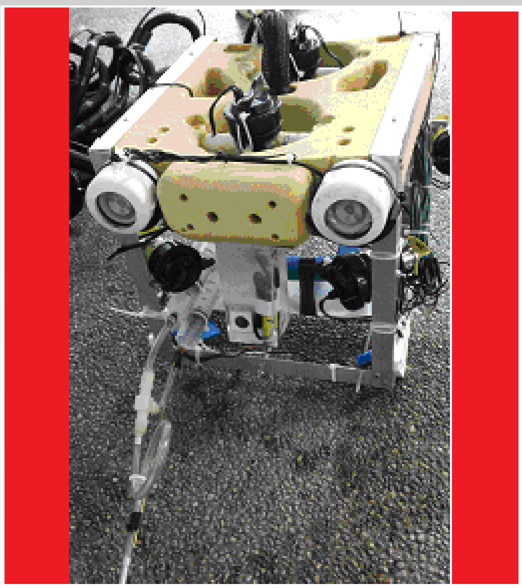
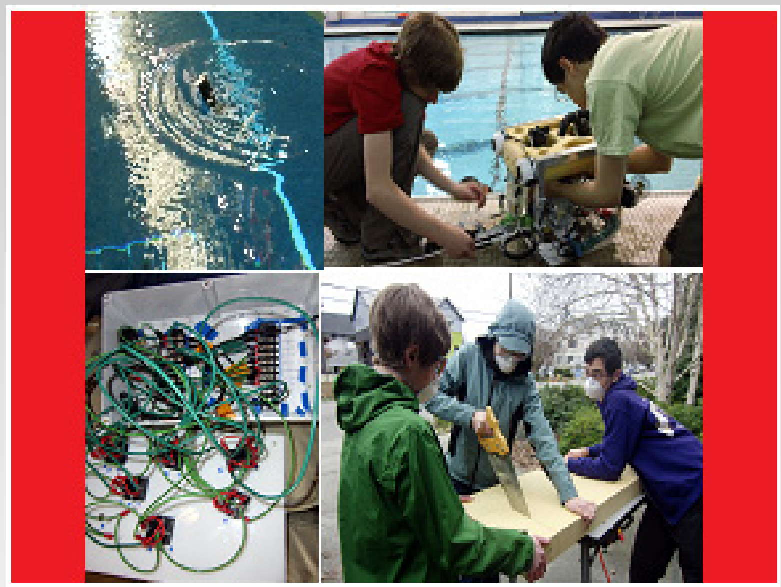
2012 MATE INTERNATIONAL ROV COMPETION
TECHNICAL REPORT ~ RANGER CLASS

AMNO & CO

~THE RUST BUCKET~





Alex Miller: Machinist, Troubleshooter, Pilot

Nicholas Orndorff: Mechanical Engineer and Pilot

Clara Orndorff: CEO, CFO, Electrical Engineer, and Tether Manager

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1. Abstract

We are the AMNO & CO ROV Team and we have 3 years of experience building specialized ROVs. Our name is an acronym for the initials of our first and last names.

We have conducted extensive research pertaining to ROVs and their systems and have used this information in order to assess the *SS Gardner*.

This year's ROV contains some mission related features. In our control system, we use potentiometers in a way that we have never before encountered while reading technical reports from previous years' competitions. In addition, we have a versatile manipulator that can accomplish the surveys required of the *SS Gardner*.

Last summer we were very successful in our fundraising, and throughout the year we solicited and received donations from many professional businesses. We raised enough money to almost cover the entire cost of the project.

We have eliminated many – if not all – of the challenges we were faced with in the 2011 competition and we have done our best with those that arose this year. We know that this year's ROV is better than any we've made before and we hope that it will accomplish the assigned tasks.

2. Team Information

Alex Miller

Company role: Machinist and Troubleshooter
Competition role: Pilot

Alex Miller, 13, is participating in the competition for the third time. He enjoys taking apart electronics, building things, playing cello, skiing, and playing with his dog – team mascot Pekoe. He is in 7th grade at Washington Middle School in Seattle, Washington.

Nicholas Orndorff

Company role: Mechanical Engineer and Research Specialist
Competition role: Pilot

Nicholas Orndorff, 13, is participating in the competition for the 3rd time. He enjoys designing manipulators, reading about ROVs, playing trumpet, playing soccer, and playing with his parakeet, Hoku. He is in 7th grade at Hamilton Middle School in Seattle, Washington.

Clara Orndorff

Company role: CEO, CFO, and Electrical Engineer
Competition role: Tether Manager

Clara Orndorff, 15, is participating in the competition for the third time. She enjoys, playing violin, running, and playing with her parakeet, Hoku. She is in 9th grade at Ingraham High School in Seattle, Washington.

3. Mission Theme

World War II shipwrecks, especially tankers, pose a significant threat to the environment and must therefore be dealt with. They could, at any point in time, release huge amounts of oil that would create an enormous amount of environmental, technical, and economic difficulties. The oil from these wrecks could damage many habitats and could cause many species to become extinct or threatened. There are, however, many challenges in dealing with these shipwrecks.

Figure 1: Oil from a leaking wreck[1]

First of all, many countries claim custody over their wrecks as underwater graveyards[2]. This means that the Japanese government cannot remove a hazardous United States wreck unless the US government grants them the right to handle the wreck. This is unlikely, and, even so, many of the Pacific island nations are without the funding or technology needed to take care of the wrecks. A great example of the required technology is an ROV.

The wrecks must also be handled carefully. Many of them contain unexploded weapons that could still explode if jostled or removed. Other wrecks contain toxic oils, fuels, and

Figure 2: A WWII shipwreck[3]

chemicals that must be entirely removed from the environment.

Also, before a wreck can be cleaned up it must be inspected and declared a threat[4]. This is not a good method – many leaking ships can leak one day and not on the day of inspection, therefore giving negative results on the test. These ships are then left as they were.

Unfortunately, making a shipwreck "safe" is hard, time-consuming, and expensive. Still, making them safe costs less than cleaning up after leaking ships.

4. Design Rationale

This year's ROV, The Rust Bucket, is designed and optimized for the mission tasks pertaining to shipwrecks. We have developed customized systems that can perform the tasks assigned.

4.1 Frame

Our frame is designed to be simple yet functional. We decided on 1" aluminum angle for easy handling and mounting and because it has less mass than other materials such as PVC pipe, which traps water. It is also cheap and durable, as well as more professional and adaptable. We cut the pieces for our frame with a hacksaw and held them together at the joints with stainless steel bolts and lock nuts (Figure 3).

Attached to the bottom of the frame is a pair of skids, optimized for moving across the pool bottom and lowering friction. They are made of HDPE plastic, and they have holes in them so there is less drag for horizontal movement. They help to laterally brace the frame. Without the skids, the dimensions of our frame are 35.5 cm x 30.5 cm x 30.5 cm (see figure 3). The dimensions with the skids are 35.5 cm x 30.5 cm x 33 cm.

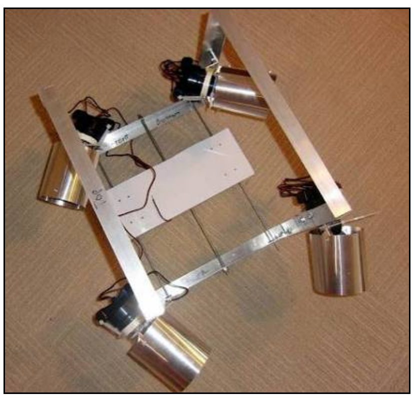

Figure 3: Our frame, with nothing mounted and our first prop guard idea (see 4.3)

4.2 Buoyancy

Based on our experiences with other foams crushing at depth, for buoyancy we used R-3315 Last-A-Foam, a special polyisocyanurate foam generously donated by General Plastics in Tacoma, Washington (see Appendix 3). This is a closed cell rigid foam, meaning that it won't even compress at 100 meters. We shaped the foam with an orbital sander and a jigsaw and mounted it inside the frame in order to produce a nice, compact ROV. It was quite easy to work with and had the consistency of wood. We worked with the foam in two pieces, cutting out semicircles in which to mount the motors. Later, because we had 5.4 kilograms too much of the flotation, we used a hacksaw, a drill, and a file to remove the excess buoyancy (Figure 4).

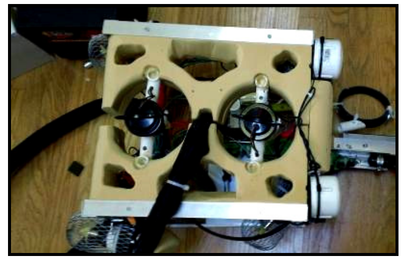

Figure 4: Top view of the flotation

4.3 Propulsion

For propulsion we chose to use bilge pump replacement motor cartridges (Figure 5) because they are already waterproof, easy to mount, and proven effective. Because of the depth of the pool, the up/down function was the most important to us. We used two 1250 gph (4732 Lph) cartridges for these motors and four 750 gph (2839 Lph) cartridges for the forward and backward motors.

Figure 5: A bilge pump replacement motor cartridge

Our motors are in a vectored configuration because we were originally planning to use them for strafing motion. This did not work out

because of the complexity of constructing the required control system. These motors are shrouded with drain guards, a method that works very well (we used drain guards last year too).
We used Octura propellers and Master Airscrew mounts. We also tested the thrust of our motors (Table 1).

Table 1: Our bilge pump specs and measurements at 12 V DC

Motor type	750 gph	1250 gph
Theoretical[1] current (amps)	3.5	3
Actual current[2] (amps)	~4	~3.5
Power[3] (watts)	48	42
Resistance[4] (ohms)	3	3.4
Thrust[5] (kilograms)	0.95	1.2

[1]Theoretical current is the value given for bilge pump cartridges in their intended use (a pump).

[2]Actual current is the value of a bilge pump cartridge's current in its actual use, underwater with a propeller. We measured this with a clamp meter.

[3]We calculated these values according to the rule *Watts = Volts x Amps.*

[4]We found these values using Ohm's Law *Resistance = Volts/Amps.*

[5]We measured the thrust ourselves with a spring scale, uncertainty of ~0.025 kilograms.

4.4 Cameras

We chose to use a camera donated by Supercircuits in Austin, Texas. Our camera was a Sony color board camera (Figure 6) with high resolution, 120 degrees of view, and the capability to see in low light. We found all these functions useful – the low light rating meant we didn't need lights. Although we didn't have to use them, we decided to implement glowsticks – an easy method of obtaining light that didn't require electricity.

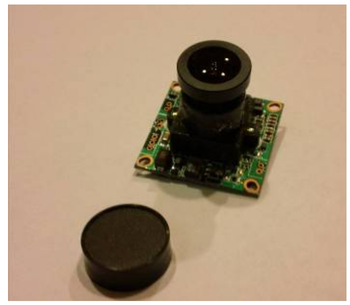

Figure 6: A not yet waterproofed board camera

The trickiest part of using these board cameras was waterproofing them. We broke the connector to one camera by moving it too much while trying to find a good location for it, so we made sure to be more careful with the other one. We mounted both the camera and the connector in a polycarbonate box and filled it with epoxy (Figure 7).
We then mounted the camera on the front, screwed into the foam.

Figure 7: The main camera potted in epoxy

4.5 Control System

As a result of this project, we have come to believe that the control system is the most important system of an ROV. To control our motors we used switches. We considered using joysticks, but we could not find a good way to do so without using microcontrollers, which we did not want to do at this time. In accordance with the mission specs, we have a 25 amp main fuse. We also have a 0.5 amp fuse for our camera.

To control the up and down motors, we used a DPDT, three position, non-momentary switch. We wired both motors together as one in order to minimize the size and weight of our tether. This resulted in a single switch for both motors.

To control the four forward and backward motors we used two DPDT, three position, momentary switches. The switches are momentary and therefore optimized for controlling fine movement. Two of these four motors can be found on each side of The Rust Bucket.

We also have switches for the manipulator (see 4.7), the water sampler (see 4.8), the metal detector (see 4.9) and for our main power.

In order to attain speed control and the ability to hover, we added to our control system two potentiometers (Figure 8) donated by Ohmite in Arlington Heights, Illinois. These potentiometers are wirewound, meaning that each potentiometer is wrapped in wire – the farther the power has to travel along the wire, the less will come out. We have one potentiometer for our two up/down motors, and we have one potentiometer for our four forward/backward motors.

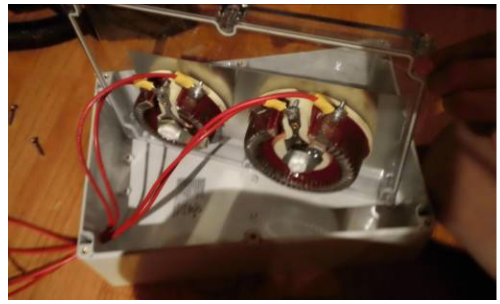

Figure 8: Our potentiometers

We are especially pleased with this design because we have read all the technical reports from the Ranger and Explorer class competitions in the last five or six years. In all this reading we have never seen a team use a single potentiometer for fixed control to more than one motor as we have (several teams did use potentiometers for more than one motor, but they used joysticks with potentiometers, not potentiometers by themselves).

For our up/down motors, the potentiometer is rated to a maximum of 1 ohm and 100 watts. For our forward/backward motors, the potentiometer is rated to a maximum of 1 ohm and 150 watts. This higher wattage is because we have four motors for forwards and backwards, but only two for up and down (see 4.4).

Unfortunately, these potentiometers can get very hot and are constructed from ceramic to withstand this heat. To make sure none of our systems are damaged, we implemented heat sinks, a computer fan, and a piece of aluminum flashing to dissipate the heat (Figure 9).

Figure 9: Close up of the heat sinks and fan

We housed our control system in two boxes donated by Polycase in Avon, Ohio. We used one main box for our switches and a secondary enclosure for our potentiometers. To ease troubleshooting and to improve our organization, the wires from the tether are connected to terminal blocks in the main control box before they reach the switches (Figure 10). We also have a clear control box lid so we can easily see if there are loose wires. Our ROV gets power through fifteen feet of twelve gauge wire with banana snap plugs.

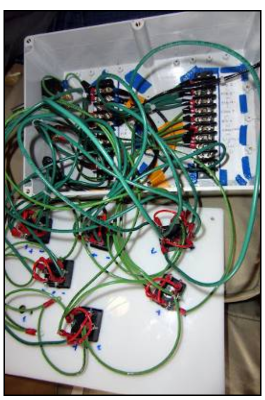

Figure 10: The inside of the control box (unfinished)

4.6 Tether

During previous competitions we have found that it is extremely difficult to find a tether that has the right number of conductors. In addition, commercially available tethers often increase in drag when additional wires or cables are attached to the outside. Because of this we made our own, using split-braid self-wrapping cable sheathing donated by Techflex in Sparta, New Jersey, and wire donated by Harris Electric in Seattle, Washington. This gave us flexibility as to what we could put into the tether. Also, everything would be inside and therefore hydrodynamic.

Our tether contains two 14 gauge conductors, twelve 16 gauge conductors, and a coaxial cable for our cameras. We chose to use the 14 gauge conductors for our up and down motors (see 4.3) because we wanted them to have the most power in order to take us to the bottom and back to the surface quickly.

Our tether is 18.3 meters long. Because it is weighs 10.7 kg, we added some of our R-3315 Last-A-Foam (see 4.2) along its length so it wouldn't affect our driving or our buoyancy. In addition, there is strain relief both on the ROV and in the control box. The strain relief is constructed from pipe insulation and zip ties.

For ease of transport, we carry the tether in a large bag.

Let out a lot of tether at first to help speed the descent.
Make sure there is some slack, but not so much that the ROV will get tangled.
DO NOT PULL ON THE TETHER.
When the ROV ascends, pull the tether in carefully. Don't let it get tangled.
After the mission is finished, coil the tether neatly.

Table 2: Our tether managing protocol

4.7 Manipulator

Our aim was to construct a versatile manipulator that could accomplish many tasks (Figure 11, 12). This was an improvement over last year's ROV because last year we built many attachments, each with limited functionality.

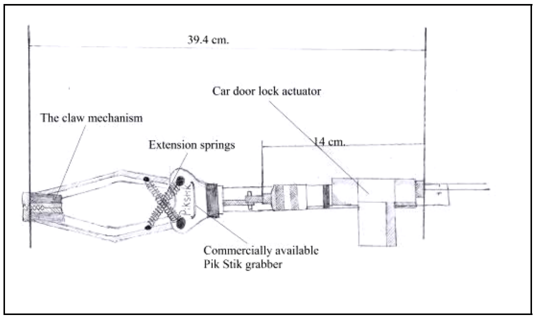

Figure 11: Manipulator diagram

This year's manipulator was made from a commercially available Pik-Stik™ Reacher. We sawed off the handle and the pole, keeping only the end that opened and closed. We then connected this to a car door lock actuator (made to open and close the locks on car doors).
We waterproofed this actuator in the sleeve of a shoulder-length neoprene rubber glove. We sealed the ends with silicone and zip ties, making sure to leave some air inside the sleeve to neutralize the pressure.
When we tested our manipulator, we found that it didn't have enough holding force. To fix this problem a spring was added to the manipulator. The actuator could open the manipulator with the spring, and the spring held the manipulator closed. On the ends of the manipulator we attached aluminum pieces with filed ridges. These allow us to get a good grip on objects. This manipulator is used to transport and attach the lift bag, to remove the corals, and to cap the fuel tank. Our attachment for the lift bag has pins that fit into holes drilled into these pieces of aluminum (Figure 13). There are attachments incorporating the manipulator to allow us to carry the compass and the metal detector as well.

Figure 12: Our manipulator

Figure 13: Our lift bag attachment

4.8 Water sampler

For taking our fuel sample we used an in-line pump – a pump that has tubing coming out of both ends. Our pump runs at 6.5 liters per minute at 12 volts.
Connected to the tubing on one end of the pump is a probe for penetrating the petroleum jelly, and from the tubing on the other end is a repurposed ½ liter (500 mL) IV drip bag.
Coming from the end of the IV bag is a piece of tubing that goes in front of the

camera. This piece of tubing is open so that when the IV bag is full the fuel will flow in front of the camera, allowing us to see when we have a large enough of a sample (a ½ liter is more sample than required but the pump is fairly quick).
The probe for penetrating the petroleum jelly is made of metal for sturdiness and designed so that it will not get clogged.

4.9 Sensors

Our ROV is equipped with several sensors to help accomplish the mission tasks. One of these sensors is a metal detector (Figure 14).
To construct our metal detector, we built and modified a commercially available kit (see Appendix 2). The metal detector works in the following way:

- There are two coils of copper wire.
- A current is put through the first coil.
- The current generates a magnetic field in the first coil.
- The magnetic field in the first coil generates a current in the second coil.
- The metal detector is then calibrated when there is no metal nearby.
- When there is metal in the vicinity of the sensor, the second coil tells the LED to light up.

The kit is made to light up one small LED. However, this LED is neither big enough nor bright enough for our camera to see. Because of this, we wired in two more LEDs so the camera can see it better.
In addition, the kit is made to run off of nine volts. Because our ROV is made to run off twelve volts, we implemented a nine volt regulator in a circuit with a 0.1µF capacitor and a 0.33µF capacitor in order to limit the voltage (see Appendix 2). Because the voltage regulator transforms the excess energy into heat, it is equipped with an aluminum fin to dissipate the heat into its surroundings.

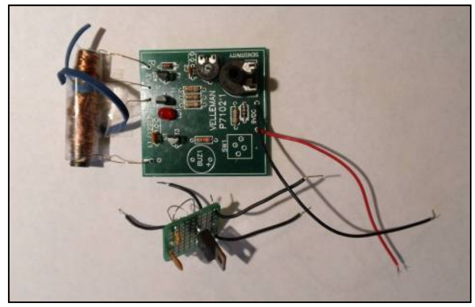

Figure 14: The metal detector, not yet waterproofed

Also, our metal detector was not waterproof. To accomplish this task, we put the entire system in a small Pelican case and sealed the case with silicone (Figure 15). We drilled through a bolt and made a through-connector for the wires with the aid of heat shrink, epoxy, and silicone.

Figure 15: The metal detector mounted

Because this sensor takes up a lot of space in the camera's view, we can't have the metal detector in front of it for the whole mission. When it is not in use, we have it attached to the front of the flotation with Velcro. Then, we come up to the surface and move the metal detector to a bracket on the claw where it attaches, also with Velcro.

Another sensor we have onboard our ROV is a Ritchie X21BB compass for measuring the orientation of the shipwreck. This mounts on the claw with Velcro. When we use the compass we also have to mount a magnifying lens in front of it to make it readable by the camera – the water between the compass and the camera makes the distance seem. Unfortunately, this compass does not have internal compensation – the ability to detect north while in the presence of ferrous or magnetic objects – something we discovered when we accidentally used some magnets as weights during a testing session.

For task two, our ultrasonic thickness gauge and neutron backscatter device are combined into one unit (Figure 16). This sensor is made out of 2" PVC pipe with a flat HDPE square on the end to make it easier to touch the hull of the ship and the calibration tank. This sensor also has holes to let water in as well as some R-3315 Last-A-Foam so our buoyancy is not affected. On the side of the PVC pipe there is a piece of Velcro-covered aluminum so that the sensor can attach to the claw's aluminum bracket.

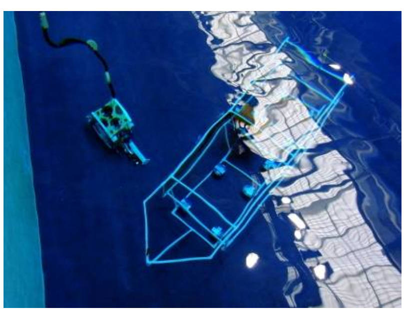

Figure 16: The Rust Bucket with the ultrasonic thickness gauge and the neutron backscatter (the white piece attached to the front)

One more attachment we have on The Rust Bucket is a device to measure the length of the shipwreck. This is a tape measure on a pivot mount attached to a 10.2 cm weighted ABS ring (Figure 17). This ring can be dropped over the post on either the stern or the bow of the shipwreck. To make reading the tape measure easier for the camera, we color-coded the tape measure every foot.

Figure 17: Our measurement system

5. Troubleshooting

This year we encountered many problems, some large and some small. Here are some of the problems we encountered and the ways in which we solved them.

One problem we had was with our flotation (see 4.2). At first, we didn't realize how buoyant it was and we cut way too much – at the first practice, the ROV wouldn't go down even with a ten-pound dive weight. To fix this problem, we used a hacksaw, a drill, and a file to remove a lot of foam.

Another problem we had was with waterproofing our first camera. We originally thought the problem was with the waterproofing process, but we found that it wasn't. It turned out that fiddling with the wires while we were trying to place the camera had broken a connection. In the end, another camera was waterproofed.

Yet another problem was with our water sampler. Our original design was to have a 500 gph (1893 Lph) bilge pump replacement cartridge pull back two sixty milliliter syringes that were connected to a long metal probe (Figure 18). Unfortunately, however, the syringes required so much force to pull them that this method proved untrustworthy and time consuming– the motor drew an unprecedented number of amps and blew fuses. We replaced this design with that of the in-line pump.

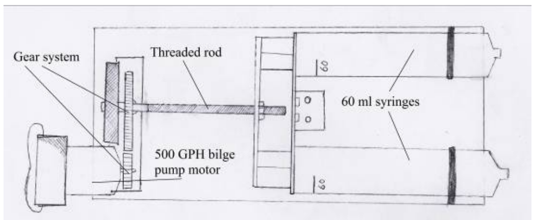

Figure 18: Our original water sampler design

One final problem occurred at the Pacific Northwest Regional competition itself. During our second mission, our up and down motors were running, but they weren't getting enough power to bring the ROV to the surface. After the competition, we realized that the heat shrink connections on the motor wires were not as good as they should have been. This let some water in and corroded the wires, resulting in weak connections. We replaced the motors as well as their heat-shrunk connections. In addition, we took apart a used motor and found it severely corroded, which may have been part of our motor problem (Figure 19).

Figure 19: A corroded bilge pump replacement motor cartridge

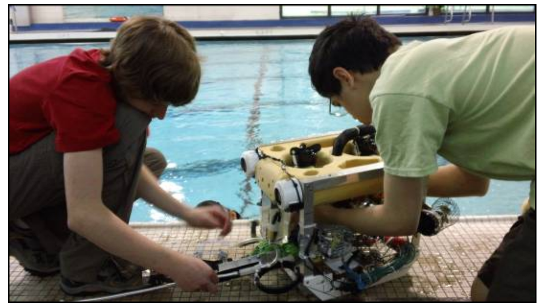

Figure 20: Fixing the tether's strain relief at a testing session

6. Safety

This year, we had many safety features on The Rust Bucket, at the surface, and for when we were working.
Safety features on board The Rust Bucket:

- Completely shrouded motors
- Danger labels for moving parts (Figure 21)
- Strain relief on the tether Handholds provided by the flotation that made launching easier

Figure 21: A danger label on The Rust Bucket

Safety features at the surface:

- A 25 amp main fuse (see 4.5)
- A 0.5 amp fuse for our camera (see 4.4)
- A main power shutoff switch (see 4.5)
- Heat sinks, a fan, and aluminum flashing on the potentiometers

(see 4.5) to dissipate heat and to prevent burns
- Strain relief on the tether (see 4.6) and on the power wires

Safety features we observed when working on The Rust Bucket:
- We always wear safety glasses when we use tools
- We wear masks when we work with the foam (it produces a lot of dust) (Figure 22)
- We wear gloves when we work with potentially harmful substances such as epoxy

Figure 22: Us cutting the R-3315 Last-A-Foam

7. Development

Before we made The Rust Bucket, we experimented with many possible designs for our systems.

One system we experimented with was the idea of pressure canisters for our camera and for our onboard electronics. We even built these pressure canisters, but we used the wrong kind of gasket material – foam rubber when we should have used neoprene rubber – and the waterproof seal was not reliable. We decided to use our previous methods – epoxy for the camera, solder and heat shrink for the wires – for this year's competition.

We also worked on several other ideas for a manipulator because we liked the idea of making the whole thing ourselves instead of cannibalizing part of a commercially available product. However, these designs took up a lot of time and we wanted to move on to being able to test.

Perhaps the most important part of The Rust Bucket's development was research. Nicholas, our research expert, read and practically memorized all the technical reports in the history of the MATE ROV competition, as well as the MATE center's textbook[5]. He also went out of his way to get books on related topics – it's harder than it sounds. Based on this research, we were immediately able to rule out some of our designs and begin others. From looking online and at the technical reports, we also found the names of many companies who were delighted to donate products to us.

8. Improvements

This year's ROV was a huge improvement over last year's ROV for many reasons. Last year's ROV was clumsy, slow, and larger than we wanted it to be. The Rust Bucket is maneuverable, faster, and compact.

In addition, we already have a multitude of ideas for improvements to next year's design. Here are two of them.
- Start earlier. We have put this in our improvements section every year so far, but we feel that we always seem to be rushed in the last few weeks.
- Purchase an already waterproofed camera. Every year, we spend valuable time in a waterproofing process that we already know that we feel would

be better spent in designing and building a more capable manipulator.

9. Reflections

As a whole, we really enjoyed this year's competition. This is our third year of competition and we have loved it. We really got a lot out of it.

Overall, we think the most challenging part of the design process is waterproofing systems. Making the control system, however, was a close contender for the role of most challenging. Having systems fail unexpectedly and for no obvious reason was definitely the most frustrating.

The most satisfactory part of the competition was seeing how fast and maneuverable The Rust Bucket was at our first practice. This was huge improvement over last year (Figure 23). We feel we accomplished our goal to fix that.

Figure 23: Us with 2011's ROV

In 2011, we only earned forty points as our mission score. This year, we were very delighted to get a much higher score. Of all the tasks, we succeeded in:

- Transporting and attaching the lift bag
- Determining the orientation
- Detecting which samples were rock or metal
- Mapping the wreck
- Using both the ultrasonic thickness gauge and the neutron backscatter
- Scanning the shipwreck with SONAR

A frustrating component of our missions was that both times, we hooked the lift bag on the mast, and both times, our pilots knocked it off. The bad news was that we lost valuable time returning for the lift bag that we could have used for the tasks we didn't get to. The good news was that we went up to the surface, retrieved the lift bag, and did it again; both times.

Figure 24: The lift bag surfacing after a successful second try at the PNW regional

10. Budget

This is a roughly accurate budget according to our receipts. Some values had to be estimated. Products in italics reflect the approximate value of donated items.

Frame		
Product	Source	Cost
Aluminum angle	Ace Hardware	$31.25
Misc. fasteners	Ace Hardware	$1.27
Total cost		**$32.52**
Amount we spent		**$32.52**

Buoyancy		
Product	Source	Cost
R-3315 Last-A-Foam	*General Plastics*	*$150.00*
Misc. fasteners	Ace Hardware	$3.98
Total cost		**$153.98**
Amount we spent		**$3.98**

Cameras		
Product	Source	Cost
Cameras	*Supercircuits*	*$270.96*
100 ft. BNC to BNC cables	*Supercircuits*	*$103.96*
Development	TAP plastics	$74.22
Epoxy	Ace Hardware	$29.99
Misc. fasteners	Ace Hardware	$4.99
Containers	Storables	$6.48
Total cost		**$490.60**
Amount we spent		**$115.68**

Water sampler		
Product	Source	Cost
Threaded rods	True Value	$9.47
Misc. fasteners	True Value	$2.72
Misc. fasteners	True Value	$1.95
Aluminum tubing	True Value	$9.95
Nylon fittings	True Value	$3.98
Tubing	Creation Station	$2.00
Total cost		**$30.07**
Amount we spent		**$30.07**

Control System		
Product	Source	Cost
Control box	*Polycase*	*$36.35*
Control box	Polycase	$36.25
Potentiometers	*Ohmite*	*$250.00*
Terminal blocks	Jameco	$25.16
Ring terminals	Radio Shack	$20.51
Switches	Radio Shack	$54.43
Heat sinks	Jameco, Creation Station	$2.35
Misc. fasteners	Tacoma Screw	$1.19
Total cost		**$426.24**
Amount we spent		**$189.89**

Motors		
Product	Source	Cost
750 gph motors	*West Marine*	*$271.92*
1250 gph motors	*West Marine*	*$191.94*
500 gph motors	*West Marine*	*$45.98*
Propellers	Fun RC Boats	$23.12
Propeller adapters	Windsor Propellor Company	$39.92
Aluminum flashing	Ace Hardware	$3.29
Total cost		**$576.17**
Amount we spent		**$327.19**

(continued on next page)

Tether		
Product	Source	Cost
Heat shrink	*Techflex*	*$15.00*
Heat shrink	*Harris Electric*	*$50.00*
Wire	*Harris Electric*	*$200.00*
Cable sheathing	*Techflex*	*$200.00*
Wire	North Coast Electric	$50.00
Total cost		**$515**
Amount we spent		**$50**

Manipulator		
Product	Source	Cost
Pik-Stik Reacher	Ace Hardware	$19.99
Neoprene rubber gloves	Amazon	$29.99
Aluminum bar	Ace Hardware	$16.98
Rudder gloves	Lowe's	$4.50
Springs	True Value	$1.39
Development	Ace Hardware	$4.98
Aluminum angle	Home Depot	$7.17
Total cost		**$84.50**
Amount we spent		**$84.50**

Profits	
Item	Profit
Bake Sales	$440.06
Monetary donation	$200.00
Miniature book sales	$220.00
Competition winnings	$1,500.00
Total	**$2,360.06**

Totals (includes travel and hotels)	
Item	**Total**
We spent (including travel fees)	**$3,270.81**
Approximate value of donated parts	**$1,350.96**
We raised	**$2,360.06**
Total cost of The Rust Bucket	**$4,617.27**
Amount we paid	**$ 910.75**

10. Acknowledgements

There are many people without whom we would not have been able to accomplish this project.

- Mary Chang, Robert Orndorff, Rachel Miller, and Steve Miller – for being great parents and supporters and for driving us to the hardware store
- Pekoe Miller – Alex's dog and our mascot, for letting us work around her
- Rick Rupan, Wes Thompson, and Fritz Stahr - for organizing the PNW regional
- Pete Orndorff – for financial support
- Art Tanaka – for a monitor and advice
- Everyone who bought from our bake sales at Alki Beach or our book sales in Dublin, Ireland

There are also many companies without which we would not have been able to accomplish this project.

11. References

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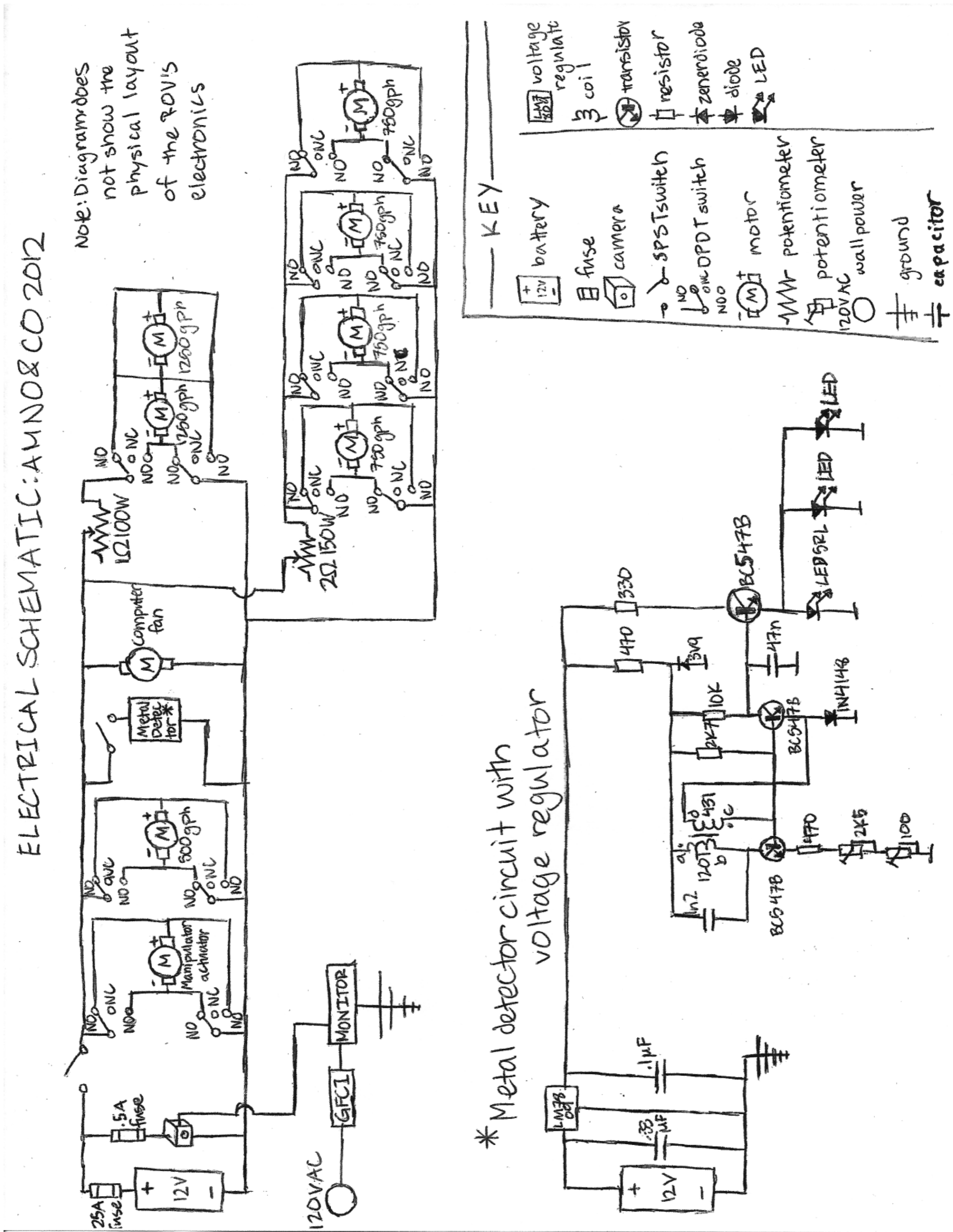
Appendix 1: Electrical Schematic



Appendix 2: Metal Detector

The metal detector is made by Velleman and draws 30 mA.
Instructions for intended use (these directions are taken from the kit but include our modifications):

1. Connect a 9V battery to the battery holder[1].
2. Go to a place where NO metal object is known to be in the vicinity.
3. Turn preset RV1[2] fully clockwise.
4. Turn RV2[3] fully anti-clockwise.
5. Depress the push button and hold it in during the final adjustments[4].
6. Turn RV1 anti-clockwise until the LED[5] goes out.
7. Turn RV2 until the LED is weakly lit.

These adjustments were made prior to waterproofing the metal detector.

[1]The kit was made to run off 9V. We adapted it for 12V.
[2]RV1 is a potentiometer.
[3]RV2 is a potentiometer.
[4]Instead of a push button we control the metal detector from the surface with a switch.
[5]We used multiple LEDs

Appendix 3: R-3315 Last-A-Foam

This foam, R-3315 Last-A-Foam, is a special polyisocyanurate foam. It is closed cell, meaning it won't compress at depth.

Density: 240 kg/m^3

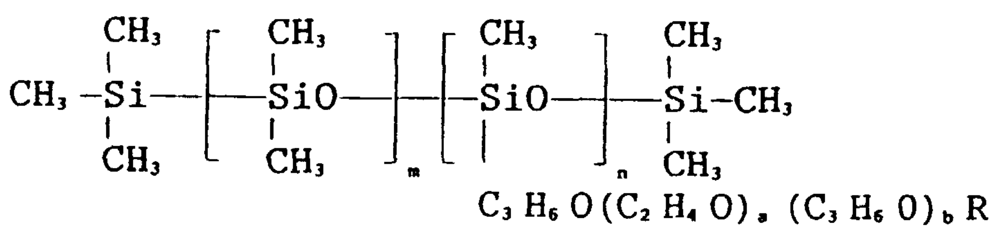

[1]

Figure 25: The chemical structure of a polyisocyanurate

Figure 25 shows the chemical structure of a polyisocyanurate. Polyisocyanurates are most commonly used as insulation because they have a have a high thermal resistance due to the presence of hydrochloroflorocarbons (HCFC), a low-conductivity gas[6].