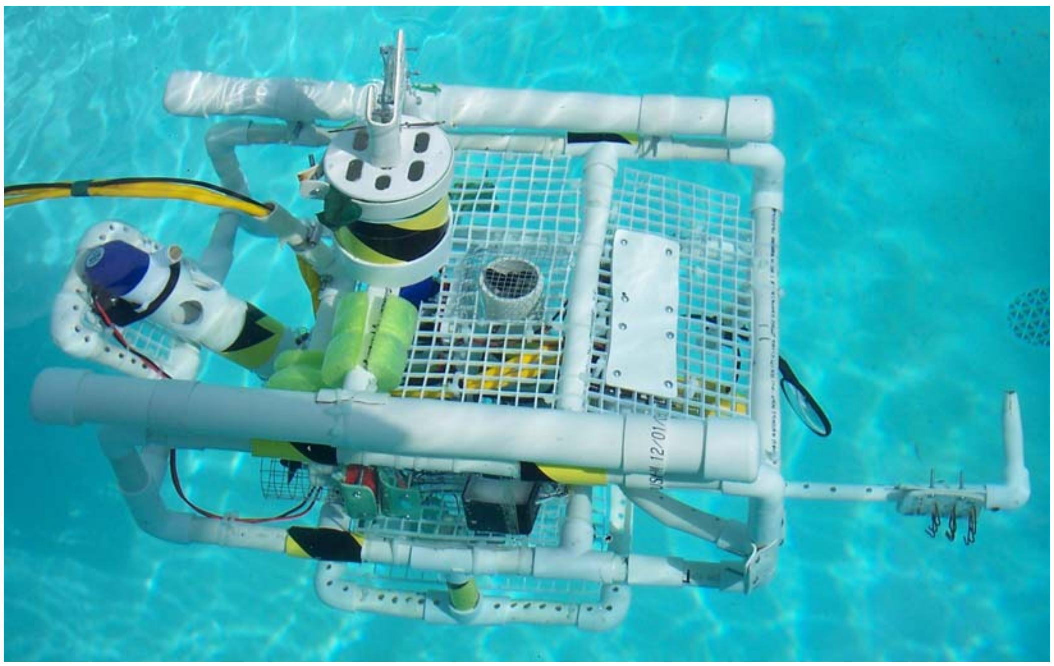
Haltom High School
ROV TEAM

Project: Haltom 2
June 23-25, 2006



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Abstract

The Haltom High School ROV team accepted the task of designing, building and operating a remotely operated vehicle (ROV) to perform specific tasks. The ROV requires the mechanical flexibility to complete two independent tasks. The first task requires the ROV to place a communications module into a trawl resistant frame. Upon completion of this task, the ROV must then open a door to reveal the communications port. A communications probe must then be retrieved and inserted into the communications port. The second task requires the ROV to locate and release an instrument package by pulling a pin. These tasks must be completed within a twenty minute time limit. Using PVC and polycarbonate plastics, the Haltom team created an ROV capable of performing all of the tasks. The ROV uses a 12 volt topside power supply with a 25 amp inline fuse to operate two 1890 Liter/hour bilge pump thrusters, three 3030 Liter/hour modified bilge pump thrusters, and one gear head release motor. To achieve neutral buoyancy, the team created static air filled PVC cylinders. Variable buoyancy to accommodate the communication module was achieved through the use of a cylinder which traps a volume of air. Upon insertion of module the air is released which allows the ROV to maintain neutral buoyancy. Manipulators to perform the required tasks were developed separately and then incorporated into a final design. The simple design and ease of operation make the Haltom ROV reliable and efficient.

Design Rational

Frame:

The frame was created in two parts. The main frame contains the thrusters, cameras, electronics, and buoyancy devices. The lower, payload, frame, contains the module release mechanism, manipulator arm, and ballast. The creation of the payload frame resulted from the need for additional space on the ROV.

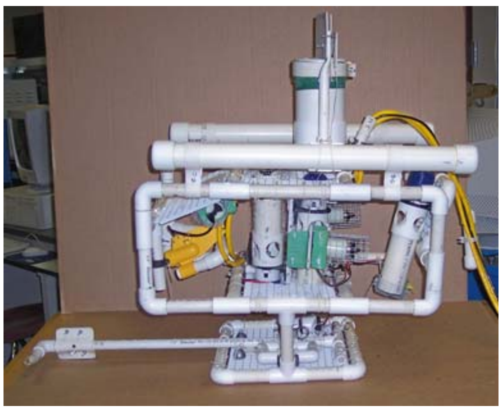

Figure 1 – Full view of Frame

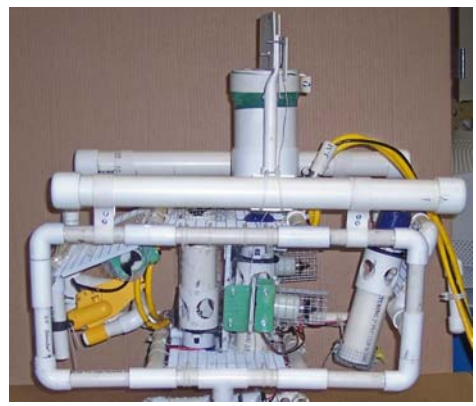

Figure 2 – Upper Frame

Upper Frame:

The dimensions of the upper frame are 63.00 cm in length, 42.00 cm in width and 27 cm in height. The upper frame is constructed of thick walled 1.91 cm poly vinyl chloride (PVC) tubing. The material was chosen because it was easy to work with, it possesses strength and it can be made water tight. The top and bottom platforms of the upper frame are made from plastic egg crate. This material is attached to the frame using plastic cable ties. These platforms provide support for the attachment of thrusters, cameras, and electronics.

Pay Load Frame:

The lower payload frame was added to the original design out of necessity. The size of the thrusters required more area than originally estimated. Rather than begin a new design, the team decided to add to the existing frame. The payload frame extends 17.50 cm below the upper frame. This frame measures 33.00 cm in length and 36.50 cm in width. The platform is made from plastic egg crate, which provides support for the release mechanism and the manipulator arm.

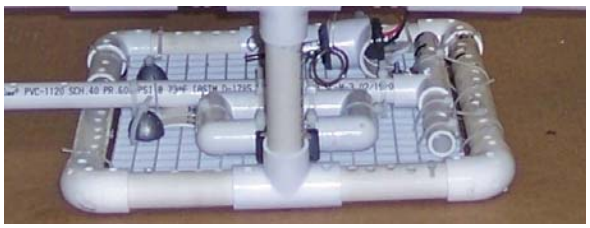

Figure 3 – Pay Load Frame

Thrusters:

The ROV utilizes a total of three 3030 Liter/hour modified bilge pump thrusters and four1890 Liter/hour bilge pump thrusters. The larger thrusters are used for submerging and surfacing as well as aft movement. The smaller thrusters are used for fore and aft as well as side to side movement. To provide a measure of safety, all thrusters are covered by hardware cloth screen.

Large Thrusters:

Thrust tubes were created to increase the power of the 3030 Liter/hour pumps. The thrust tubes are made from 6.00 cm outside diameter PVC cut to a length of 13.50 cm. These are attached to a 6.00 cm coupling, which is then attached to the pump motor. To allow for water flow, four 3.50 cm diameter holes are cut into the coupling. The motor shaft is extended to a length of 19.00 cm by using .635 cm round stock. A 3.50 cm support rod is inserted into the thruster tube to stabilize this long shaft. A Traax 1584 propeller is attached to the end of the shaft. When tested, forward thrust was found to be 14.50 N and rearward thrust 2.50 N. (See Appendix C). A total of three of these thrusters are incorporated into the design

Figure 4 –Large Thrusters

Figure 5 – Small Thrusters

Small Thrusters:

The 1890 Liter/hour thrusters are attached to the frame with flattened PVC brackets. The brackets are made by flattening and bending the material to a shape that will hold the bilge pump in place. Traax 1584 propellers are attached to the existing shaft on these thrusters. Testing revealed that these thrusters produce a forward thrust of 3.48 N and a reverse thrust of 1.65 N (See Appendix C). This smaller amount of thrust allows for more control of the ROV during the performance of the task.

Manipulator Arm:

The Haltom ROV utilizes two types of manipulators to perform the tasks to complete the mission. These manipulators were created separately and then combined in the final product. Both manipulators are permanently attached to the single arm. The combination of manipulators allows the ROV to remain submerged for the duration of the mission. The manipulators incorporated into the Haltom machine are effective in completing the tasks for which they are designed.

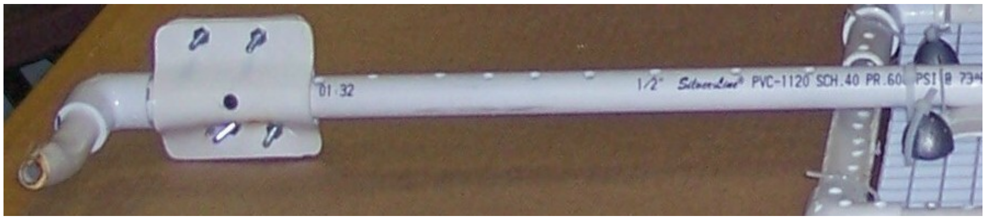

Figure 6 – Manipulator Arm

Manipulator 1:

The team explored different types of claw mechanisms without success. The resulting manipulator is the hook. It is of simple design constructed of a single 1.91 cm 90^{o} PVC fitting and 9.00 cm section and a 1.91 cm PVC. This manipulator allows the ROV to open the door as well as capture, transport, and insert the communications probe.

Manipulator 2:

The brush is designed to remove the pin from the instrument package. This manipulator is made from flattened PVC through which is inserted coat hanger wire. The wire is shaped in the form of hooks which allow for the capture of the pin. Multiple hooks allow for more opportunities for the operator to capture this pin.

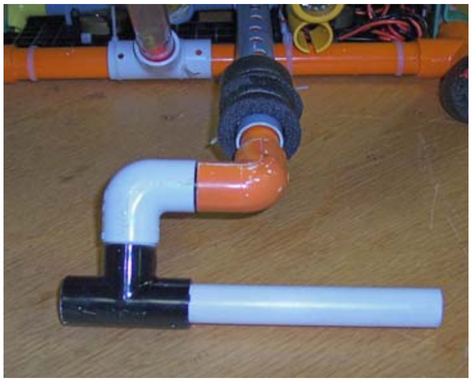

Figure 7 – Manipulator 1

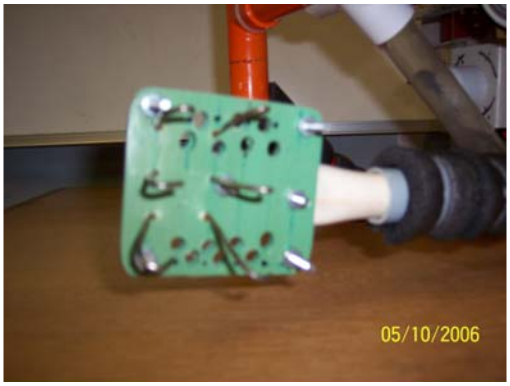

Figure 8 – Manipulator 2

Release Mechanism:

The most difficult mission task is the transport and deployment of the communications module. A reliable method for holding and deploying this module was necessary for mission success. The accomplishment of this task required the combination of extra buoyancy as well as a practical and reliable method of release. The extra buoyancy will be addressed later. (See Variable Buoyancy).

A gear head motor powers the release mechanism. The motor was water-proofed by placing it inside a PVC T fitting, sealing the gear box end with silicon, plugging the opposite end, and top with a rubber stopper. The internal cavity was then filled with toilet bowl wax to prevent the inflow of water to the electrical connections. A 3.00 cm length of 1.00 cm diameter round stock was attached to the motor shaft forming a spool. The spool is attached to a locking pin by way of a length of coated braided wire. The locking pin measures 12.00 cm in length and is made of 0.635 round stock. The pin is inserted through three sections of 1.91 cm PVC tubing. This prevents the pin from twisting while being pulled. To ensure complete insertion a magnet is placed at the insertion point. The magnet attracts the pins thus preventing premature release. This mechanism has proved to be very efficient and effective.

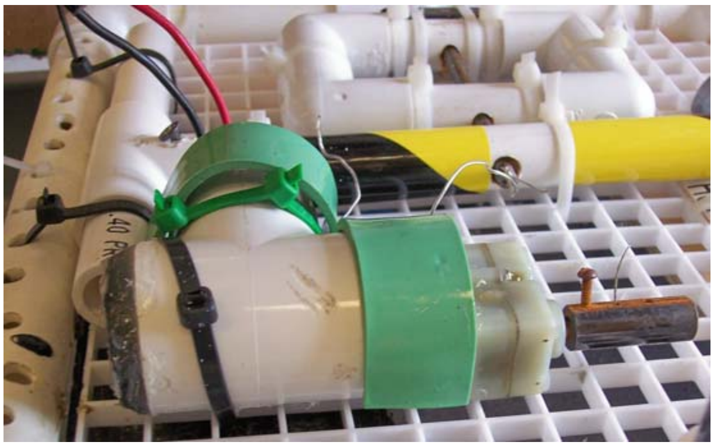

Figure 9 – Release Mechanism

Buoyancy:

The goal of the Haltom Team was to create an ROV that was neutrally buoyant and stable. To accomplish stability, the team placed all thrusters and manipulators as close to the center of gravity as possible. Thrusters were placed in parallel with each other to achieve stability. Two types of buoyancy were used in the design of the Haltom ROV, static buoyancy and variable buoyancy. Buoyancy was determined through the use of buoyancy equations. The weight of the ROV in water was measured by attaching a spring scale to the ROV and then submerging it in water. From this value, the buoyancy needed to create a condition of neutral buoyancy could be determined. (See Appendix E)

Figure 10 – Static Buoyancy

Figure 11 – Variable Buoyancy

Static Buoyancy:

Static buoyancy is in the form of two 63.50 cm length 4.445 cm diameter float tubes. These tubes were constructed of PVC tubes with end caps glued together to create a water-tight seal. Net buoyancy of each of these tubes was found to be 9.10 N. This produces a total net static buoyancy of 18.20 N. In addition, small sections of buoyant foam were added to the frame to compensate for the water weight of the release mechanism motor.

Variable Buoyancy:

Variable buoyancy was added to the ROV to compensate for the water weight of the communications module. This device is the most unique aspect of the Haltom ROV. The device is constructed from an 18.00 cm tall, 11.00 cm diameter PVC tube. An end cap is attached at each end. The upper end cap contains seven openings to allow for the addition of water. This container is oriented vertically and is supported by a 35.00 cm 1.91 cm PVC horizontal brace. To achieve neutral buoyancy when the communications module is attached, the ROV is placed in water and water is added to the container until neutral buoyancy is achieved. The ROV and attached module is then lifted to the pool deck and a rubber diaphragm is stretched across the upper surface of the container. The diaphragm is then locked in place with a locking ring. The ROV and module is then placed into the water to start the mission. For this device to function correctly it must work in conjunction with the release mechanism as described earlier. (See Release Mechanism). A spring loaded hammer is attached by a cable trigger to the release pin by means of a ring. At the end of the hammer is a razor knife blade. When the operator is ready to release the module, the release pin is pulled, the trigger is released, and the spring-loaded hammer causes the knife blade to rupture the diaphragm. The trapped air is released and the ROV becomes neutrally buoyant and can carry on the mission. If the mechanism fails, the ROV will rise to the surface and the topside crew will have to rupture the diaphragm to continue the mission.

Visual System:

The Haltom ROV has been upgraded from the Texas Regional competition and will now operate with three cameras. Two Chicago Electric 91309 and one Atlantis

AUW 502 camera systems provide the operator viewing options. The operator can have three views simultaneously or can opt to turn on or off any of the cameras. Camera 1 faces forward which permits easy navigation. Camera 2 is aimed at the manipulators, giving the operator an up close view of the task. Camera 3 is pointed downward to provide the operator with a global view of the entire task. In addition the view from camera 3 should provide evidence that the communications module is properly placed prior to release. Additionally a convex mirror is placed forward on the ROV frame to allow the operator the ability to see the bottom of the communications module for correct placement. The addition of two cameras should add to the abilities of the ROV.

Tether System:

The tether system used on the Haltom ROV was donated from CGGE International, Sound Ocean Systems Inc. The total length of the tether when received measured 30.00 m. This tether contained four pairs of wires, which would allow for control of four devices. By cutting this tether into two equal pieces, eight devices could be controlled. The team decided to cut the tether to allow for the control of additional devices. Optical cables are attached, with tape, to the main tethers at 30.50 cm intervals. This marking system allows the tether operator to know the amount of tether deployed in the water. Foam flotation is added to the tether at 60.96 cm intervals to increase the buoyancy of the tether.

Control System:

The control system is powered by a Vector Start It Pro power supply. This power supply provides 12 volts and 1200 peak amps. To comply with the power restrictions, a

25-amp in-line fuse is placed within the system. This power supply provides power to all onboard thrusters, the release motor and the camera systems.

The 1890 Liter/hour bilge pump thrusters are wired together in pairs. These thrusters provide fore and aft movement, as well as port to starboard movement. The 3030 Liter/hour thrusters are wired individually and are used for diving, surfacing, and increased reverse thrust. A 12-volt gear head motor, which is wired individually, is used to pull the release pin. Thrusters, which are wired together in pairs, are joined and soldered to a length of copper wire. Individual wires are also soldered to a length of copper wire. These connections are covered with liquid electrical tape and then sealed in silicon. These waterproofed connections are then routed through one side of a project box. Within this project box is located a buss bar. This buss bar allows for easy connection of the onboard wiring to the tether. Routed through the other side of the onboard project box are the tether wires. These wires are connected to the opposite side of the buss bar thereby connecting the circuit. All external insertions into the project box are coated with silicon. The interior of the project box is filled with wax to complete the waterproofing.

Figure 12 – Control Box

The control box is made from a plastic storage box. The box contains six double pull double throw toggle switches. One switch controls the camera system; a second switch controls the release mechanism. Since the release mechanism is extremely important to the success of the mission, an indicator light is wired in series with the toggle switch. This indicator light informs the operator that the release mechanism has been activated. Single toggle switches control the diving, surfacing, and extra reverse thrusters. The remaining two switches control the paired thrusters for fore and aft movement, and port and starboard movement.

Budget

The goal of the Haltom team was to keep cost as low as possible. A budget of $1000 was established for the completion of the ROV. The team utilized existing parts from previous competitions. The 1890 Liter/hour bilge pump motors were salvaged from last years ROV. In addition, a number of scrap pieces of PVC pipe were used to create many of the devices found on the ROV. For more details on the budget refer to Appendix A.

Challenges

During the design and construction of the Haltom ROV, the team experienced a great many challenges. Possibly the greatest challenge faced by the team was the maintaining of the team concept. The original eight-member team became fragmented during the design process. Team members who were not willing to commit to the project dropped out of the competition. The remaining team members split into two groups and began the construction of two ROV's. This split in the team resulted in a loss of valuable time and resources, which delayed construction. Lack of planning by team members as well as other commitments also contributed to construction delays. Unnecessary mistakes and misplacement of various parts created frustration among team members. Many components had to be rebuilt, and designs changed throughout the process. As the deadline for completion approached the team began to work together to complete both ROV's.

The greatest ROV challenge faced by the team was the creation of a variable buoyancy system. Due to the weight of the communications module a change in buoyancy would need to occur upon release. To solve the problem, the team decided to determine the buoyancy necessary to make the frame neutrally buoyant. After succeeding with this task, the team added the module to determine the additional buoyancy necessary to maintain neutral buoyancy. After a great deal of trial and error a device was created which allowed the team to complete the task.

Troubleshooting

The Haltom team conducted brainstorming sessions in the initial stages of the project. Basic principles of thrust, and buoyancy were discussed. Designing the frame was the first step attempted by the team members, propulsion system designs and finally manipulator devices followed this. A number of frame designs were considered before construction took place. The final frame was glued together to provide additional strength and buoyancy.

Thruster testing provided the team with information needed to determine the placement of thrusters on the ROV. A testing device was created which allowed team members to measure the thrust and current draw of each type of thruster motor. The testing device used the concept of torque to determine the thrust of each type of motor while under load. Three types of motors and two types of propellers were tested. Testing results are presented in Appendix C. The information obtained through this testing allowed team members to make decisions on which type of thrusters to use, and where to place them on the ROV.

The creation of manipulator devices was accomplished for each task. Manipulators were designed to perform each task separately. A hook type mechanism was developed to open the door and capture and insert the communications probe. A brush type mechanism was developed to capture and pull the pin on the instrument package. The success of these devices is dependent upon the ability of the operator. With consistent practice, the team is confident that they can be successful in completing the necessary tasks.

Lessons Learned

During the process of constructing the Haltom ROV, many valuable lessons were learned. Team members learned the importance of organization and planning. The team wasted valuable time and resources until a plan of action was developed. Construction goals were set and not met. This led to a decreased amount of practice time for the ROV operators.

Team members learned how to use PVC to create many components found on the ROV. The ability to reshape PVC allowed the team members to develop creative solutions to problems, which arose during the construction process. Team members also learned how to water proof motors and electrical connections. The importance of teamwork also became apparent to team members during the testing of the ROV. Team members have learned that it takes more than one person to be successful in accomplishing such a complex task as the designing and building of an ROV.

Future Improvements

In the future, the Haltom team will need to be more organized. A more cohesive approach toward designing and building a ROV could channel the total energy of the team. Specific goals and deadlines must be set and adhered to. All team members must commit to finishing the project. Additionally, more research should be conducted into the making of more efficient thrusters, and more efficient methods of establishing buoyancy. The intent of the Haltom team is to learn from other teams who will be competing at the 2006 MATE International ROV competition.

Acknowledgements

The Haltom team would like to thank the following people.

1. Our instructors Mr. Steve Bucholtz and Mr. David Worley for their time and efforts to make our team successful.
2. The Wood and Hensarling families for allowing us to use their pools.
3. Tarrant County Community College for the use of their pool for deep water testing.
4. Ms. Jeri Lewis for making arrangements for pool usage
5. Mr. Dan Lewis for donating dive weights
6. The staff and students of Haltom High School for their support
7. Mr. and Mrs. Kwast for their support and ideas.
8. Dr. Linda Anderson for funds for travel expenses
9. Our parents for their support during this project

Support for Mission Themes

Remotely operated vehicles (ROV’s) are used for many different purposes around the world. The US Navy funded most of the early ROV technology in the 1960’s. These early ROV’s made it possible to perform deep-sea rescue operations and recover objects from the ocean floor. The ROV’s of today are far more advanced then their predecessors.

However, the newest generation of ROV's is being used to complete the same tasks that their forerunners peformed and much more.

After the terrorist attacks on 9/11, the military began to speed up it's development of ROV's. The VIDEORAY is just one example of the newest developments in military ROV's. The VIDEORAY is an 8-pound swimming video camera on a tether. With the capability of being manipulated from a ship or dock, the VIDEORAY is being used to examin hulls, docks, mooring buoys, bridges, dams, nuclear power plants and other submerged structures, The VIDEORAY is also equiped with a manipulator that it can use to retrive an object in excess of 100 lb.

One of the Versions of the ROV VIDEORAY

Jason Jr. (JJ) was used to explore the Titanic

ROV's have been used to determine the location of many historical shipwrecks. One such ROV is Jason Jr. (*JJ*). *JJ* is a small ROV that is equipped with two powerful strobe lights and a camera. This little ROV was used in the first close-up examination of the shipwreck of the Titanic in 1986. *JJ* was attached to a submarine known as Alvin by a tether. Thanks to this ROV, the explorers of the Titanic were able to investigate parts of the Titanic that they would have been unable to explore otherwise. *JJ* also made it possible for the crewmembers to explore certain parts of the ship without having to venture into potentially dangerous places. ROV's have also been used to study several other famous shipwrecks and recover artifacts from these ships. Some of the shipwrecks that ROV's have explored are the Bismarck, USS Yorktown, and SS Central America.

Though we have focused on two of the main uses for ROV's, many more are not mentioned. ROV's are used to inspect and repair oil pipelines, and other underwater faculties. They are being used by marine biologists to explore the ocean floor. As we continue to make advances in technology, the ROV's we produce will be able to perform more challenging tasks. Perhaps, one day, we can send an ROV to explore the deepest part of the sea.

Sources:
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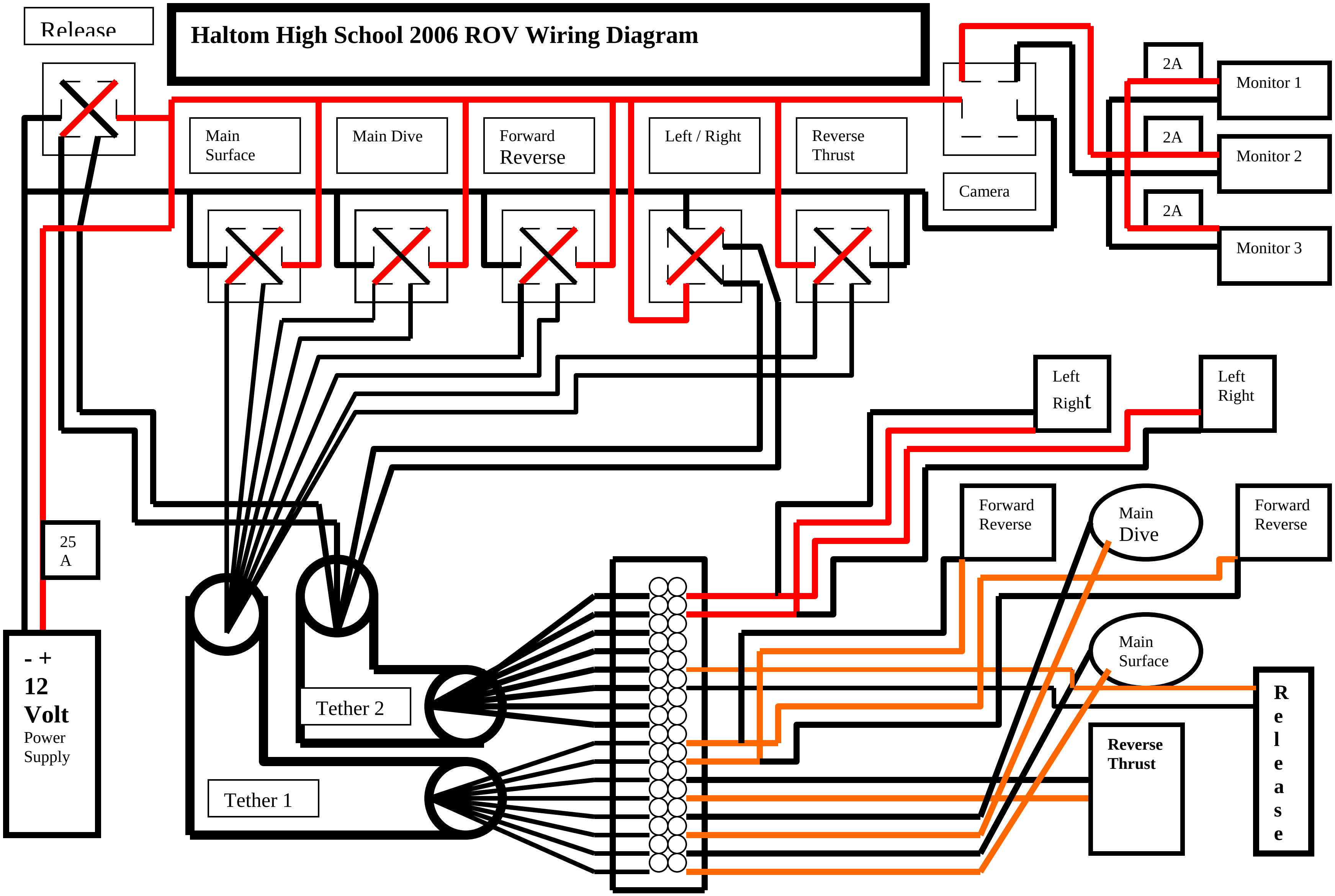
http://www.frc.ri.cmu.edu/~hagen/samplers/text/JJ_Sampler.html
http://images.ask.com/pictures?q=VIDEORAY&qsrc=2072&tool=img
Exploring the Titanic by Robert D. Ballard



Release
Haltom High School 2006 ROV Wiring Diagram
Main Surface
Main Dive
Forward Reverse
Left / Right
Reverse Thrust
Camera
2A
Monitor 1
2A
Monitor 2
2A
Monitor 3
Left Right
Left Right
Forward Reverse
Main Dive
Forward Reverse
Main Surface
25 A
- +
12 Volt
Power Supply
Tether 2
Tether 1
Reverse Thrust
Release

Table of Appendices

Appendix A: Haltom Robotics 2006 ROV Budget

ROV Component	Description	Notes	Quantity	Cost	Total Cost	Balance
Starting Balance	Haltom High School	Robotics Fund				1000.00
Plastics	1.91 cm PVC pipe	Purchased	2 x 305cm	2.13	4.26	995.74
	1.91 cm PVC 90^0	Purchased	12	1.90/10	3.80	991.94
	1.91 cm PVC Tee	Purchased	18	2.30/10	4.60	987.34
	1.27 cm PVC pipe	Purchased	1 x 305cm	1.62	1.62	985.72
	1.27cm PVC Tee	Purchased	2	1.90/10	1.90	983.82
	1.27 cm PVC 90^0	Purchased	5	1.90/10	1.90	981.92
	Poly Carbonate	On-hand	2	0.00	0.00	
	Egg crate	Purchased	1 sheet	5.00	5.00	976.92
	10.16 cm PVC pipe	On hand	various	0.00	0.00	
	10.16cm drain caps	Purchased	2	1.94	3.88	973.84
	3.81 cm PVC pipe	Donated	1 x 305cm	0.00	0.00	
	3.81cm end caps	Purchased	4	1.90	7.60	965.44
	2.54cm PVC Tee	On hand	1	0.00	0.00	
	Cable ties	Purchased	assorted	6.95	6.95	958.49
Metal	Round Stock	On hand	assorted	0.00	0.00	
	Lead Ballast	On hand	1	0.00	0.00	
	Coated wire	On hand	60 cm	0.00	0.00	
	Razor Knife Blade	On hand	1	0.00	0.00	
	Spring	On hand	1	0.00	0.00	
	Coat hanger Wire	On hand	1	0.00	0.00	
	Hardware Cloth	On hand	various	0.00	0.00	
	Pipe Clamp	On hand	1	0.00	0.00	
Propeller	TRA 1584	Purchased	5	3.00	15.00	943.49
	TRA 1583	Purchased	2	3.00	6.00	937.49
Tether	CGGE International	Donation	1	8.00	8.00	929.49
Cameras	Atlantis AUW 503	Purchased	1	216.00	216.00	713.49
	Chicago Electric 91309	Purchased	2	120.00	240.00	473.49
Thrusters	1890 liter / hr	Salvaged	4	0.00	0.00	
	3030 liter / hr	Purchased	3	14.95	44.85	428.64
Electronics	Toggle Switch	Purchased	6	3.99	23.94	404.70
	Indicator light	Purchased	1	1.90	1.90	402.80
	25 amp fuses	Purchased	1 box	1.49	1.49	401.31
	In-line fuse holder	On-hand	1	0.00	0.00	
	Banana Plugs	Purchased	2/pkg	2.90	2.90	398.41
Power Supply	Vector Start It Pro	On-hand	1	0.00	0.00	
Flotation	Foam Pool Noodles	On-hand	1	0.00	0.00	
	Rubber Stoppers	On hand	2	0.00	0.00	
	Paraffin Wax	On hand	1 pkg	0.00	0.00	
	Liquid Tape	Purchased	1	5.75	5.75	392.66
	Silicon	Purchased	1	6.95	6.95	385.71
	Balloons	Purchased	3 pkg	2.00	6.00	379.71
Hardware	Nuts / bolts/ washers	On hand	assorted	0.00	0.00	

Total Cost of Project **$620.29**

Appendix B: Testing Data Haltom High School Robotics 2006

Tests were performed on three potential thrusters. Testing was done using a torque-measuring device. This device was made from a 100 cm section of 1.91 cm PVC pipe. A pivot was created at the center of this pipe. Spring scales were placed at various intervals above the pivot point. The thruster to be tested was placed at the opposite end of the pivoting rod. Force readings were taken from the spring scales at four locations. By measuring the distances from the pivot point combined with the spring scale readings, the force produced by the thruster could be calculated at each location. By taking the average of the calculated forces, the average thrust could be determined. In addition the current draw was also measured. Each type of thruster was tested in both the forward and reverse directions. Two types of propellers were also tested; the Traax 1584 propeller and the Octura 1250. The results are presented in Appendix C.

Figure 1 – The Motor Testing System

Torque = Force x Distance

(Force A)x(Dist A) = (Force B)x(Dist B)

$$(\text{Force B}) = \frac{(\text{Force A}) \times (\text{Dist A})}{(\text{Dist B})}$$

Force B = Thrust produced under load

Figure 2 – David, Jordan, and Micah are assisted by Mr. Bucholtz while they test the thrusters

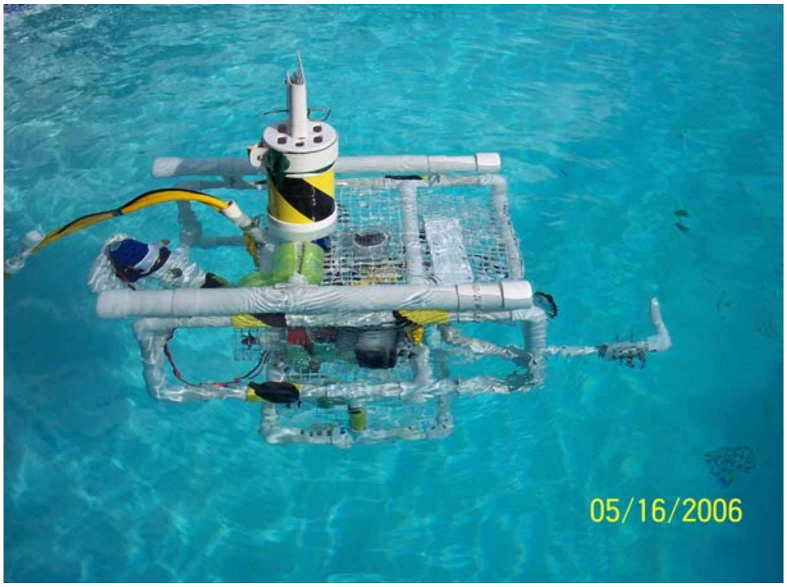
Appendix C: Thruster Testing Data Haltom High School Robotics 2006

Motor	Prop	Pos	For /Rev	Current	Dist A	Dist B	Force A	Force B
Rule 500	Tra 1584	A	Forward	3.5 A	50 cm	57 cm	4.0 N	3.5 N
	Tra 1584	B	Forward	3.5 A	40 cm	57 cm	5.0 N	3.5 N
	Tra 1584	C	Forward	3.5 A	30 cm	57 cm	7.0 N	3.7 N
	Tra 1584	D	Forward	3.5 A	20 cm	57 cm	9.0 N	3.2 N
Avg				3.5 A				3.48 N
Rule 500	Tra 1584	A	Reverse	3.5 A	50 cm	57 cm	2.0 N	1.8 N
	Tra 1584	B	Reverse	3.5 A	40 cm	57 cm	2.5 N	1.8 N
	Tra 1584	C	Reverse	3.5 A	30 cm	57 cm	3.0 N	1.6 N
	Tra 1584	D	Reverse	3.5 A	20 cm	57 cm	4.0 N	1.4 N
Avg				3.5 A				1.65 N
Atwood	n/a	A	Forward	>15 A	50 cm	59 cm	9.0 N	7.6 N
In-line	n/a	B	Forward	>15 A	40 cm	59 cm	12.0 N	8.1 N
Blower	n/a	C	Forward	>15 A	30 cm	59 cm	14.0 N	7.1 N
	n/a	D	Forward	>15 A	20 cm	59 cm	25.0 N	8.5 N
Avg				> 15 A				7.83 N
Atwood	n/a	A	Reverse	>15 A	50 cm	59 cm	2.5 N	2.1 N
In-line	n/a	B	Reverse	>15 A	40 cm	59 cm	3.0 N	2.0 N
Blower	n/a	C	Reverse	>15 A	30 cm	59 cm	4.5 N	2.3 N
	n/a	D	Reverse	>15 A	20 cm	59 cm	7.0 N	2.4 N
Avg				> 15 A				2.20 N
SeaRaider	Tra 1584	A	Forward	7.5 A	50 cm	56 cm	8.0 N	7.1 N
Turbo800	Tra 1584	B	Forward	7.5 A	40 cm	56 cm	11.0 N	7.9 N
	Tra 1584	C	Forward	7.5 A	30 cm	56 cm	13.0 N	7.0 N
	Tra 1584	D	Forward	7.5 A	20 cm	56 cm	20.0 N	7.1 N
Avg				7.5 A				7.28 N
SeaRaider	Tra 1584	A	Reverse	7.5 A	50 cm	56 cm	3.5 N	3.1 N
Turbo800	Tra 1584	B	Reverse	7.5 A	40 cm	56 cm	4.5 N	3.2 N
	Tra 1584	C	Reverse	7.5 A	30 cm	56 cm	6.5 N	3.5 N
	Tra 1584	D	Reverse	7.5 A	20 cm	56 cm	8.5 N	3.0 N
Avg				7.5 A				3.20 N
SeaRaider800	Tra 1584	B	Forward	7.5 A	40 cm	56 cm	20.0 N	14.29 N
With thrust tube	Tra 1584	C	Forward	7.5 A	30 cm	56 cm	26.0 N	14.00 N
Avg				7.5 A				14.15 N
SeaRaider800	Tra 1584	B	Reverse	7.5 A	40 cm	56 cm	3.50 N	2.50 N
With thrust tube	Tra 1584	C	Reverse	7.5 A	30 cm	56 cm	4.67 N	2.50 N
Avg				7.5 A				2.50 N
Rule 500	Octura1250	A	Forward	2.5 A	50 cm	56 cm	4.00 N	3.57 N
Rule 500	Octura1250	B	Forward	3.0 A	40 cm	56 cm	5.00 N	3.57 N
Rule 500	Octura1250	C	Forward	2.5 A	30 cm	56 cm	7.00 N	3.75 N
Rule 500	Octura1250	D	Forward	2.5 A	20 cm	56 cm	10.00 N	3.57 N
Avg				2.6 A				3.62 N
Rule 500	Octura1250	A	Reverse	2.5 A	50 cm	56 cm	2.00 N	1.79 N
Rule 500	Octura1250	B	Reverse	2.5 A	40 cm	56 cm	3.00 N	2.14 N
Rule 500	Octura1250	C	Reverse	2.5 A	30 cm	56 cm	4.00 N	2.14 N
Rule 500	Octura1250	D	Reverse	2.5 A	20 cm	56 cm	5.50 N	1.96 N
Avg				2.5 A				2.01 N

Torque = Force x Distance
(Force A) x (Distance A) = (Force B) x (Distance B)

$$(\text{Force B}) = \frac{(\text{Force A}) \times (\text{Distance A})}{(\text{Distance B})}$$

Appendix D: ROV Specification Sheet



Total Weight		12.15 kg
Main Frame	Length	63.00 cm
	Width	42.00 cm
	Height	27.00 cm
Pay Load Frame	Length	33.00 cm
	Width	36.50 cm
	Height	17.50 cm
Static Buoyancy	Length	63.50 cm
	Diameter	4.86 cm
	Volume	1175.00 cm^3
	Buoyancy per tube	9.10 N Total = 18.20 N
Variable Buoyancy	Height	18.00 cm
	Diameter	11.00 cm
	Maximum Volume	1709.73 cm^3
	Maximum Buoyancy	13.70 N
Large Thrusters	Flow	3030 Liter / hour
	Forward Thrust	14.15 N
	Reverse Thrust	2.50 N
	Current Draw	7.5 Amp
Small Thrusters	Flow	1890 Liter / hour
	Forward Thrust	3.50 N
	Reverse Thrust	1.65 N
	Current Draw	3.50 Amp
Performance	Forward Speed	0.123 m/s
	Reverse Speed	0.094 m/s
	Max Diving Speed	0.145 m/s
	Max Surfacing Speed	0.138 m/s

Appendix E: Determination of Static Buoyancy

Mass of ROV	= 12.23 kg
Mass of ROV in Water	= 1860.00g =1.86 kg
Weight of ROV in Water	= (mass) x (9.81 m/s^2) = 18.21 N
Weight of water displaced	= ($1cm^3$ = 1 g)
Mass of Buoyancy Tube	= 245.00 g = 0.245 kg
Length of Buoyancy Tube	= 63.00 cm
Diameter of Buoyancy Tube	=4.86 cm
Volume of Buoyancy Tube	V = (3.14) x ($radius^2$) x (length)
	V = (3.14) x $(4.86cm/2)^2$ x (63.00 cm) = 1169 cm^3
	Accounting for end caps = 1175 cm^3
Weight of water displaced	= ($1cm^3$ = 1 g) = 1175 g = 1.175 kg
Buoyant Force on Tube	= (weight of water displaced by tube) x (9.81 m/s^2)
	= (1.175 kg) x (9.81 m/s^2)
	= 11.50 N
Weight of Buoyancy Tube	= (mass of tube) x (9.81 m/s^2)
	= (0.245 kg) x (9.81 m/s^2)
	= 2.40 N
Net Buoyancy of Tube	= (Buoyant Force on Tube) – (Weight of Tube)
	= 11.50 N – 2.40 N
	= 9.10 N
To Achieve Neutral Buoyancy	Weight of ROV in Water = Net Buoyancy
	(18.21 N) = (2 tubes) (9.10 N)
	18.21 N = 18.20 N

Appendix F: Determination of Speed:

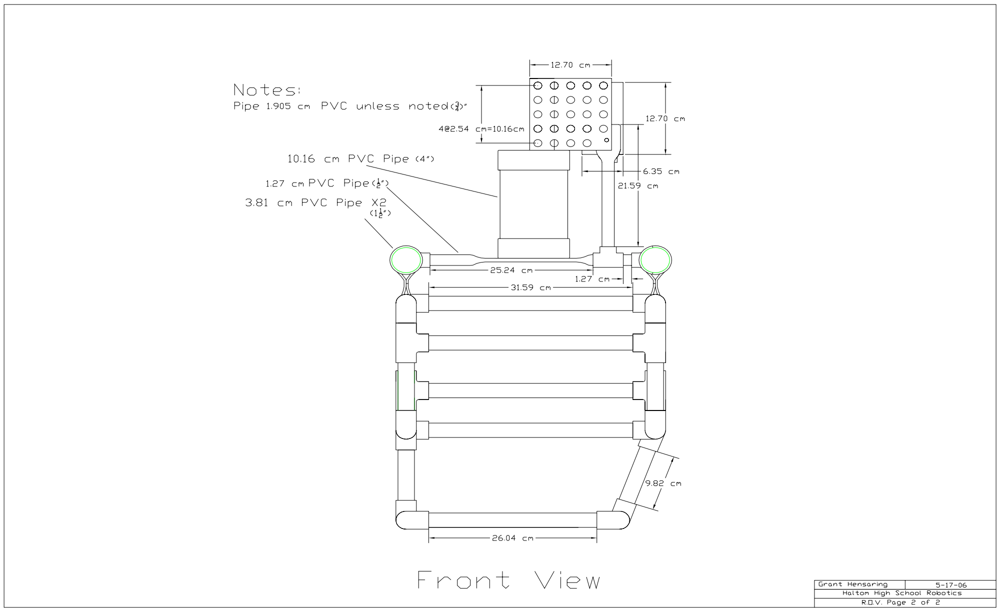
The underwater speed of the ROV was measured during pool trials. To measure the forward speed a 5.00 m course was created. Markers were place on the pool bottom. Timing began when the front of the ROV reached the first marker and ended when the front of the ROV reached the second marker. The speed of the ROV when diving and surfacing was also tested. All tests were conducted in a pool with a maximum depth of 3.00 m.

Trial	Direction	# Thrusters	Distance (m)	Time (s)	Speed (m/s)
1	Forward	2	5	42.00	0.119
2	Forward	2	5	40.20	0.124
3	Forward	2	5	39.43	0.127
4	Forward	2	5	40.38	0.124
5	Forward	2	5	40.88	0.122
Average	Forward	2	5	40.58	0.123
1	Reverse	3	5	57.03	0.088
2	Reverse	3	5	49.29	0.101
Average	Reverse	3	5	53.16	0.094
1	Dive	2	3	22.77	0.132
2	Dive	2	3	19.60	0.153
3	Dive	2	3	19.64	0.153
Average	Dive	2	3	20.67	0.145
1	Dive	1	3	22.36	0.134
2	Dive	1	3	21.96	0.137
3	Dive	1	3	21.55	0.139
Average	Dive	1	3	21.96	0.137
1	Surface	1	3	22.60	0.133
2	Surface	1	3	21.10	0.142
3	Surface	1	3	23.77	0.126
Average	Surface	1	3	22.49	0.133
1	Surface	2	3	22.23	0.135
2	Surface	2	3	21.33	0.141
3	Surface	2	3	21.82	0.137
Average	Surface	2	3	21.79	0.138

Appendix G: Determination of Buoyancy Constants

A number of different size PVC pipes where measured to determine the net buoyancy per cm of length. These values can then be used to determine the length of a particular size pipe necessary to achieve neutral buoyancy. The creation of this chart will greatly assist the Haltom Team in the future.

A	B	C	D	E	F	G	H	I
Type of Pipe	Mass/cm of pipe (g /cm)	Weight of pipe (B/1000)*(9.81) Force Down (N/cm)	Diameter of pipe (cm)	Radius of pipe D / 2 (cm)	Volume/cm of pipe V=(3.14)* r^2h (cm^3 / cm)	Displaced Weight $1cm^3$=1g (g)	Weight of Water Displaced (G/1000) *(9.81) (N / cm)	Net Buoyancy H - C (N / cm)
.127cm	2.33	0.023	2.16	1.08	3.66	3.66	0.036	0.013
.191cm thin	1.88	0.018	2.65	1.33	5.55	5.55	0.054	0.036
.191cm thick	3.15	0.031	2.65	1.33	5.55	5.55	0.054	0.023
2.54cm thin	2.52	0.025	3.33	1.67	8.76	8.76	0.086	0.061
2.54cm thick	4.70	0.046	3.33	1.67	8.76	8.76	0.086	0.040
3.81cm thin	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
3.81cm thick	3.89	0.038	4.86	2.43	18.54	18.54	0.182	0.144
5.08cm thin	6.47	0.063	6.00	3.00	28.26	28.26	0.277	0.214
5.08cm thick	10.51	0.103	6.00	3.00	28.26	28.26	0.277	0.174
7.62cm thin	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
7.62cm thick	15.35	0.150	8.95	4.48	63.02	63.02	0.618	0.468
10.16 cm thin	12.36	0.121	10.70	5.35	89.87	89.87	0.882	0.761
10.16 cm thick	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Foam Pool Noodle	0.597	0.006	6.60	3.30	106.83	106.83	1.048	1.042


Notes:
Pipe 1.905 cm PVC unless noted (¾")
12.70 cm
12.70 cm
4@2.54 cm=10.16cm
10.16 cm PVC Pipe (4")
6.35 cm
1.27 cm PVC Pipe (½")
21.59 cm
3.81 cm PVC Pipe X2 (1½")
25.24 cm
1.27 cm
31.59 cm
9.82 cm
26.04 cm
Front View
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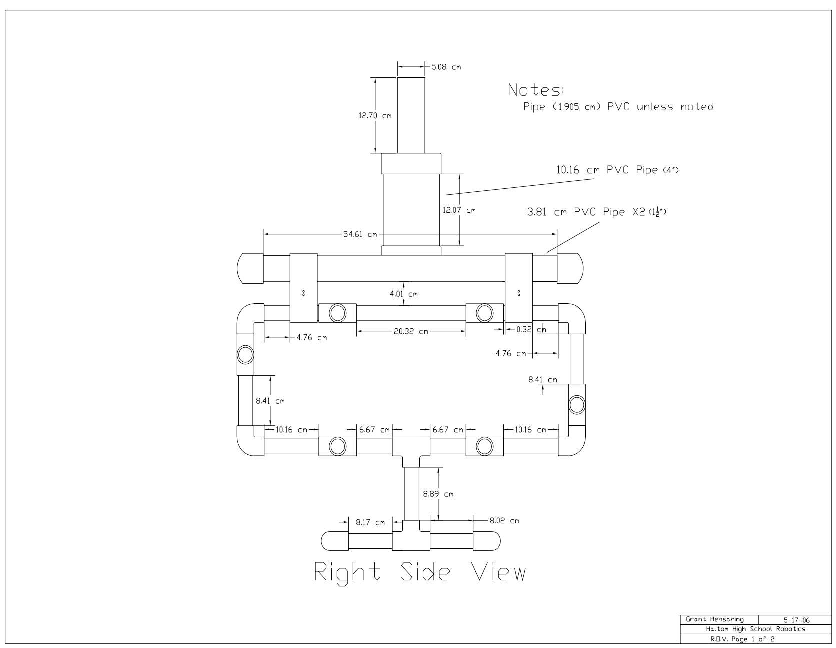
5.08 cm
12.70 cm
Notes:
Pipe (1.905 cm) PVC unless noted
10.16 cm PVC Pipe (4")
12.07 cm
3.81 cm PVC Pipe X2 (1½")
54.61 cm
4.01 cm
4.76 cm
20.32 cm
0.32 cm
4.76 cm
8.41 cm
8.41 cm
10.16 cm
6.67 cm
6.67 cm
10.16 cm
8.89 cm
8.17 cm
8.02 cm
Right Side View
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