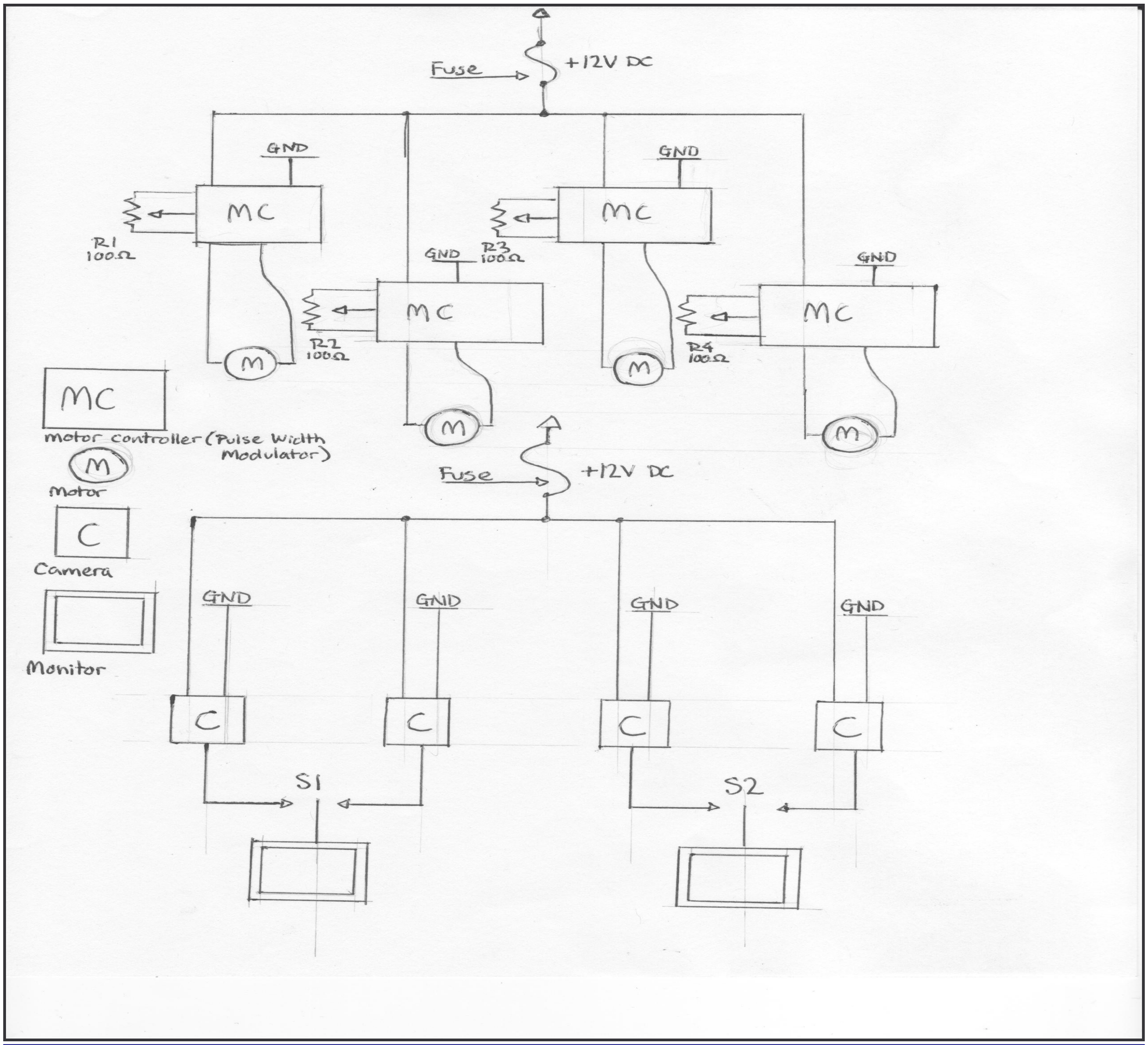
Figure 1: SRV1 NATO Underwater Rescue Vehicle

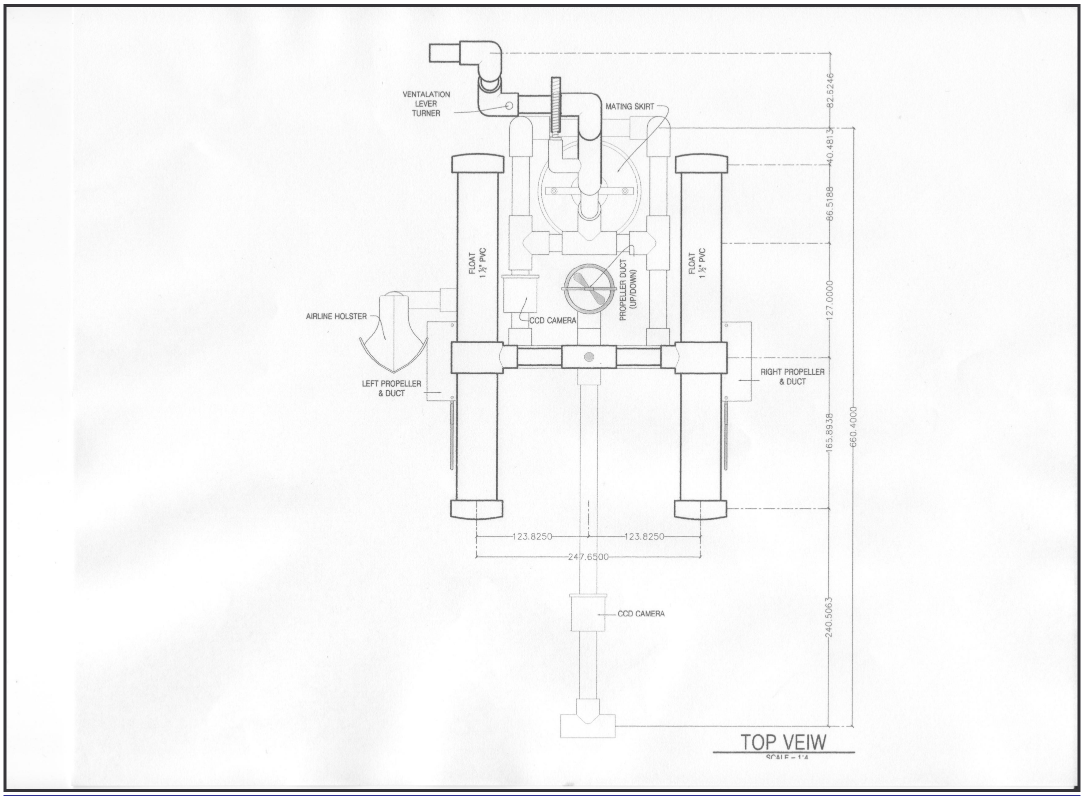
2http://www.defenseindustrydaily.com/NATOs-Submarine-Rescue-System-04819/

3 http://www.photolib.noaa.gov/htmls/nur09505.htm

4http://www.analox-blog.co.uk/index.php?entry=entry 070523-113659

Electrical Schematic and CAD Drawings




VENTALATION
LEVER
TURNER
MATING SKIRT
FLOAT
1 ½" PVC
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(UP/DOWN)
AIRLINE HOLSTER
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LEFT PROPELLER
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RIGHT PROPELLER
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82.5246
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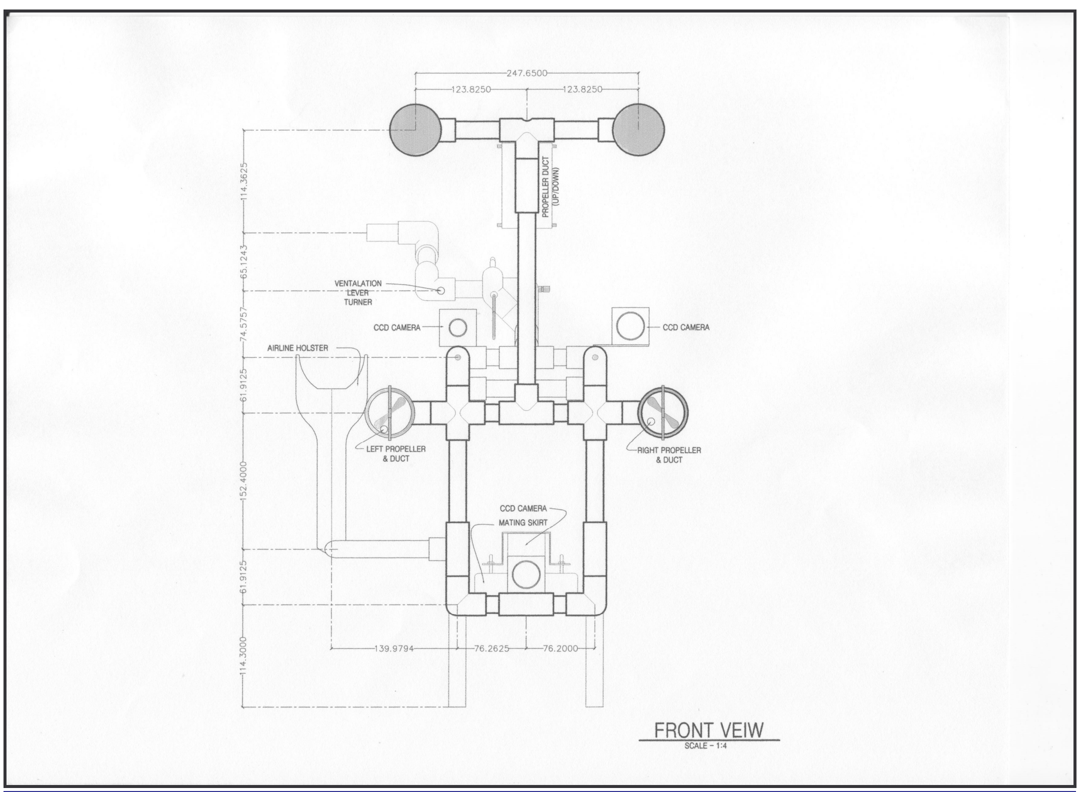
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CCD CAMERA
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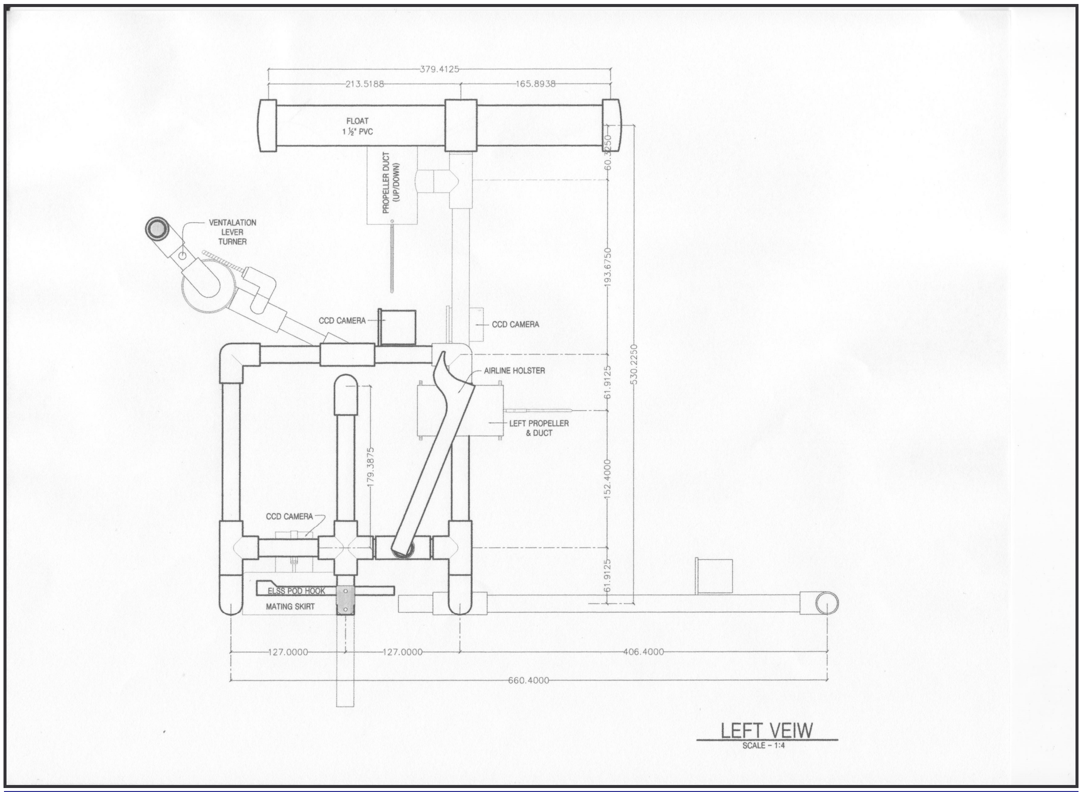
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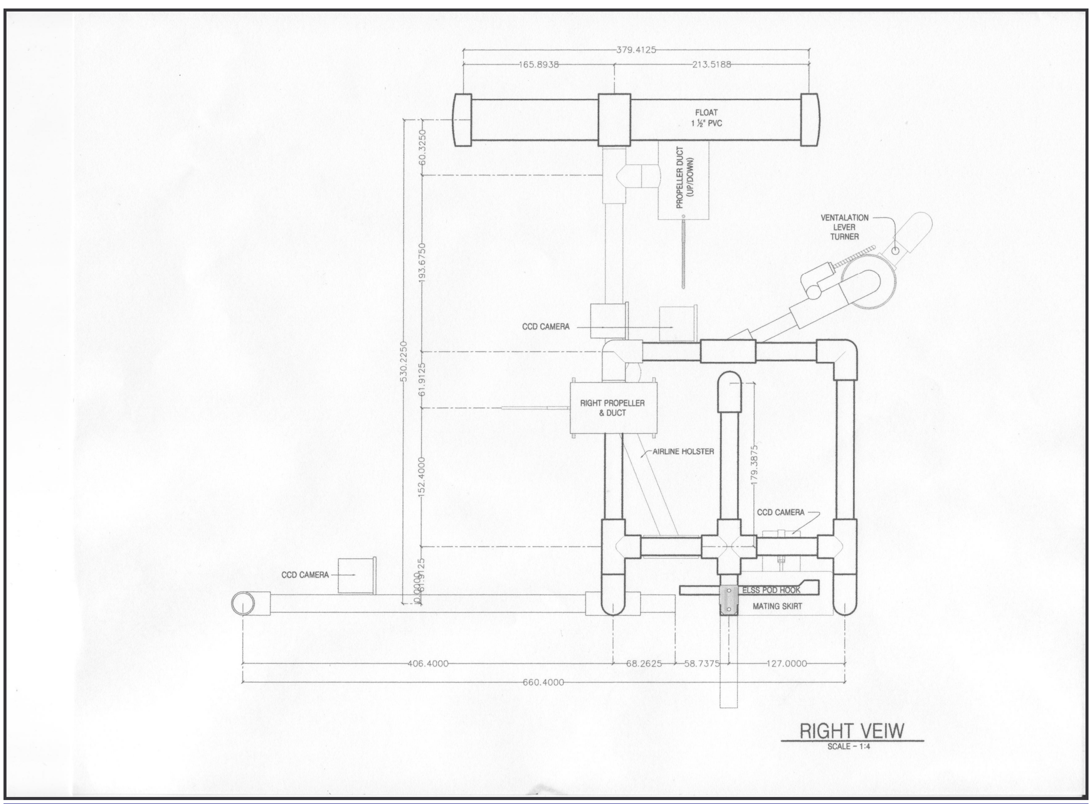
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RIGHT VEIW
SCALE - 1:4

Expense Report

Fortunately, we were able to use the motors and motor stand from last years craft; therefore, they are not included in this year's expense report. We also only included our expenses through the PNW Mate Regional Competition in May.

Budget/Expense Sheet

South Whidbey High School
Eric Wilson

Period:
From: May 2008
To: June 2009

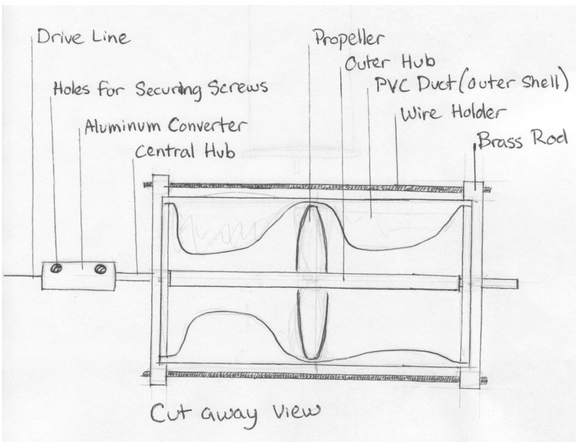
Description	Notes	Amount	Balance
2008 Mate prize money		$ 500.00	$ 500.00
Summer fundraisers		$ 732.00	$ 1,232.00
PVC test models		$ 18.00	
PWM Motor Controllers		$ 105.00	
Power supply		$ 16.00	
Joy sticks		$ 5.00	
Electronics		$ 21.00	
PVC/ABS fittings		$ 19.00	
Hose nozzle		$ 3.00	
Rope and PVC		$ 10.00	
Spiral wrap tubing		$ 68.00	
Plastic Sheet		$ 25.00	
Screws		$ 6.00	
Brass for propellers		$ 7.00	
Cameras		$ 411.00	
PVC pipe and brass		$ 24.00	
Wiper Motor		$ 7.00	
Pocket box		$ 10.00	
Electronic connectors		$ 9.00	
Drive lines		$ 140.00	
Camera epoxy		$ 51.00	
Aluminum and stainless steel		$ 44.00	
PVC glue		$ 4.00	
Avermedia		$ 60.00	
Pictures		$ 22.00	
Poster Materials		$ 41.00	
	Total Expense:	$ 1,126.00	$ 106.00

Design Rational

Our design process for our craft began with lots of brainstorming. What were the parts of the challenge? How might we accomplish the tasks? We threw out our ideas and mapped them on a white board. When the white board became too small, we stuck our ideas on sticky notes all over our mentor's family room wall. At first the challenge seemed complicated. It seemed like it would take many gadgets and gizmos to accomplish. This bothered us because we preferred simple solutions with few moving parts. As we discussed and threw out ideas, we were thrilled by being able to design a fairly simple craft that could perform the challenge well. The major parts of our craft are described in the following sections. !!Brainstorming picture!!

Propulsion System

Our propulsion system consists of three propeller assemblies capable of moving the craft forward, backwards, left, right, up, and down. The propeller assemblies, two located on either side of the craft and one on top, are positioned so their thrust passes through the craft's center of gravity. This keeps the craft stable when moving.



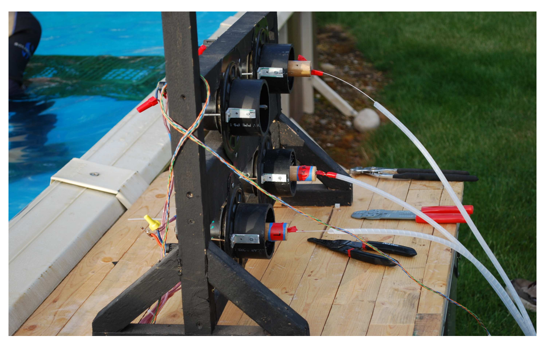
While considering which propellers to use, we realized that by making them ourselves we could easily manipulate the shape and angle of the blades to determine the combination that would provide us with the highest thrust to amps ratio. Upon recommendation, we began with a "square" propeller design which means that the propeller's diameter equals the distance it travels during one revolution. We then experimented with the propeller angles, until we found one that met our design goal. At 6 amps of power, each propeller produces 4.4 Newtons of thrust.

Designing our own propellers meant manufacturing each propeller assembly ourselves also.

The blades, made from brass because it is easy to cut and solder, and is corrosion resistant, are soldered to a brass hub and supported within the PVC housing by a brass rod located at each end of the housing. Then we manufactured an aluminum union with two screws to connect the brass hub to the drive line. The complete assembly is shown in the following diagram.

Motors

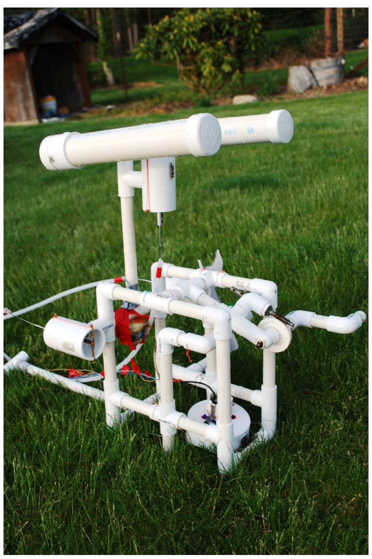
Our journey to using onshore motors started with propeller testing. Anxious to test our homemade propellers before the bilge pumps arrived, we jerry-rigged a Ford Aerostar fan motor we had on hand to spin them. Since the motor couldn't go into the bathtub with the propeller, we attached a flexible drive line between the motor and the underwater propeller. This idea worked well. Excitedly, we realized that perfecting this concept of onshore motors would give us a small, very lightweight craft free of heavy motors. In addition, when the bilge pumps arrived, we discovered that the fan motor produced a two to 4 times higher thrust to power ratio. On full power and under load, each motor draws 6 amps.



Since we needed more than one motor, we scoured local wrecking yards for three more Ford Aerostar, 12V DC fan motors which cost a total of $9 (spent during the 2008 challenge year). We mounted the motors on a wooden frame to keep them aligned, portable, and off the ground where water could create a potentially dangerous problem. Three of these motors propel the craft and one powers the lever turner.

We had one additional design consideration. The motors were originally cooled by the fan they turned. Because we needed to remove the fan to connect the motors to the drive line, we had to devise a motor cooling system. To solve this issue we made fans by cutting and bending Kerr canning jar lids. Then we stapled each one to a wooden motor hub, which we connected to the drive line. This little piece of ingenuity has received several stares and comments.

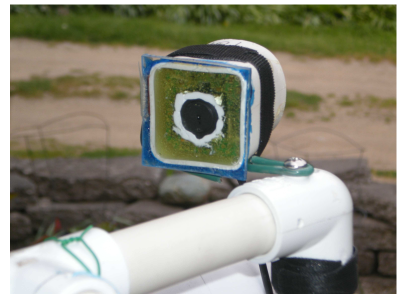
Frame



The frame of the APIA submersible for the 2009 challenge is made out of 1.27 cm (.5 inch) PVC piping. The pipes are cut and glued together for shape and stability. Some of the piping is not glued but are wire tied for fast and easy disassembly of the craft for easy transportation. The frame is built to be sturdy and durable, yet light and fast. The frame consists of three extensions for propellers, one for the lever turner, and an extension out the back to keep the tether in tow of the craft. The ballast system is made of larger pieces of PVC pipe, located at the top of the craft that have caps glued and sealed on both ends to hold in air and keep out water, either keeping the craft neutrally buoyant, or at least having the craft very slightly positively buoyant.

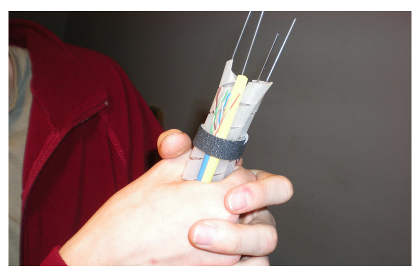
Cameras

Cameras were our nemesis. We bought nine and burned up or flooded six of them; therefore, we covered our trials more fully in the "Challenges Overcome" section. Our craft now has four personally waterproofed, black and white, CCD cameras to monitor forward movement, skirt mating, airline holster, and lever turner. To operate, each camera requires a video line, and all cameras share a positive and ground wire, which allows us to have a smaller, lighter tether.



Tether

The onshore motor system provided two unique design considerations for our tether: what to use as drive lines and how to keep them from tangling as the craft moved under water. We knew the drive lines needed to be "flexible" so the craft could maneuver, "strong" to resist breaking, and "straight" to reduce power loss due to friction. Stainless steel piano wire met our requirements.



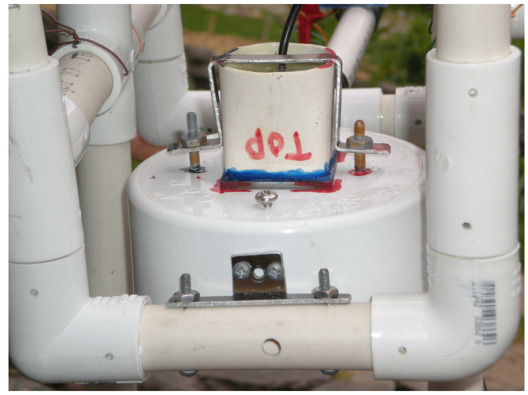
To keep the lines from tangling, we encased each one in plastic housing typically used to bundle electrical wires. Our completed tether measures 12-meters long. The four, plastic encased, drive lines and electrical power lines are bundled using Velcro zip ties. Neutral buoyancy was achieved by attaching thin strips of closed cell foam cut from a swimmer's kick board.

Pod Hooks

Our pod hooks were designed to open the hatch; lift, carry, and deposit two ELSS pods at a time; and close the hatch. The hooks, made of thin aluminum, are supported by parallel, vertical shafts which can retract under the force of the craft. These shafts are reinforced with a cross bar at the top. To open the hatch, the craft is lowered, positioning the shafts between the crossbars of the hatch. The craft can then be turned to open the hatch. Then the tips of the hooks are used to lift the hatch. The hooks are then able to lift two pods at a time from the rack and deposit them in the newly opened crate. During testing, we found that the pods slipped off of the hooks; so we wrapped the ends with electrical tape to create a lip. To close the hatch, we wanted to use the back of the hooks; but we found it was easier to turn the craft and use the front of the hooks. Because the hooks interfered with the mating skirt operation, we redesigned them to retract when the craft was lowered.

Mating Skirt

Our mating skirt is a 10.2 cm (4 inch) PVC pipe end cap. We thought it would be easier for the operator to align the skirt with the receptacle if we drilled a hole in the middle of the cap and placed a camera to look down. The skirt is attached to the bottom of the craft, between the pod hooks.



Airline Holster and Lever Turner

The Airline holster, cut from a piece of drain pipe, carries the airline down to the submarine. The holster is angled to correctly insert the airline in the receptacle.

After the airline is in place, the lever turner opens the air valve. Originally we wanted to use a shaft to lift and rotate the lever by moving the whole craft. Although this was a simple solution we felt it used too much valuable time moving the craft. What if we could just open the valve without moving the craft after the airline is inserted? With this in mind, we chose a worm gear assembly, to rotate the lever and positioned it on the craft to be in alignment with the air valve. The worm gear was removed from a windshield wiper motor. The craft is able to insert the airline and open the air valve from a stationary position.

Control Panel

Our control panel has a wood base that supports the joysticks, motor controllers, camera switches, wire connection strip, and fuse.

Each joystick has an x-axis and a y-axis potentiometer, which are wired to pulse width modulator motor controllers. We only use four of the six motor controllers. The used controllers, which are connected to the motors, operate by using three op amps: one to create a triangle wave, and two as voltage comparators. The potentiometer controls the

voltage at which the triangle wave operates. When the triangle wave's voltage crosses the voltage comparators threshold, the motor spins. Its speed is directly proportional to the percentage of the triangle wave that has crossed the threshold. The motor controllers are encased in a opaque plastic housing to protect them from damage and to help keep them cool.

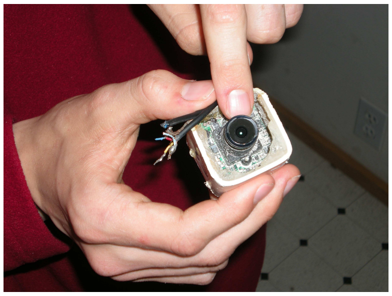
The camera wires are connected to switches on the control panel which allow the operator to choose the camera view.

A wire connection strip facilitates camera wire attachment and battery power distribution. Also incorporated into the control panel is a fuse for safety. The wire connection strip is protected with a clear plastic cover.

Challenges Overcome

One challenge we had was finding a pool to test our craft. When it looked like we might not have access to any of the local pools, we set out to dig our own. It was quite the undertaking and the absurdity of it all gave us much to laugh about; however, it was very useful for testing in the beginning stages. We are very grateful to friends who allowed us their private pool during our final testing and practice stages.

The most problematic aspect of our craft was waterproofing and wiring the cameras. We wanted to use inexpensive cameras and waterproof them ourselves. Hating to completely submerge the cameras in epoxy, we simply waterproofed the sides of the camera housing. This method would also us to retrieve the camera in case something went wrong. That something just happened to be water, which accessed the cameras quite easily, rendering our easy access to the cameras moot. When we saw that our method failed, (or didn't see, as there was only static) we realized that any airspace could be filled by water; therefore, we had to completely surround the cameras with epoxy. Our next fiasco was burning up the two most expensive cameras we purchased by wiring them incorrectly. Finally, during the Regional Competition, some of the cameras' wire connections failed because the splices were not watertight and we were probably losing power into the water. We unconnected all but two of our cameras between rounds and were able to see well enough to complete the challenge during our second trial. Now we have butt splices for the wires, heat shrink tubing to cover the splices, and loads of epoxy to completely encase the cameras. We also have the knowledge that water travels through the tiniest opening and extra care needs to be taken when wiring!

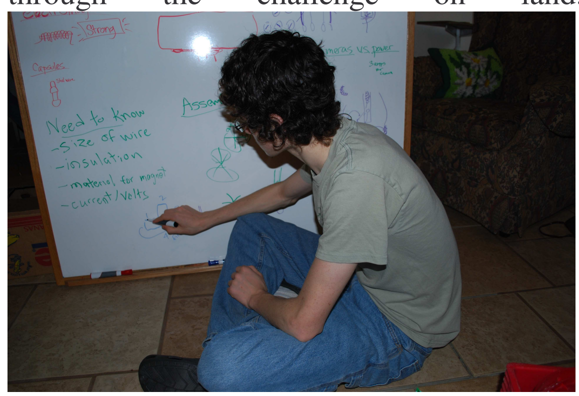


Troubleshooting Techniques

Before designing our 2009 craft, we discussed what we liked and disliked about our 2008 craft. However, before that, we liked to unwind, in order to get focused (as evidenced in the picture below)

The concepts that we liked (onshore motors, PVC frame, three propeller propulsion system, using scrap materials, and few moving parts) served as a foundation for our 2009 design.

The versatility of one particular idea, the PVC frame, was very useful. As we designed the tools necessary to complete each of the 4 tasks, we were able to easily modify the frame to support them. Being lightweight, we could easily carry the craft around our downed submarine replica, located in our mentor's family room, to test our design. This allowed us to observe interferences caused by tool placement. The placement of our mating skirt and pod hooks is a good example of interferences we discovered carrying the craft through the challenge on land.



The first interference was discovered while lowering the mating skirt onto the hatch. The pod hooks would not allow the craft to lower far enough to cover the hatch. We didn't want to move the hooks to another location, so we decided to allow them to slide up, out of the way, when the craft descended onto the hatch. This resolved the interference problem nicely.

The second interference involved the pod hooks again, when we twisted the craft to open the hatch. To resolve this conflict, we lengthened the part of the support pipes underneath the pod hook. This kept the hooks out of the way and gave us a more sure connection with the hatch.

Throughout the ROV design process, we had to constantly think through the challenges from several angles, in order to come up with a workable solution. Our lightweight craft and submarine replica were invaluable to this problem solving process.

Skills Gained

This competition has allowed us to develop an amazing assortment of skills that we will be able to use in different ways throughout our lives. Some of these skills are organization, ability to clearly convey ideas to others, use of shop equipment, and following wiring and soldering diagrams. All of these skills have helped us to complete the challenge.

Organization was a real issue for us. From showing up on time to losing parts, we all have had our share of issues. During the months, and especially weeks leading up to the regional competition, we all pitched in, making huge efforts to be more organized. Tools were straightened out and sorted, and members began showing up early. To everyone's credit, this has been an area of drastic improvement.

The ability to communicate ideas amongst ourselves and with others can be challenging! We spent most of our time in the design phase, talking and explaining ideas to each other. Over time this has become easier. Fund raisers have given us opportunities to learn how to explain our project clearly to others. This practice was invaluable during the Regional Competition, when we had to answer people's questions, as well as give a presentation.

Skill with shop equipment is vital when you are determined to make your own parts. Many of the propellers and connectors which we manufactured needed to be remade several times as we honed our skills with the lathe, jigs, and soldering equipment. It is rewarding to be able to think about a part, then go make it by yourself. Learning these skills gave us many few shocking moments, electrical, or otherwise, and we are all pleased to say that we came through with all fingers intact.

Wiring and soldering diagrams look like hopeless mazes the first time you look at one. That's probably why we burned up two of our cameras. The beauty of looking at the diagrams for long periods of time is that they begin to make sense. We have learned that patience in soldering and wiring is invaluable if you want the finished product to work correctly. We are excited to take all of these skills with us to future projects.

Future Improvements

There are three things about our experience this year which we feel could be improved. First, setting up and sticking to a schedule would help us a lot. In September, May seems along way off. Combine that fact with the fact that we are such good friends, and we end up spending most of our meetings talking and laughing together. By calendaring mini deadlines throughout the year, we could avoid some of the crunch which we felt the last four months.

Learning how to solicit business sponsors would be another great improvement! We feel that a lot of our ingenuity came from not having a huge budget and it is rewarding to be able to make something out of a pile of materials on hand. However, cameras are expensive and it would be nice to have the funds to buy them when needed.

Now that we know how to wire cameras and solder circuits, next year it would be great to be neater and more organized with our wiring. It seems that messy looking wiring is a recipe for disaster and is hard to change without adversely affecting something else. Neatness in design we have learned is easier to maintain and runs smoother.

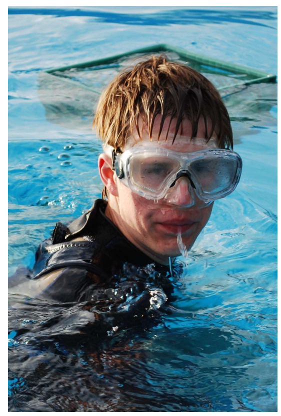
Improvements in all three of these areas would help us immensely.

Reflections

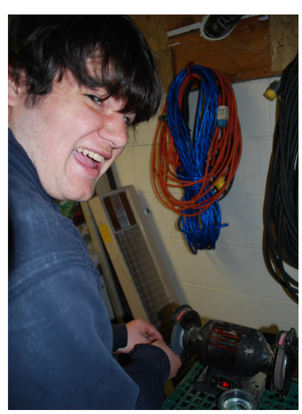
Geoffrey Wilson

I have to admit that field robotics and engineering have always been somewhere in my mind as a potential future career. High-tech creations, whether digital or analogue have always been fascinating to me. This competition has really opened my eyes to the fact that a mechanical creation doesn't have to have expensive servos or pneumatic systems to work well – it just has to have creative people designing it! My experiences with the APIA team members this year have all been enjoyable and educational. I have learned many things including how to fine tune the structure of the craft in order to get it ready for the competition. I am really proud of the craft that we, as a team designed this year, an whether or not we win, it will be satisfying to know that our ideas, and creations have been shown to such a diverse group of people.

Kip Hacking



At the beginning of this year, the team was just a bunch of kids. Now we have become a close group of friends. Long-term friendships and comradely have been formed. I absolutely loved learning how to wire cameras and waterproof them. One thing I never thought I would do, but this year I did it. It was to wire my own circuit board all on my own! I had always thought only electricians and engineers could do this. Now I know that anything I'm curious about I can learn. Another great experience I have had is working on fund-raising and being able to give presentations to local non-profit groups, and businesses. It's a skill I can use my whole life and it will be beneficial in many aspects of my life. After having done the MATE ROV Competition I've found that the goal, I had since 5th grade, of going into medicine is something I don't want to do now. Now I want to go into either engineering or underwater robotics. This competition has not only given me many technical skills,



but also altered my future career path.

Kimmer Webb

As a member of the APIA ROV team, I have come to realize that I really enjoy science, engineering, and building. It has changed what I want to major in when I go to college. I have learned how to use more tools than I did 2 years ago. I have used some larger machinery (Band Saw, Lathe etc.) and have learned the simple lesson that everyone needs to know; procrastination just makes the work much harder. In addition, I have learned that small mistakes can be tough to fix, but simple mistakes, which are easy to fix, get overlooked way too often. Being on this team has gained me some great friends and has led me to look at the world past my computer. The challenge for this year has been an interesting one with some minor complications for our team which should be fixed. All mechanical, electrical, and human error have occurred, but that just adds to the challenge. Being part of the MATE ROV competition is a great experience and a lot of fun. I am very glad to be a part of it and wish to for some years to come.

Evan Mattens

The experience of being on the APIA submersible has been a unbelievable experience. It has really changed my life forever. Getting to know everyone on the APIA submersible team at a personal level has been really great. Looking over the past couple years I have really learned a lot and am proud to say that I am a part of the APIA submersible team. Our team has really progressed the past two years with becoming more organizing and more experienced to come up with better ideas. I learned that in able to solve problems you have to test. Solving the problems was my favorite part because when you fixed the problem I felt success.

Aren Mattens

Being a part of APIA has been a life changing experience. I have been involved in APIA submersible for two years, and let me say I have grown a larger understanding of underwater robotics. I learned a lot about electrical engineering that involves variable resisters solder joints, and wiring a control board. The big aspect of being a part of APIA is friendship, as a team we all had to work together to make an underwater submersible. Even though we all went through some hard times we all came out of this adventure side by side standing together.

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