WARRENTON AQUATIC ROBOTICS

WARRENTON OREGON, USA

THE RAYS

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Dalton Wallace	ROV Mechanical Engineer
Dwayne Wallace	Float Mechanical Engineer
Declan Wallace	Team Assistant
Heidi Lent	Coach
Craig Battles	Mentor

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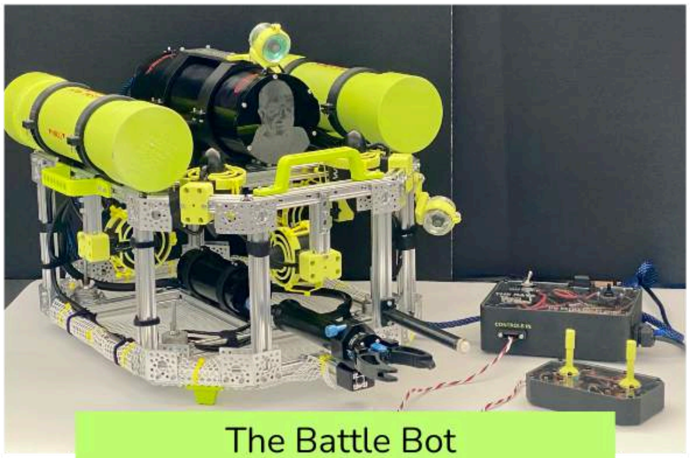


The Battle Bot
Photo Credit: Dwayne Wallace

ABSTRACT

We are The Rays, a branch of Warrenton Aquatic Robotics based out of Warrenton Oregon on the North Oregon Coast. Our company designs and manufactures easy-to-operate ROVs to improve the vitality of our oceans, waterways, and marshes.

To design these ROVs, we carefully analyze our goals. These goals could include installing SMART cables (Science Monitoring And Reliable Telecommunications) or recovering a multi-function node. We then generate concepts for multiple solutions, such as reusing tools from previous designs or developing radical new designs.

After careful deliberation, we devised a combination of tools, such as magnets to easily pull pins out of multi-recovery nodes or digital cameras that can assist in 3D modeling coral. This process allows our company to develop high-quality and innovative ROVs to enable the protection and repair of our waterways. In this document, we would like to share the development of our ROV, The Battle Bot, and our float.

TEAM-WORK

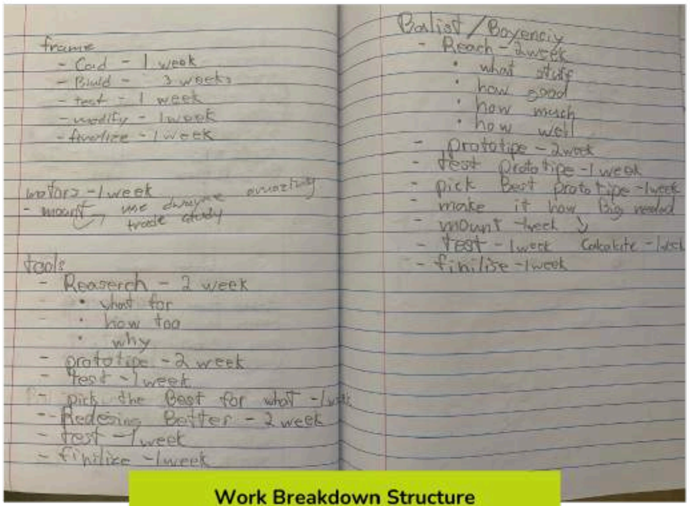
Our company consists of two teams. One team to design the ROV and another team to design the float. The ROV team includes Owen Cross, designer of the control and electrical systems as well as software, and Dalton Wallace, who designed the mechanical structures of the ROV. The float team consists of Dwayne Wallace, who is responsible for the design of mechanical and electrical/electronic subsystems, and Micah Larson who designed, developed, and tested software for the float. Each team member wrote the sections of this document relating to their responsibilities. Clear lines

Micah, Dwayne, Dalton, Owen
Photo Credit: Heidi Lent

of responsibility allow us to focus on the tasks at hand while sharing reports allows us to efficiently share ideas and work to integrate our subsystems.

Scheduling

As a company, we like to use mind maps. The mind map allows us to identify the alternative approaches for each subsystem. We then analyze the alternatives to see which are possible. We look at cost, technical difficulty, effect on other subsystems, and other attributes. In some cases, we may not know everything we need to know to do the analysis. We create a Work Breakdown Structure of tasks that must be completed to research or experiment on the alternatives and add them to the known tasks. The WBS is then examined to determine the logically required order of completion. For example, we can't design mounts for the motors before we decide what motors to use. Then we apply resources to each task and subtask and estimate the time required to complete them. We found that working backward and putting deadlines on the tasks you need to do last produces better results. You can review our schedule in Appendix B. The schedule allows us to ensure the tasks can be done in the time we have and updates to the schedule identify problem areas that may need more resources or attention.



Work Breakdown Structure
Photo Credit: Dwayne Wallace

DESIGN RATIONALE

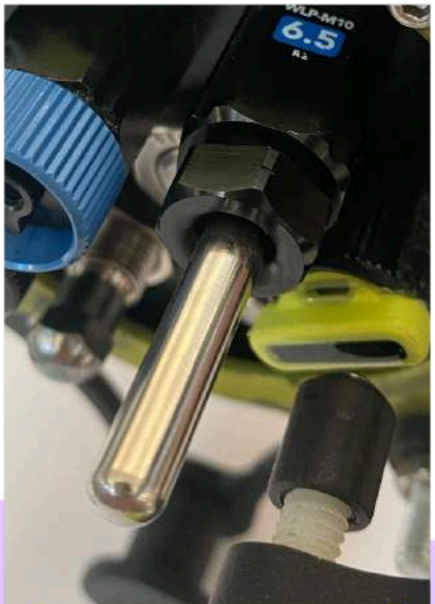
Engineering Design Rationale

When our company has to design something, we start by making a list of design requirements. These requirements can stem from must-have safety features to nice-to-haves that would make operation easier. This year with creating a new machine, our design requirements were pretty basic, make sure we fit inside MATE guidelines, the machine is safe to use, and the machine is functional. Once we have our list of design requirements we can start our concept development state. We start by using mindmaps, sketching out our subsystems and possible solutions for each subsystem. From the mind map, we create a schedule to follow and ensure we get the task done orderly.

Using trade studies and weighted decision matrices based on our design requirements, we can filter out some of the concepts we brainstormed. This prevents us from hitting a local maximum with our design and allows us to start on the right track. Some of these trade studies were about what sensors we should use, what microprocessors, or what thrusters to use. You can find our thruster trade study in Appendix A. Overall, the design of our ROV consists of an octagonal X-Rail frame that houses eight brushless motors, multiple watertight enclosures, and an electric claw all driven by an Arduino control system with analog cameras for remote use.

Innovation

What sets our team apart from the competition is that we strive for innovation, producing high-performing ROVs at a reduced cost. For example, we have created a watertight, accurate, and easy-to-use temperature probe by using a steel-encased DS18B20 temperature probe and a Blue Robotics WetLink Penetrator for a total cost of eight dollars. By using the OneWire serial, we are easily able to use this sensor on any device. We have included one on The Battle Bot and our float.



Temperature Probe
Photo Credit: Dwayne Wallace

Custom Float PCB
Photo Credit: Dwayne Wallace

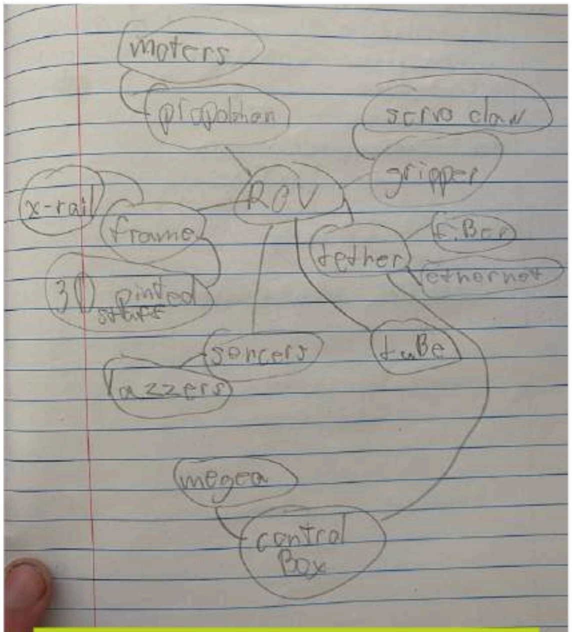
We have heavily used the power and flexibility of 3D printing. We manufactured numerous parts for our machines. What this does is allow us to create fine-tuned and specific parts at a low cost. We also made tools to ease the use and maintenance of the ROV.

The use of custom PCBs was new to us this past year. The use of custom PCBs allowed us to create robust connections between small electronics while being extremely inexpensive. We used a custom PCB on the float due to the restricted space.

Another innovation for our team is the thrusters. These new thrusters replaced our brushed bilge pump motors with brushless motors with twice as much thrust with lower power consumption while being 15% cheaper. The specific values can be found in Appendix A. This allowed our machine to perform better at a lower cost.

Problem-Solving

In our concept development stage, we try to come up with seven different concepts for each subsystem. We find that seven gives us a good number of ideas to consider while not taking up too much time to consider each idea. To come up with these ideas we start by sketching out our subsystems on a mindmap. Then as a team, we talk and share our mindmaps for the projects we are working on so we can brainstorm ideas together. This would be accomplished in tandem with our weekly status and working meetings. By doing this we can make sure that we shed light on every avenue and make sure we are not missing anything.



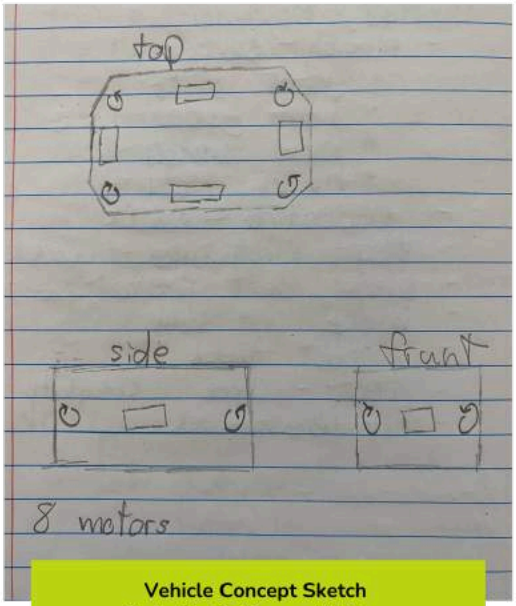
Mindmap
Photo Credit: Dwayne Wallace

Once we have our seven concepts, we do a trade study for each subsystem. We take the design requirements for that subsystem and we put quantitative values for each design requirement. These values could be how much thrust a thruster puts out or how many amps the microprocessor pulls. Once we have values we can find the concept that fits our design requirements best. That way we can make sure when going into the design stage we have the best ideas.

Systems Approach

It is very easy when you chop the ROV into subsystems that you come up with designs that don't fit together. To prevent this, our team uses Interface Control Documents or ICDs. This document lists the inputs and outputs of each subsystem and every interface between each subsystem. For example, the ESC has a servo input and an output for the motors. It interfaces with the control system and the thrusters. So when we design or choose components. We use the interface controls like design requirements to ensure good integration between subsystems.

Vehicle Structure



Vehicle Concept Sketch
Photo Credit: Dwayne Wallace

As a company, we have decided that an ROV with eight thrusters would benefit the performance of the ROV greatly, but our team had to think of a way to mount all of these thrusters. Our company decided to have all four navigation thrusters mounted on the sides and have the heave thrusters in the corners. We then figured out that it would be very difficult to mount the motors in each corner of a cube or prism. We realized that an octagon was the perfect shape to mount all eight motors. This saved costs by reducing the amount of 3D parts needed.

By having the front corners cut off, The Battle Bot can get into smaller places, more safely than other shapes. The Battle Bot structure is also aesthetically pleasing while being equally as functional. The octagonal shape gave us the ability to mount components like tools and cameras in a variety of ways.

Vehicle Systems

Frame

Our company has researched different frame materials like PVC, HDPE, and X-rail. We have decided to reuse our X-rail frame material because of the cost, reusability, and the fact that you only need one tool to put the whole frame together. This makes modification and repair of our ROV extremely simple. Due to the modularity of the X-Rail, we can very easily add and mount tools, cameras, and lights. This makes a very future-proof ROV.

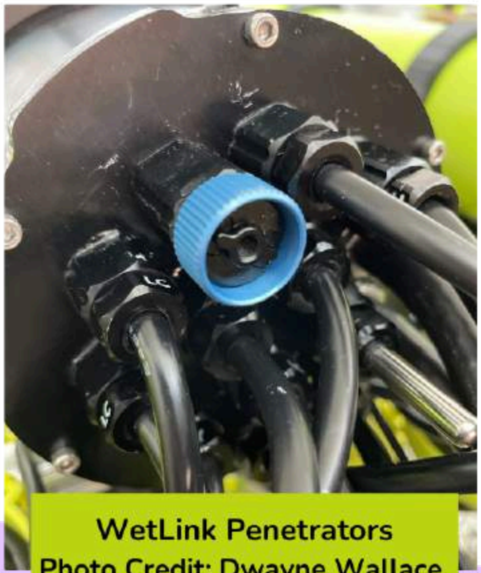
Cameras

The Rays have designed the camera system using 3 analog backup cameras potted in epoxy resin. Our company has designed tiny enclosures and waterproofing techniques that greatly reduce the weight and size of the cameras by using 38.1 mm (1.5 inches) acrylic tubes cut 38.1mm (1.5 inches) long. This creates a small, lightweight, simple, and cost-effective camera that we can place anywhere on the ROV with the addition of our custom 3D printed mounts.

Size comparison of new and old potted cameras
Photo Credit: Heidi Lent

Tether

Tether strain relief is an issue for every tethered robot. Too much force on the electrical connection can destroy a robot, so we spent a lot of resources designing tether strain relief solutions to protect the ROV. We used a rope on the ROV that would go into tension before the tether did, and we did the same thing on the control box side.



WetLink Penetrators
Photo Credit: Dwayne Wallace

Penetrators

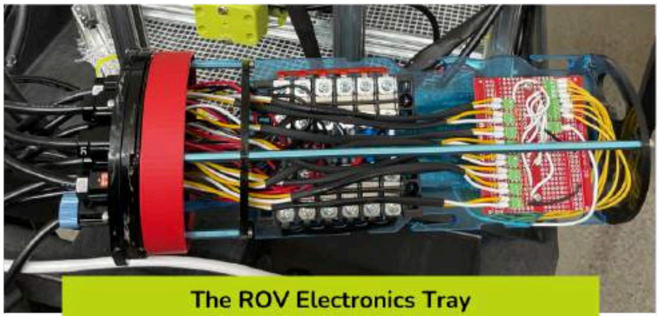
We experimented with new technology this year, allowing our machine to go deeper. In the past, we have tried to design and pot our penetrators but we were rarely successful. Our solution was to invest in the BlueRobotics Wetlink Penetrator system. From testing, we proved that they can handle going at least 30 meters below the surface by using vacuum tests. Reusing these penetrators can also reduce costs in the future.

Control/Electrical System

The electrical system is based on two independent systems. The first is the control system located in the main 4-inch enclosure at the top of the ROV. This system is run by two Arduino Megas, one in the control box and the other onboard the machine. They transmit data to each other via serial communication using RS485. The user interface to the controller connects to the main control box with a custom-built mag-safe connector which uses magnets to ensure polarity while making it easy to connect and disconnect.

ROV Controller
Photo Credit: Dwayne Wallace

We have designed a thruster hub. The thruster hub helps organize control system wiring and keeps the enclosure organized. This ensures that all the thruster wiring can be located on the bottom of the tray, and then only a few wires can connect with the microcontroller.



The ROV Electronics Tray
Photo Credit: Heidi Lent

Propulsion

For five years our company has been using brushed bilge pumps as our thrusters. These motors are inefficient, expensive, and have a limited lifespan. We were done dealing with the cons of these thrusters and wanted to find an alternative solution. We wanted a thruster that would give us the most thrust per amp of current draw per one dollar per unit. You can see more about this in our thruster trade study in Appendix A. With this information, we concluded that we should invest in the Diamond Dynamics TD1.2 thruster. It includes an exterior ESC which will help with space and heat within the watertight enclosure.

Buoyancy and Ballast

The buoyancy on the machine is made up of two 3-inch ABS pipes. We decided to go with this option because of its resistance to compression under pressure, unlike some foams. The downside of using ABS pipes is that you have to get the right length to achieve a neutral buoyancy.

For the ballast, our company is using a tunable weight system in the four corners of the ROV. This system allows for precise ballasting and is easy to fine-tune without any preparation. With the ballast being in four different spots on the frame it allows us to adjust the trim.

Ballast System
Photo Credit: Dwayne Wallace

Payload and Tools

On The Battlebot, we have many different kinds of tools and sensors with all their purposes. The gripper is the main tool on The Battle Bot. It is a BlueRobotics Newton Subsea Gripper. We have made a buy-over-build on this due to the great features it has, such as fine adjustment and the current limiting functions on the gripper, but most importantly the lack of resources to develop our gripper that would perform better than the BlueRobotics Newton Subsea Gripper.

The magnet tool on the ROV is something we designed and made in-house. This tool is specifically designed to activate the recovery process on the multi-purpose node. This makes the operation of The Battle Bot easier at a very low cost.

ROV tools
Photo Credit: Dwayne Wallace

SAFETY

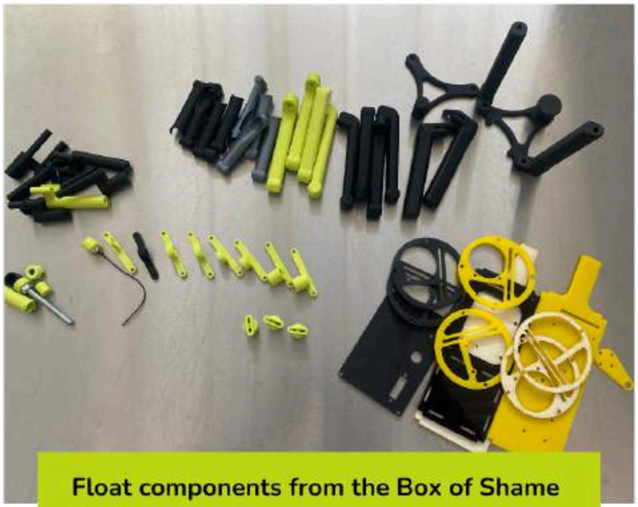
Team members in their safety gear
Photo Credit: Heidi Lent

Our company values safety as the number one priority. We have set procedures for everything we do in our Job Safety Analysis manual. This manual lists the hazards we might run into such as airborne particles when sanding or hot metals when soldering. Our manual states the safety precautions and the proper PPE required for every task. This may include wearing a respirator and safety glasses when sanding or soldering in a ventilated area with safety glasses. On top of the JSA manual, we have checklists set in place for the operation of the ROV. These checklists follow the JSA manual and list what we need to do for the safe operation of the ROV. You can see our safety checklist in Appendix C.

When we design our ROVs, safety is a must-have design requirement. We want our machines to operate safely and pose no danger to our global ecosystem. To do this we have included; thruster shrouds that meet an IP-20 standard, a bottom safety net to protect the ROV from foreign objects, tools to protect the ROV when maintenance is being done, handles to aid in the transportation of the ROV, warning labels to communicate hazards, and many fail checks in the code to prevent any loss of control.

CRITICAL ANALYSIS

Everything can look right on paper, but it's not until you bring it into the real world you start to find the issues. That is why our company values a trial-and-error-style design process. Because of the NC machines available, we can quickly and inexpensively bring our ideas into the real world. By doing this iterative process we can better understand the issue with a current design and come up with better solutions. The by-product of this is what we like to call the “box of shame” which isn't very shameful at all. It is a box of all the failed designs that we have tested and iterated off of to create the ROVs and floats that you are seeing today.



Float components from the Box of Shame
Photo Credit: Dwayne Wallace

The testing of these designs ranges from destructive testing to functional testing. We took our designs and first passed a fitment test to see if they would function properly with the rest of the ROV. Then we could follow up with some more testing such as a destructive test if we weren't going to use the part. This gave us some good insight into how we could improve our designs to increase The Battle Bots' performance even further.

ACCOUNTING

We start with setting a budget, how much money do we have to build or modify our ROV? This value will be put in as one of our design requirements. We will design around this value making sure we are on budget. To aid in this we create a budget spreadsheet where we estimate how much funding each subsystem needs and we can divide up our total budget accordingly. You can see this document in Appendix D.

Then we have an ROV Cost Accounting spreadsheet that tracks our spending. This serves as a running total for the project. You can see this document in Appendix E. We spent the majority of our funding on the new thrusters and the new WetLink penetrators which has led to an innovative and cost-effective ROV, but our predictions needed to be corrected. We went over budget a little due to issues with reusing our gripper and some other components that were mistreated.

ACKNOWLEDGEMENTS

We would like to thank many people who made competing possible for us. We would like to thank MATE II, The Marine Technology Society, The Schmidt Ocean Coalition, Oregon

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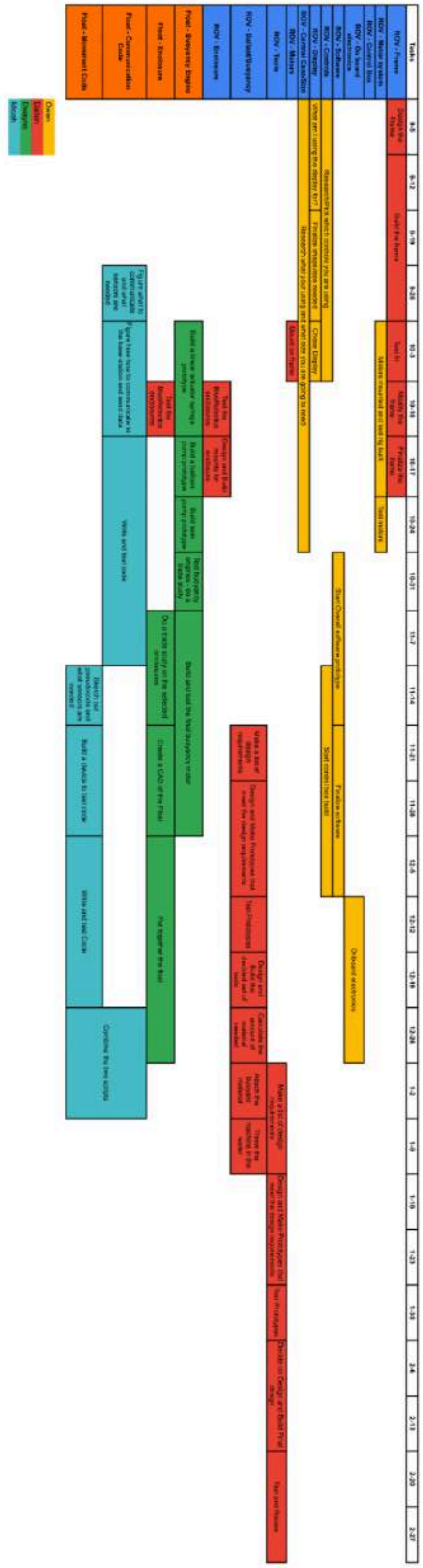
APPENDICES

Appendix A - Thruster Trade Study

Thruster	Trust (N) @ 12v / Amp	Toltal Trust (N)	Cost w/ ESC	Link	Link 2 (ESC)	Score ((Trust/Amp)/Cost)
T200	6.178 N/a	36.387 N @ 17.0a	$236.00	T200 Thruster	Basic ESC (Ele	0.026
T500	7.747 N/a	39.227 N @ 16.9a	$726.00	T500 Thruster	Basic ESC (Ele	0.011
MATE Bilgepump (New, No shroud)	3.375 N/a	13.500 N @ 4.0a	$75.00	TriggerFish/Ba	Sabertooth 2X	0.045
MATE Bilgepump (Shrouded)	1.542 N/a	5.090 N @ 3.3a	$75.00	TriggerFish/Ba	Sabertooth 2X	0.021
1000 gpm Bilgepump (No Shroud)	2.900 N/a	13.500 N @ 5.0a	$62.21	Amazon.com: J	Sabertooth 2X	0.047
Diamond Dynamics	2.354 N/a	24.517 N @ 13.0a	$64.00	Amazon.com: [		0.037
CUIFATI	1.471 N/a	11.768 N @ 8.0a	$75.71	Amazon.com: (		0.019
Hawk Hobby	1.739 N/a	26.086 N @ 15.0a	$69.98	Amazon.com: I	Amazon.com:	0.025

Appendix B - Schedule



Appendix C - On Deck Checklist

CHECKLIST

Enter Pool Deck:

- ☐ Team is ready
  - ☐ Members are wearing proper PPE
  - ☐ Hair back
  - ☐ No loose clothing
- ☐ Machine is ready
  - ☐ ROV components secured
  - ☐ Tether coiled and stowed
  - ☐ Controller secured
- ☐ Pool Deck is Ready
  - ☐ Area clear of obstacles
  - ☐ Table in position
  - ☐ Power is available

System Setup:

- ☐ ROV Ready
  - ☐ Gripper in position
  - ☐ **CHECK PRESSURE RELEASE VALVE**
  - ☐ Connections secure
- ☐ Tether Ready
  - ☐ Unstowed and ready to deploy
- ☐ Controller Ready
  - ☐ Power supply off
  - ☐ Controller plugged in
- ☐ Team Ready
  - ☐ Pilot ready
  - ☐ Tether Manager ready

Power Up Checks:

- ☐ Tether Manager clear of moving parts
- ☐ Power on

- [ ] Pilot communicates “Motor Testing” to Tether Manager
- [ ] Tether Manager communicates “clear for motor test” to Pilot
- [ ] Motor test with a joystick input
- [ ] Camera images displayed for 3 cameras

Pool Side Operations:

- [ ] Pilot zeros joystick for launch/recover
- [ ] Pilot communicates “clear to launch/recover” to Tether Manager
- [ ] Tether Manager ensures lift/launch safety
- [ ] Tether Manager communicates “open/close” to gripper control to grasp/ungrasp props
- [ ] Tether Manager communicates “ROV clear” to Pilot when joysticks can command motors

System Breakdown:

- [ ] Machine is ready
  - [ ] Power is off
  - [ ] ROV components secured
  - [ ] Tether coiled and stowed
  - [ ] Controller secured
  - [ ] Pool Deck is ready
  - [ ] Area clear of obstacles
  - [ ] The table returned to the original position if moved

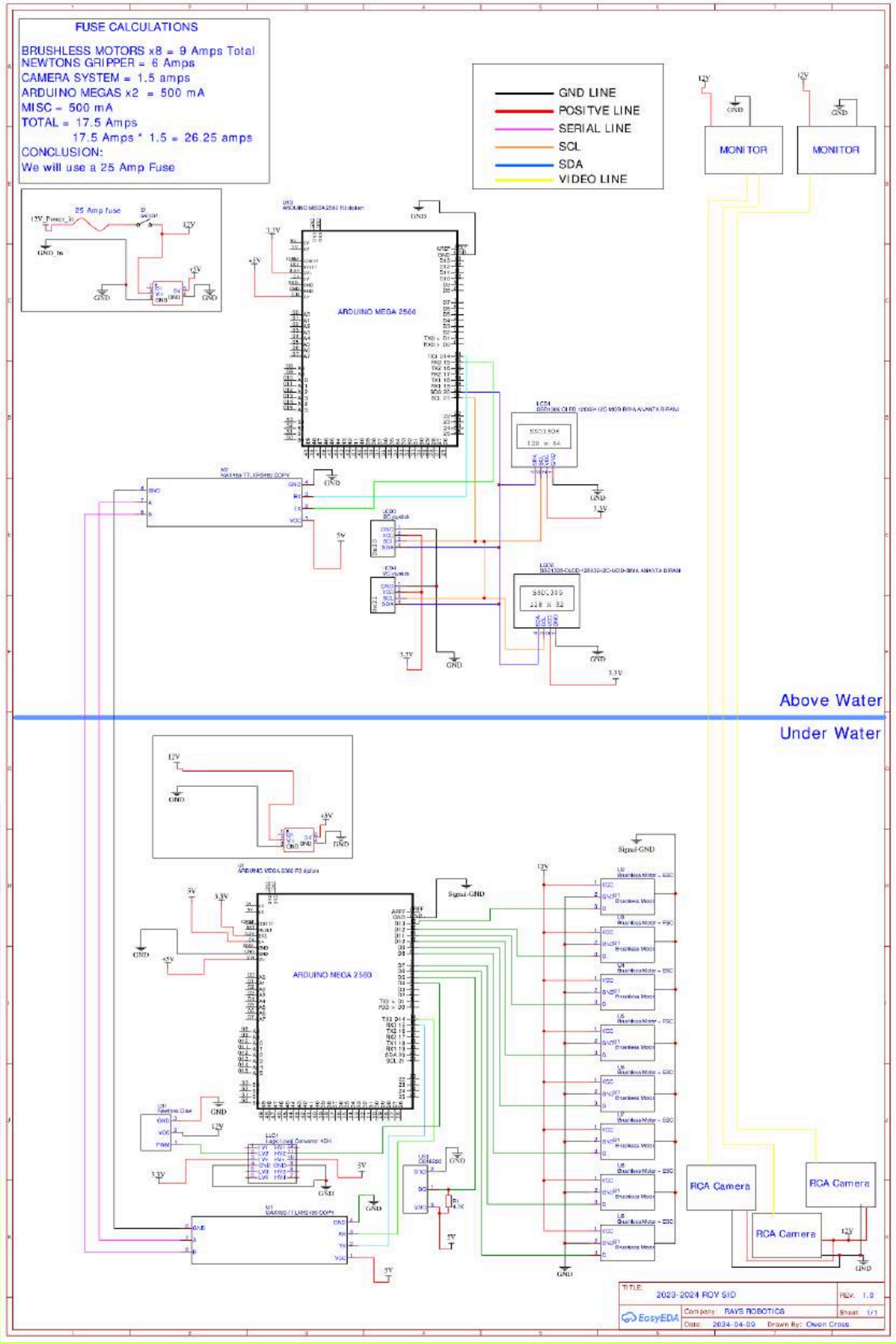
Appendix D - Budget

Income	Description		Amount
Donations	Pacific Power		$750.00
Donations	Anonymous Donor		$1,500.00
Fundraising	Bake Sale		$1,500.00
School Funding			$4,000.00
Sponsor Donations	Sexton Corp		$1,000.00
Sponsor Donations	MTS		$500.00
Sponsor Donations	Schmidt Ocean Stipend		$2,000.00
		Total	**$11,250.00**
Expenses	**Description**	**Estimated Cost**	**Budgeted Value**
Electrical System		$300.00	$500.00
Thrusters		$500.00	$500.00
Frame		$0.00	$100.00
Marketing Materials	Poster printing, Keychains	$50.00	$100.00
Employee uniforms	T-Shirts	$50.00	$100.00
Travel Expenses		$8,000.00	$8,000.00
		Total	**$9,300.00**
		Net Profit/Loss	**$1,950.00**
		Fundraising Needed	**$0.00**

Appendix E - Cost Accounting

Component	Sources	Quantity	New / Used / Donated	Individual Cost	Total cost
Frame					
336mm X-rail	https://www.servocity.	8	Used	$9.39	$75.12
120mm X-rail	https://www.servocity.	8	Used	$4.99	$39.92
192mm X-rail	https://www.servocity.	12	Used	$6.49	$77.88
96mm X-rail	https://www.servocity.	4	Used	$4.59	$18.36
45 degree Bracket	https://www.servocity.	16	Used	$2.99	$47.84
Flat Bracket	https://www.servocity.	38	Used	$1.14	$43.32
Nuts	https://www.servocity.	250	Used	$0.40	$100.00
Screws	https://www.servocity.	250	Used	$0.50	$125.00
Ballast					
Hex Screw	https://www.servocity.	4	Used	$0.19	$0.76
90 Degree Corner Bracket	https://www.servocity.	8	Used	$2.50	$20.00
Butterfly Nut	https://www.homedep	4	Used	$1.38	$5.52
Washers	https://www.homedep	38	Used	$0.23	$8.74
Buoyancy					
2 in PVC Pipe	https://www.homedep	2	New	$1.77	$3.54
2 in PVC Pipe End Caps	https://www.homedep	4	New	$2.29	$9.16
Gripper					
Newton Subsea Gripper	https://bluerobotics.co	1	Used	$640.00	$640.00
Enclosure					
4in Water Tight Enclosure	https://bluerobotics.co	1	Used	$330.00	$330.00
2in Water Tight Enclosure	https://bluerobotics.co	1	Used	$52.00	$52.00
4in O-ring Flange	https://bluerobotics.co	2	Used	$45.00	$90.00
4in 14 Hole End Cap	https://bluerobotics.co	1	Used	$32.00	$32.00
4in Blank End Cap	https://bluerobotics.co	1	Used	$30.00	$30.00
2in 4 Hole End Cap	https://bluerobotics.co	1	Used	$34.00	$34.00
2in Blank End Cap	https://bluerobotics.co	1	Used	$30.00	$30.00
Pressure Relief Valve	https://bluerobotics.co	2	Used	$28.00	$56.00
6.5mm Penetrator	https://bluerobotics.co	1	New	$12.00	$12.00
7.5mm Penetrator	https://bluerobotics.co	1	New	$12.00	$12.00
5.5mm Penetrator	https://bluerobotics.co	9	New	$12.00	$108.00
Blank Penetrator	https://bluerobotics.co	2	Used	$6.00	$12.00
Enclosure Clamp	https://bluerobotics.co	2	New	$50.00	$100.00
Camera system					
Camras	https://www.amazon.c	3	New	$16.99	$50.97
Acrylic tube	https://www.amazon.c	3	New	$10.99	$32.97
Clear Epoxy Resin	https://www.amazon.c	1	New	$34.99	$34.99
Electronics					
Buck Regulator Breakout	https://www.sparkfun.	2	Donted	$5.95	$11.90
Arduino Mega shield	https://store-usa.arduir	2	Donted	$6.00	$12.00
Arduino Mega	https://www.sparkfun.	2	Donted	$48.40	$96.80
Qwiic Adapter	https://www.sparkfun.	2	Donted	$1.60	$3.20
Qwiic OLED	https://www.sparkfun.	1	Donted	$14.95	$14.95
Arduino RS485	https://store-usa.arduir	2	Donted	$38.60	$77.20
Toggle Switch	https://www.sparkfun.	2	Donted	$2.10	$4.20
Inline Fuse Holder	https://www.napaonlin	1	Used	$3.77	$3.77
Monitor	https://www.amazon.c	2	Used	$23.99	$47.98
Video Wire	https://www.amazon.c	3	Used	$8.99	$26.97
Misc Wire		1	Used	$50.00	$50.00
Thrusters					
Diamond Dynamic Thrusters	https://www.amazon.c	8	New	$64.00	$512.00
Misc					
Filament	https://www.amazon.c	2	New	$24.99	$49.98
Waterproof Case	1800 Weatherproof Pr	1	Used	$12.99	$12.99
				ROV Value:	$3,156.03
				Total Rused/Donated:	$2,230.42
				Total Spent:	$925.61

Appendix F - ROV SID



Appendix G - Float SID