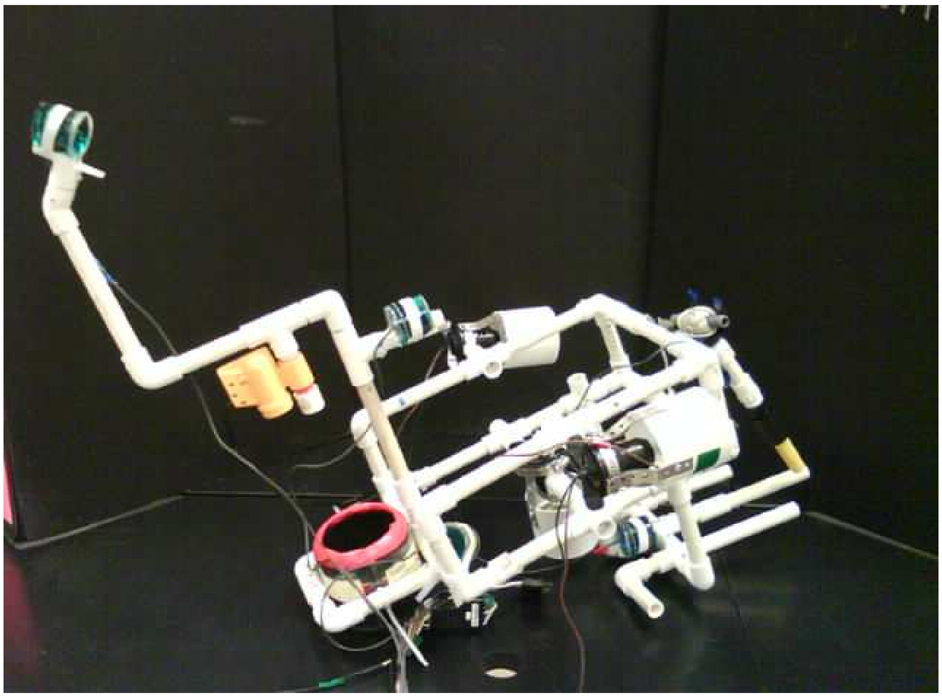
Technical Report

Submitted April 17, 2009

CAMS Ranger ROV Team
California Academy of Mathematics and Science
1000 E. Victoria Street Carson, CA 90747

2009 MATE Southern California ROV Fly-Off
May 2, 2009



ROV Name: S.S. Minnow
CAMS Ranger ROV

Team Members:
Captain: Gabriel Acuna
Tyler Anderson, Andrew Badakhasian,
Brandon Lam, Cristina Lopez,
Virginia Montalvo, Mohammed Salih, Stephanie Samson
Advisors: Thomas Jett and Cindy Bater

Abstract

A ROV (Remotely Operated Vehicle) is an unmanned apparatus that is used to perform tasks in environments that are dangerous for humans to operate in. The CAMS (California Academy of Mathematics and Science) ROV team was tasked with the design and construction of a ROV that could complete the mission at hand. The ROV was built in phases, each phase an individual task within the mission. Each phase ended with a new tool for the final ROV to use during the mission. From here, the ROV brought together the tools completed from each phase and built a frame around the final tools. The frame itself was built from Polyvinyl Chloride (PVC) pipe and was wired to a tether. A tether is a grouping of wires that functions as the connection between the operator and the ROV. Finally, this tether was connected to a control box, which serves as the control interface for the pilot. This project stayed well under budget, since most of the ROV's parts were recycled from existing ROVs no longer in service. The CAMS ROV team competed in the South California Fly Off at Long Beach City College.

Table of Contents

1 | Budget/Expense Sheet

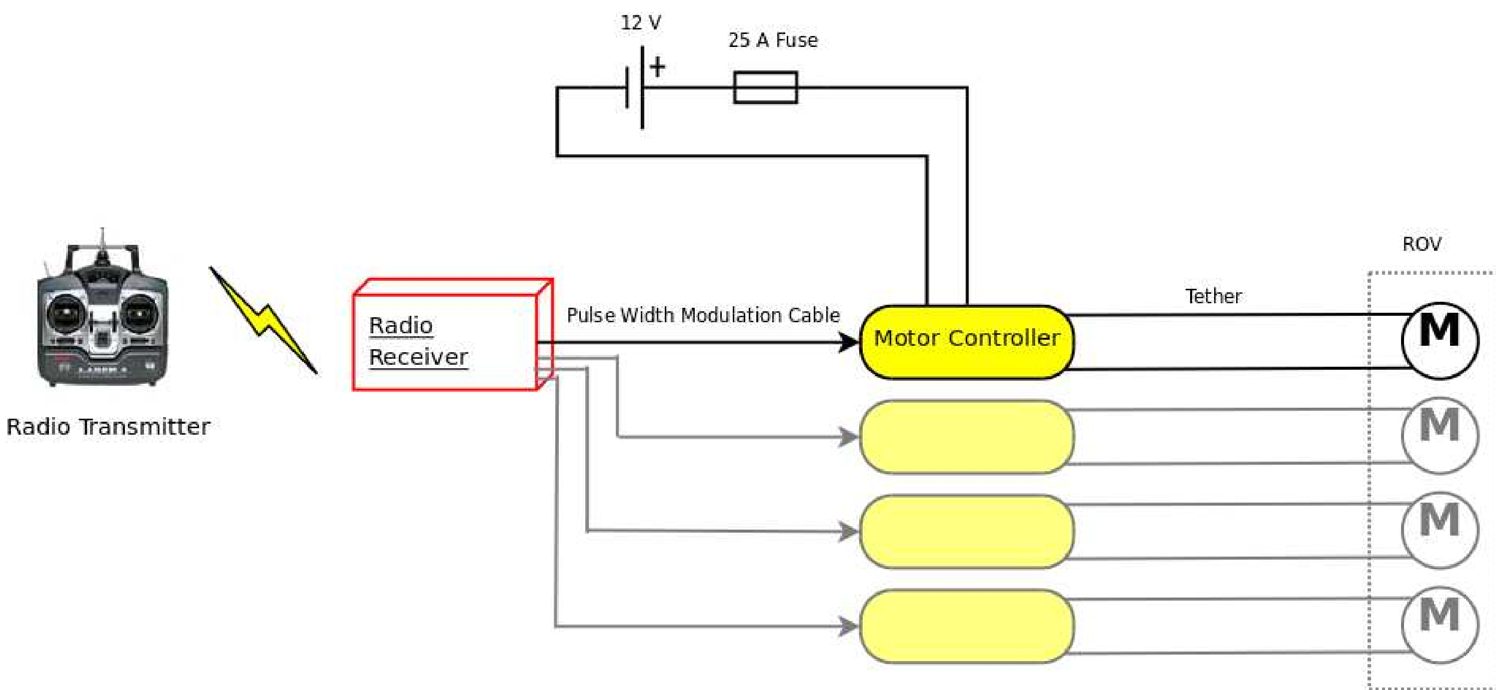
	Item	Source	Quantity	Price Per Unit	Total Value
Structure	½ inch (1.27 cm) PVC Fittings –Tees	CAMS ROV Inventory	9	$0.29	$2.61
	½ inch (1.27 cm) PVC Fittings –90 Degree Elbows	CAMS ROV Inventory	11	$0.22	$2.42
	½ inch (1.27 cm) PVC Fittings –Cross	CAMS ROV Inventory	8	$0.80	$6.40
	½ inch (1.27 cm) PVC Fittings –45 Degree Elbow	Home Depot	2	$0.46	$0.92
	½ inch (1.27 cm) PVC Fittings –Couplings	CAMS ROV Inventory	5	$0.16	$0.80
	½ inch (1.27 cm) PVC Fitting – 90 Degree Side Outlet Elbows	CAMS ROV Inventory	6	$1.18	$7.08
	½ inch (1.27 cm) PVC Fitting –PVC Male Adaptor	Home Depot	6	$0.34	$2.04
	½ inch (1.27 cm) PVC pipe	CAMS ROV Inventory	6 meters	$0.37/ ft.	$2.22
	½ (1.27 cm) inch PVC Fitting –End Cap	CAMS ROV Inventory	1	$0.27	$0.27
	Self-Tapping Screws (100 pack)	Home Depot	1	$7.87	$7.87
	Plumber's Tape (3 meter roll)	Home Depot	1	$3.23	$3.23
	Electrical Tape (assorted colors)	CAMS ROV Inventory	1	$3.94	$3.94
	3 inch (7.62 cm) ABS Pipe Coupling	Home Depot	1	$1.67	$1.67
	11.5 cm diameter Plastic Trail Mix Jar	Donated	1	$0.00	$0.00
	12 oz (340.2 grams) black spray paint can	CAMS ROV Inventory	1	$3.56	$3.56
	12 oz (340.2 grams) red spray paint can	CAMS ROV Inventory	1	$3.56	$3.56
	8 inch (20.32 cm) Nylon Zip Ties (100 pack)	Home Depot	2	$2.95	$5.90
			Subtotal		$54.49
Control System	Hitec Laser 6 FM 75MHz Radio System	Trossen Robotics	1	$134.99	$134.99

	Sabertooth dual 10A motor driver/controller for Radio Control	Dimension Engineering	2	$64.99	$129.98
	Dual 6 Position Bus Bar	Radio Shack	1	$.9.49	$9.49
	5-Amp Inline Fuse Holder	Radio Shack	1	$2.69	$2.69
	Auto-Reset Fuse 20A			$4.95	
	5 ft (1.54 meters) Red 14 Gauge Wire	CAMS ROV Inventory	1.54 meters	$0.66/ meter	$1.00
	5 ft (1.54 meters) Black 14 Gauge Wire	CAMS ROV Inventory	1.54 meters	$0.66/ meter	$1.00
	18 cm x 18 cm x 18 cm Cardboard Box	Donated	1	$0.00	$0.00
			Subtotal		$279.15
Tether	16 AWG Speaker Wire	CAMS ROV Inventory	50 meters	$17.95/ 50 meters	$17.95
	Pool Noodles	Target	2	$1.50	$3.00
			Subtotal		$20.95
Sensors	Diesel Audio NS-CAM-1 Cameras	CAMS ROV Inventory	5	$50.00	$250.00
	Underwater Black/White Camera and Monitor	CAMS ROV Inventory	1	$100.00	$100.00
			Subtotal		$350.00
Payloads	½ inch (1.27 cm) Insert T Threaded	CAMS ROV Inventory	1	$3.49	$3.49
	½ inch Male Adaptor	CAMS ROV Inventory	1	$0.34	$0.34
	½ inch (1.27 cm) – ¾ inch (1.91 cm) MHT Adaptor	CAMS ROV Inventory	1	$1.22	$1.22
	Hose Nozzle	CAMS ROV Inventory	1	$2.59	$2.59
			Subtotal		$7.64
Propulsion	Rule 27D Marine Rule 1100 Marine Bilge Pump	Amazon.com	4	$31.19	$124.76
	Master Airscrew 3-Blade Propeller	CAMS ROV Inventory	4	$4.20	$16.80
	Propeller Adaptors	CAMS ROV Inventory	4	$3.00	$12.00
	Locktite	CAMS ROV Inventory	1	$4.00	$4.00
	Hose Clamps	CAMS ROV Inventory	8	$0.44	$3.52
			Subtotal		$161.08
Buoyancy System	3 inch (7.62 cm) ABS Pipe	CAMS ROV Inventory	2 meter	$2.82/ meter	$5.64

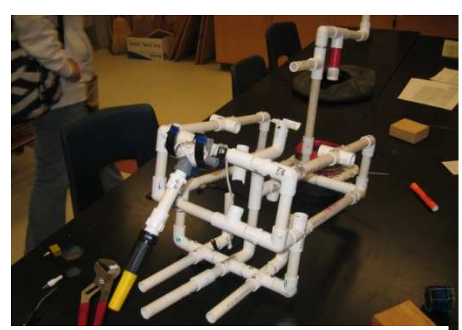
			Subtotal		$5.64
Construction of Task	3 inch (7.62 cm) ABS Pipe	CAMS ROV Inventory	1 meter	$2.82/ meter	$2.82
	3 inch (7.62 cm) End Cap	Home Depot	5	$5.21	$26.05
	3 inch (7.62 cm) Knockout End	Home Depot	5	$0.30	$1.50
	3/8 inch by 3-11/16 inch Long Style U-bolt	Ace Hardware	5	$1.76	$8.80
	½ inch (1.27 cm) PVC Fittings – Tees	CAMS ROV Inventory	19	$0.29	$5.51
	½ inch (1.27 cm) PVC Fittings – Cross	CAMS ROV Inventory	3	$0.80	$2.40
	½ inch (1.27 cm) PVC Fittings – 90 Degree Elbows	CAMS ROV Inventory	16	$0.22	$3.52
	½ inch (1.27 cm) PVC Fittings – 45 Degree Elbows	CAMS ROV Inventory	14	$0.46	$6.44
	½ inch (1.27 cm) PVC Fitting – 90 Degree Side Outlet Elbows	CAMS ROV Inventory	5	$1.18	$5.90
	½ inch (1.27 cm) PVC Fitting –PVC Male Adaptor	Home Depot	5	$0.34	$1.70
	½ inch (1.27 cm) PVC Fitting –Couplings	CAMS ROV Inventory	8	$0.16	$1.28
	½ inch (1.27 cm) PVC Fitting –End Cap	CAMS ROV Inventory	1	$0.27	$0.27
	black, blue, and/or gray milk crates (approx. 32 cm long by 32 cm wide by 27 cm tall)	Donated	9	$0.00	$0.00
	2 pound Soft Dive Weights	CAMS ROV Inventory	3	$10.82	$32.46
	Capital Letters A-E	Home Depot	5	$1.29	$6.45
	Velcro	Michael's	0.6 meters	$3.29	$3.29
	5/16 inch (8 mm)lock washer	CAMS ROV Inventory	5	$0.16	$0.80
	5/16 inch (8 mm) nut	CAMS ROV Inventory	6	$0.10	$0.60
	2.5 inch (5.46 cm) brass hinge	CAMS ROV Inventory	2	$2.83	$2.83
	5 gallon Bucket lid	Home Depot	1	$3.79	$3.79
	5/16 inch (8 mm) by 6 inch (15.24) bolt	Ace Hardware	1	$ 1.89	$ 1.89

	1/8 inch (3.2 mm) diamond braid polypropylene rope	Ace Hardware	16 meters	$7.99/ 30.5 meters	$4.20
	¾ inch (1.9 cm) plastic mesh	CAMS ROV Inventory	900 cm^2	$ 1.70	$ 1.70
	3 inch (7.62 cm) ABS		3 cm	$1.67	$1.67
			Subtotal		$125.87
			Grand Total:		$1,004.82

2 | Electrical Schematic



3 | Design Rationale


Cristina Lopez looks over the frame

3.1. Frame Design

The ROV is designed to be cost-effective, reliable, and maneuverable. A great percentage of the ROV was built with Polyvinyl Chloride (PVC). We decide to use PVC for the major part of our vehicle because it is lightweight, relatively durable, and cheap. Four motors are mounted using modified PVC T fittings (for their position and purpose, please refer to the *3.2.*

Propulsion section) and holes are purposely drilled on the PVC frame at certain points to allow the frame to fill completely with water. If the holes are not drilled the ROV would run the danger of having air trapped in different parts of the PVC.

The frame of the vehicle is a rectangular prism with the dimensions 45.72 cm x 30.48 cm x 45.72 cm. The size of the ROV gives us the constancy, practicality, and maneuverability that we need to perform the task with a low risk of vehicle failure. The team added floats (pool noodles) on various parts of the PVC frame to keep the ROV balanced and steady.

Rule 1100 GPH bilge pump

3.2. Propulsion

Four 12 V DC bilge pump motors are used to provide the ROV to be able to give it enough mobility but not too many motors that it will disrupt its stability. There are two motors used for forward and back, the third is used for up and down, and the last one is used for strafing. Each motor provides 3 to 4 Newtons of force and draws 3 amps. The motors are mounted in specific parts of the vehicle using modified PVC Ts and hose clamps. Hose clamps are preferred because they are not only adjustable, but they are also rather durable. Using a Dremel tool, the bilge pump cartridges were cut from their casings (which were used as camera mounts). They were then fitted with propeller adapters. Propeller guards made of 3in ABS pipe were added accordingly.

Bilge pump casings used as camera mounts

3.3. Sensors

Our ROV is equipped with waterproofed cameras as a source of vision from the ROV's perspective. We will have one camera placed faced forward in the middle of the ROV to see the general environment and where the vehicle is heading. The next camera is located on the lower back end of the vehicle to show us our prongs and the end tip of the airline insertion point. Another camera is placed facing the skirt that will mate with the escape hatch. The last camera will be placed facing down so the pilot can see the two pieces of PVC that will open the hatch.

Camera for the transfer skirt

In addition to cameras, the CAMS Ranger ROV utilizes and RV compass. This device is placed in the field of vision of the ROV’s forward-facing camera, allowing the pilot to view whenever the ROV is not balanced.

RV compass

3.4. Buoyancy

The ROV used to have a dual tank variable buoyancy system coupled with pool noodles. This proved to be troublesome, so we switched over to sealed 3in ABS air tanks. Our reasoning behind choosing ABS is that it doesn't compress under the pressure of the water. We discovered we were not able to surface by ourselves at 12 feet underwater because our pool noodles would compress and make us negatively buoyant.

3.5. Control System

This year's control system is designed for simplicity of construction and ease of use. We purchased a 6 channel radio control system designed for use with remote control airplanes and adapted it for use with an ROV. The system consists of a handheld transmitter and a receiver that can control several devices using pulse width modulation. Instead of attaching servo motors to the receiver we plugged in 4 fully reversible motor controllers to drive the ROV's four propulsion motors. Each motor controller is rated for 10 amps continuous draw. The receiver and motor controllers are kept on shore and are connected to the motors on the ROV through the tether. In the future, it may be possible to waterproof the system, allowing a completely "wireless" ROV.


Tyler Anderson builds the control box

The transmitter has dual joysticks plus two more auxiliary controls, allowing us to operate the four drive motors plus to additional devices if required. Five of the six channels are fully proportional, allowing the pilot to throttle the motors for precise maneuvering. The left joystick controls the vertical and lateral (side to side) motors while the right joystick controls the two forward and back motors. The transmitter we selected includes a feature called "V-Tail mixing" that allows control of airplanes with V shaped tails instead of T shaped tails. This feature conveniently allows us to mix the channels for the two forward and back motors. For instance, when the joystick is pushed forward, both motors engage in the same direction. When the joystick is pushed to the left the right motor spins forward but the left one spins in reverse, thus turning the ROV.

4 | Challenges

The team faced many challenges while building the ROV. One of the first challenges we faced was the size of the frame. At first, the team decided to have a large frame in order to best support the payload, cameras, motors, and tools for the task. It wasn't until after we built over half of the frame that we realized that having a smaller frame, allowing the pilot to have more control over the movement of the vehicle, would work better. In addition, we were not sure how many motors to use in order to maximize power and speed efficiency. In the end, we decided on four motors, giving us enough power to move quickly without adding more superfluous weight. After deciding on the number of motors, we had to wire out the control box. Unfortunately, we could not figure out which umbilical wires connected to which motors. This proved problematic because in order to correctly wire the control box, we needed to know which wire led to which motor. Instead of wasting time by following the wire along the entire length of the umbilical, one of the senior members taught the newer members to use a voltmeter to test for connections. Once, the wires were linked with their appropriate motors, the motors were attached to the ROV. The next issue arose during the testing of our cameras when it was discovered that the monitors would not display anything. To correct the problem, we tried different connections and power supplies. Once we found the source of the problem, thanks to a senior member, we fixed it and continued on to camera placement decisions. Because we wanted our pilot to have optimum view points, we had to reposition cameras often. During this process, we found that motors and other tools often blocked ideal views. In order to find the best spots, we moved the cameras around often. In some cases we built special mounts to provide for a good view.

Our final issue was balancing our ROV so that it would not tip in any given direction. Because of the skirt and turning tool, we found the ROV was back heavy; thus, to fix the problem, we put pool noodles (tubular foam flotation devices used in swimming pools) around the PVC surrounding the skirt. We also added weight to the front in order to further balance the ROV. The next problem that was encountered during the build and test stages was the lack of a way to ascend and descend in the pool. To solve the problem we created a variable buoyancy system to assist the ROV in ascension and descent ion in the pool. The variable buoyancy system was compromised of two water wings (floatation devices worn around the arms in pools) attached to the top of the ROV. An airline was attached to both water wings to allow them to be inflated independently. After the variable buoyancy system was tested, it proved to be a bad idea due to the water wings collapsing upon inflation at 12 feet in the test pool. To solve the new problems presented by the variable buoyancy system a new buoyancy system was designed and built around the concept of the ballast tank. The controlled flow of water in a study tank would be more efficient in order to achieve the goals to ascend and descend on command. The tank would not collapse on itself at depths such as nine to twelve feet. The ballast tank is build using ABS pipe in order to maintain weight.

Finally, although there were many challenges during the ROV building process, working as a team to surpass our difficulties improved group moral and increased individual understanding of ROVs.

5 | Troubleshooting

Many problems can occur while operating the ROV that will prevent it from running properly and stop it from performing the tasks. The ROV can decrease in movement (forward, back, up, down) and this problem can be caused by a variety of reasons. Battery connections, motors, and fuses can be probable reasons for the problem and we will each one to find the source of the problem. The ROV can also be too heavy or too light. If this problem would occur we attach floats around the PVC if it was too heavy. We would re-test the ROV in water and if it would be too light we would then add weights to both sides of the vehicles so it won't tip over.

The team's primary troubleshooting technique is solution synthesis. When a problem occurs, the team members who have encountered the problem call on the other team members for a round of discussion. The problem is analyzed systematically and possible causes are identified. As solutions are pitched and built upon, an optimal solution is synthesized. The most common solution was usually a combination of improvisation and optimization; for example, if there was a part shortage, the team would use improvised parts or even create a better design that did not require the part in question. Also, each team member is not limited to one specific role: every person is capable of assisting in the creation and/or optimization of any system. Should the team ever come to an impasse, the decision of what solution to use falls to a popular vote between two solutions, moderated by a neutral party.

6 | Lessons Learned

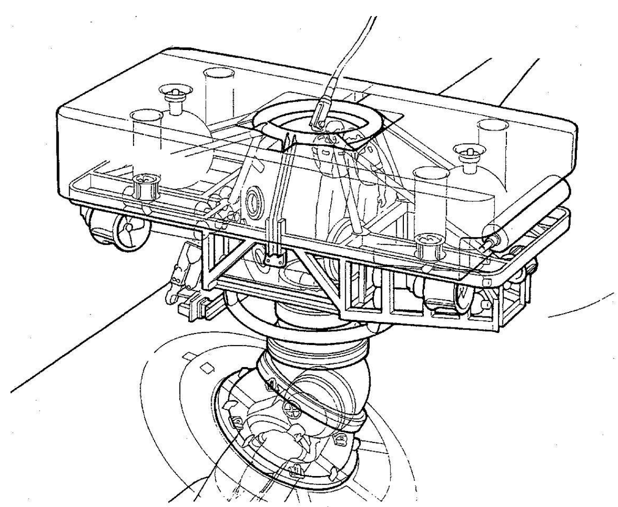
The 2009 Ranger ROV team learned new lessons in design, construction, organization, and team work. In design, the team learned to make many versions of one design with a minor alteration in each, essentially following a suggested engineering design process (please see the appendices for this document). The different alterations were a way to see the flaws and strengths of a design. In each design the team also learned to incorporate as many ideas as possible and then eliminate as necessary to suit the tasks demands. In construction, the main lesson the team learned is to "measure twice, cut once" (when the wrong measurement is cut, the cut piece must be replaced). The team also learned to organize all meeting dates to include enough time for design, construction, and testing of the ROV. Most importantly the team learned to work together to complete the most daunting of tasks. Above all other lessons learned, one lesson that should always be taken into consideration is "safety first."

7 | Future Improvements

Major improvements to the ROV can be made by having a more extensive design process, maybe one spanning into the summer the year before each competition. The CAMS Ranger ROV is constructed out of PVC and held together with screws; perhaps an improvement would be the inclusion of additional support materials to create a stronger frame while allowing for more space for articulation, instrumentation, and propulsion systems as well as sensors. Also, if the team is able to, in the future, cheaply and effectively waterproof motors/servos, the articulation can became more sophisticated. This could especially benefit the ROV's ballast system (please refer to the *Design Rationale* portion of this document for details), eliminating the great effort necessary to manually pump air into the system (also, this method makes the ballast system rather difficult to control to inexperienced operators).

8 | Submarine Rescue System Research

Rescue ROVs, such as the REMORA, help save the lives of unfortunate crewmen in sunken submarines. The REMORA is the Australian Submarine Rescue Vehicle (ASRV) delivered by OceanWorks International and used by the Royal Australian Navy. Despite its mishap in 2003, the REMORA and its suite as well as the knowledge gained from its usage help to brighten hopes for survival of passenger of sunken submarines and push research and development of submarine rescue



systems forward (Mackenzie, “Australia's Submarine Rescue Vehicle In Dock”).

The highly-portable REMORA is linked to the surface control by and is powered with 440V through a 914m electro-fiber optic umbilical. Able to function in depths in excess of 500m and carry six survivors, the REMORA is able to travel to sunken submarines to execute its primary rescue functions. By mating to submarines to transfer up to six survivors (with a three hour rescue cycle time) and/or delivering Emergency Life Support Systems (ELSS) Pods, the REMORA helps to increase survival prospects of victims of submarine accidents or malfunctions (OceanWorks International, “Submarine Rescue Systems”). The REMORA’s skirt can mate with a submarine at up to 60 degrees (π/3 radians), a relatively extreme angle. After survivors have been rescued, the REMORA’s featured Personnel Pressure Suite (PPS) provides a safe decompression environment from the dangerous, high-pressure situation from which the sunken submarine’s crew was rescued (“Research – Submarine Rescue Systems”)(Royal Australian Navy, “Submarine Rescue Vehicle”).

Artist’s rendering of the REMORA. Picture courtesy of http://www.idpm.biz/downloads/Remora_Fact_Sheet.pdf

Realistically, the CAMS Rangers ROV cannot truly “transfer” survivors into its interior into a safe zone or decompression chamber though it can still deliver “necessary supplies.” Unlike the REMORA, however, the CAMS Ranger ROV can only carry about two ELSS pods at once in comparison to the REMORA’s 12. Additionally, due to budget and time constraints, the mating skirt of the CAMS Ranger ROV cannot mate at variable angles. The CAMS Rangers ROV is of a considerably smaller scale but is still relatively portable like the REMORA. Regardless of these differences, the CAMS Rangers’ ROV’s primary functions include transferring ELSS Pods and mating to “transfer” survivors.

The REMORA. Photo courtesy of http://www.defencejobs.gov.au/submariners

9 | Reflections

Planning, designing, and building the ROV was a wonderful, exciting, and knowledgeable experience for all the members of the CAMS Ranger team. The experience was very informative because we had four new members added to our group of eight that which motivated us to teach them and explain to them in detail our tasks as a group and as competitors. The new members learned group work and the importance of brainstorming ideas. The other members had the opportunity to be presented with new perspectives and concepts on how to go about solving problems. All the members of the team were provided with hands on experiences because the team went about solving tribulations as a group without excluding anyone. The competition was a motivation that propelled all the members to think of new and interesting ideas. At the beginning, the experience seemed like a long and frustrating journey because of all the planning troubles; however, at the end, every member of the CAMS Ranger team felt that participating was enjoyable and would encourage anyone else to join.

10 | References

Works Cited

Mackenzie, Christina. "Australia's Submarine Rescue Vehicle In Dock." Aviation Week. 30 Dec. 2008. 17 Apr. 2009 <http://www.aviationweek.com/aw/blogs/defense/index.jsp?plckController=Blog&plckScript=blogScript&plckElementId=blogDest&plckBlogPage=BlogViewPost&plckPostId=Blog%3A27ec4a53-dcc8-42d0-bd3a-01329aef79a7Post%3A8ca741a3-daa0-4ac1-b8cf-241204afdaf5>.

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"Research - Submarine Rescue Systems." Nuytco Research Ltd. 17 Apr. 2009.

11 | Acknowledgements

The CAMS Ranger team has learned and has overcome many troubles over the past few months. The team could not have accomplished everything without the support of friends and family. The CAMS Ranger ROV team would like to thank the following people:

- The MATE (Marine Advanced Technology Education) Center for giving us the opportunity and privilege to participate
- Mr. Jett, our mentor, who advices and guides the team.
- he school staff and PTSO for donating supplies and giving the team the funds to build and compete.
- Mrs. Cindy Bater for assisting us and helping us manage our budget.
- Mrs. Cathy Arakaki for input regarding the management of the team and for providing supplies for the tasks.

The help of our mentors, sponsors, and parents have propelled the CAMS Ranger members to where they are now. The ROV team gives thanks to these people who have made it possible.

Meet the Team!

Back Row (Left to Right):
Brandon Lam, Gabriel Acuna, Tyler Anderson
Front Row (Left to Right):
Andrew Badakhasian, Stephanie Samson, Cristina Lopez, Virginia Montalvo
Not Pictured:
Mohammed Salih

Photograph courtesy of Ian Goegebuer

Appendices

ROV Design Process for 2009 Competition

Adapted from Andrew Williams 2007

Design Brief - each step feeds back to the step above when the process breaks down! This means, backing up to the step(s) above is how to really get the project to the final evaluation form.

1) Investigate: Design specifications and physical requirements of each task. Build a mock up of each and understand exactly what the ROV must do for each task.

2) Generate Ideas for completion of each task. Sketch ideas for each way proposed to complete each task (remember top, side and front projections?) Form follows function – KISS

3) Design Synthesis: Look at the requirements in step 1 and propose a sequence in which to complete each for the best score in competition. Match the best fit idea to the completion of each task. Propose how to place and attach each to ROV, Then design frame. At this point, decide how to test each tool or procedure to determine if it is appropriate the complete each task. Draft testing plan for final design(s).

4) Manufacture: This is the first evaluation phase. Here you catch design flaws and /or fantasies that got through the Design syntheses step. Do not spend a lot of time trying to make a bad idea work- go back to steps 3, 2 or 1 as needed. Evaluate the process on paper – you will get better at it each time.

5) Evaluation: Test Plan goes back and includes all steps and also goes in your engineering report for MATE presentation.

6) Engineering report for MATE presentation. Remember, a failed design can be discussed in presentation and the redesign process scores points. Failure is not fatal.