Technical Documentation

CORAL CRUSADERS

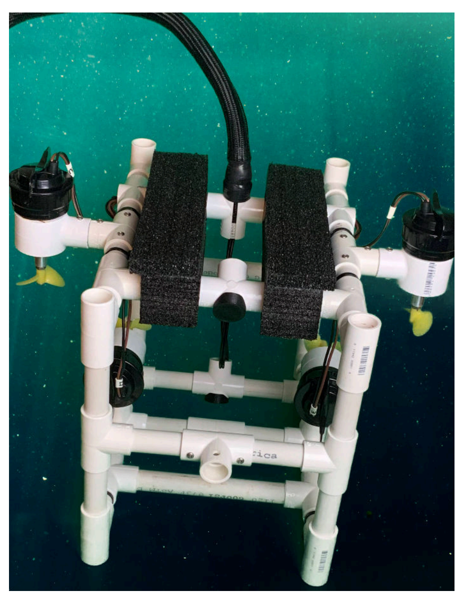
Non-Affiliated Redmond, Washington, USA

Dhruv Darbha - General partner, control system

Dylan Wu - General partner, ROV design

Kounish Bhattacharjee - Limited partner, tether and prop specialist

Mike Pesavento - Mentor



Abstract

Coral Crusaders is an unaffiliated Redmond-based company, composed of 2 full-time members (Dhruv and Dylan) and one part-time member (Kounish) under coached instruction. It is the first year Coral Crusaders have created an ROV for the MATE competition. Though few in number, all members have dedicated time and effort to conceive the final product. Our ROV **Sylvia Earle** is specially designed to achieve the MATE and UN goals of helping with marine renewable energy and supporting healthy marine environments.

Sylvia Earle is constructed from PVC, supporting 4 propellers, 2 cameras, and 2 tool spots for interchangeable tools. Its PVC structure has been optimized for tidiness and ease of access through tether modifications and wire management. The downward-facing camera will prove especially useful in the many tasks that require scanning from above, such as flying a transect to monitor frog populations. Additionally, special tools have been constructed for returning dace fry to safe release areas. Variously shaped hooks have been implemented for certain general tasks such as pulling or lifting. We value simplicity and cleanliness in our ROV design as this helps us diagnose issues quickly and compete more effectively.

With these tools and attributes at hand, Sylvia Earle will be of great service to this increasingly developed world, where renewable energy and environmental health are of utmost priority.

1| Company Information

Coral Crusaders competed in the MATE competition for the first time this year and hence operated as a general partnership* comprising of the following members –

Company Photo *Photos by Coach Mike or Dylan unless otherwise stated

Dhruv Darbha (left) - General partner and co-owner of the partnership that has contributed to the designing and building of the control system, testing of the ROV, dividing the ROV tasks strategically, and working on the poster board. He is well-versed in VEX VRC Robotics and enjoys programming.

Dylan Wu (middle) - General partner and co-owner of the partnership that has contributed to building of the control system. He also designed and created the ROV, managed the team task list, and constructed the poster board. He enjoys marine biology and volunteering at the Seattle Aquarium.

Kounish Bhattacharjee (right) **-** Limited partner who helped with tethering, testing, and outreach efforts. He loves water sports and professionally competes in water polo.

Coach Mike Pesavento - Coach who provided mentorship to the team on designing and building the control system and the ROV, coordinated multiple testing sessions, and provided overall strategy to structure and grow the company in the years to come. He has been affiliated with the MATE competition for many years.

*Below is a description of the roles of a general and limited partner in our general partnership company:

- Shared Ownership and Management: A general partner is one of the co-owners of the partnership. Along with other general partners, they have equal authority and decision-making power in the management of the business.

- Decision Making: General partners actively participate in making key business decisions. They contribute to the development of the partnership's strategic direction, business plans, and policies. Consensus among the general partners is typically required for major decisions, such as expanding operations, or making investments. Limited partners generally do not have the authority to make binding decisions on behalf of the partnership.

- Management and Operations: General partners play a crucial role in overseeing the day-to-day operations of the partnership. This includes tasks such periodic progress checks of projects, coordinating with team, and ensuring the smooth functioning of business activities. Limited partners have a passive role in the day-to-day management and operations of the partnership.

- Collaboration and Communication: Effective communication and collaboration among general and limited partners are essential for the smooth functioning of the partnership.

- Financial Contributions: General partners are expected to contribute capital or assets to the partnership. This contribution may be in the form of cash, property, or expertise. Limited partners often invest in the partnership with the expectation of receiving a share of the profits generated by the business.

- Legal and Fiduciary Duties: General and limited partners have a fiduciary duty to act in the best interest of the partnership. This duty requires exercising care, loyalty, and good faith when making decisions or engaging in activities that affect the partnership.

2| Safety

Safety is our priority here at Coral Crusaders, and we take proper precautions.

2.1| Injury Prevention

- Wear safety glasses (soldering, power tools)
- Gloves when cutting
- Being cautious around heat (heat guns, soldering iron)
- Ensuring proper guidance from coach Mike before using a tool for first time
- Closed-toed shoes, long pants

2.2| System Precautions

- Ensure system is off when not in use
    - Check that everything is properly connected before turning on (so that nothing malfunctions)
- Easy access to power and reset switches on the control box (in case anything out of the ordinary happens)
- Wires are cleaned up (nothing will get tangled and accidentally pulled out)
- 25 amp fuse always utilized
    - Within 30cm of the power source (ensure that if something goes wrong, there are minimal wires with live current)

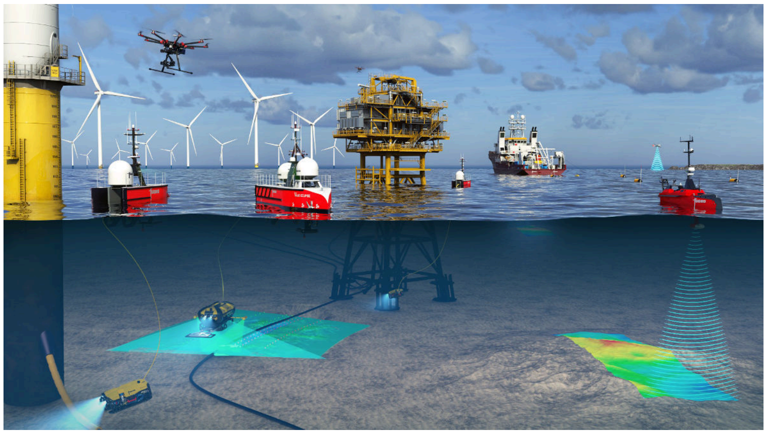
2.3| ROV Safety Features

- Strain relief which can lift five times ROV weight (so ROV can be pulled up safely if anything goes awry)
- All propellers are properly shrouded according to MATE standards
- More in-depth description in Design Rationale

3| Mission Theme

3.1| Marine Renewable Energy

As greenhouse gas emissions continue to rise, it is imperative to switch to renewable energies. Renewable energies are derived from natural sources (sun, wind, currents), that can constantly be replenished, unlike fossil fuels. Marine renewable energy provides several advantages over land-based renewable energies, including no land-use conflict, but this also means that maintenance would also be harder. Thus, automated ROVs would be critical to remote maintenance, and allow marine renewable energy to succeed.

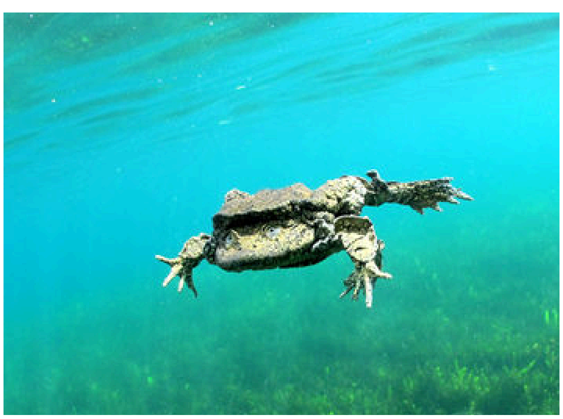


Future of Marine Renewable Energy Credit: fugro.com

3.2| Healthy Environments from the Mountains to the Sea

Climate change impacts everything - from the mountains to the sea. ROVs prove to be a valuable resource for conservation biology and data collection. For instance, the northern redbelly dace is considered endangered in certain states. The two main threats include invasive fish species and habitat alteration. With ROVs, habitats can be scouted for these non-native fish, and the dace can be reintroduced to safe habitats.

Likewise, they can be used for population monitoring. The Lake Titicaca frogs are listed as endangered on the IUCN Redlist and are threatened by pollution. Since they are fully aquatic, they are extra susceptible to aquatic pollution as they breathe through their skin. To monitor population trends, ROVs can be used to fly transects and count the frogs. This data can then be used to implement legislation to help ensure a healthy Lake Titicaca.



Lake Titicaca Frog Credit: iucn-amphibians.org

4| Project Management

Coral Crusaders met every Thursday starting in August, though more consistently starting in January. In March, we started meeting on Saturdays as well to make sure we were able to compete well at regions. We would meet at Coach Mike's house to discuss the next steps and work on high-level designs, after that we would take things home to work some more on physical builds. At every meeting, we would have a goal to be done by the next meeting, all to prepare for a wet test before May.

To keep things organized, we kept everything on OneNote, making everything easily digitally accessible.

Team Tasks

1. Check the Moving Forward 2022-23 page every week.
2. Read the 2023 Ranger Class Preview Mission document.
3. Continue looking for opportunities to recruit members for your team.
    a. Visit and talk with students in the Eastside Prep Robotics Club.
    b. Ask the Environmental Science teacher about students that might be interested.
    c. Submit a notice in the volunteer newsletter at the Seattle Aquarium.
4. Read the 2023 Product Demonstration and Specs Briefing document.
    a. Look through the references sited in the document to learn about the RFP background.
    b. Make a preliminary task list that will help guide your ROV design.
5. Read the 2023 Ranger Class Competition Manual.
    a. Deconstruct, summarize, and create 3x5 cards for the Mission Tasks. Divide the tasks into three categories based on their difficulty and ROV design requirements.
    b. Organize the tasks into a completion order strategy.
6. Redesign the ROV per discussions we have had on task deconstruction. Items we have discussed include:
    a. Remount the up/down thrusters so they can be vectored.
    b. Add a downward facing camera.
    c. Relocate the forward camera.
    d. Add a mount for bottom tools.
    e. Add a probe tool for pushing the button in the docking station.
    f. Rethink the tether connection (to make it less obtrusive).
7. Complete a PVC cut list for the ROV v2 redesign.
8. Put together a spreadsheet for running tether neutral buoyancy calculations. Here's an example.
9. Watch the Prop Building Demo and Q&A video. Take notes and write down questions.

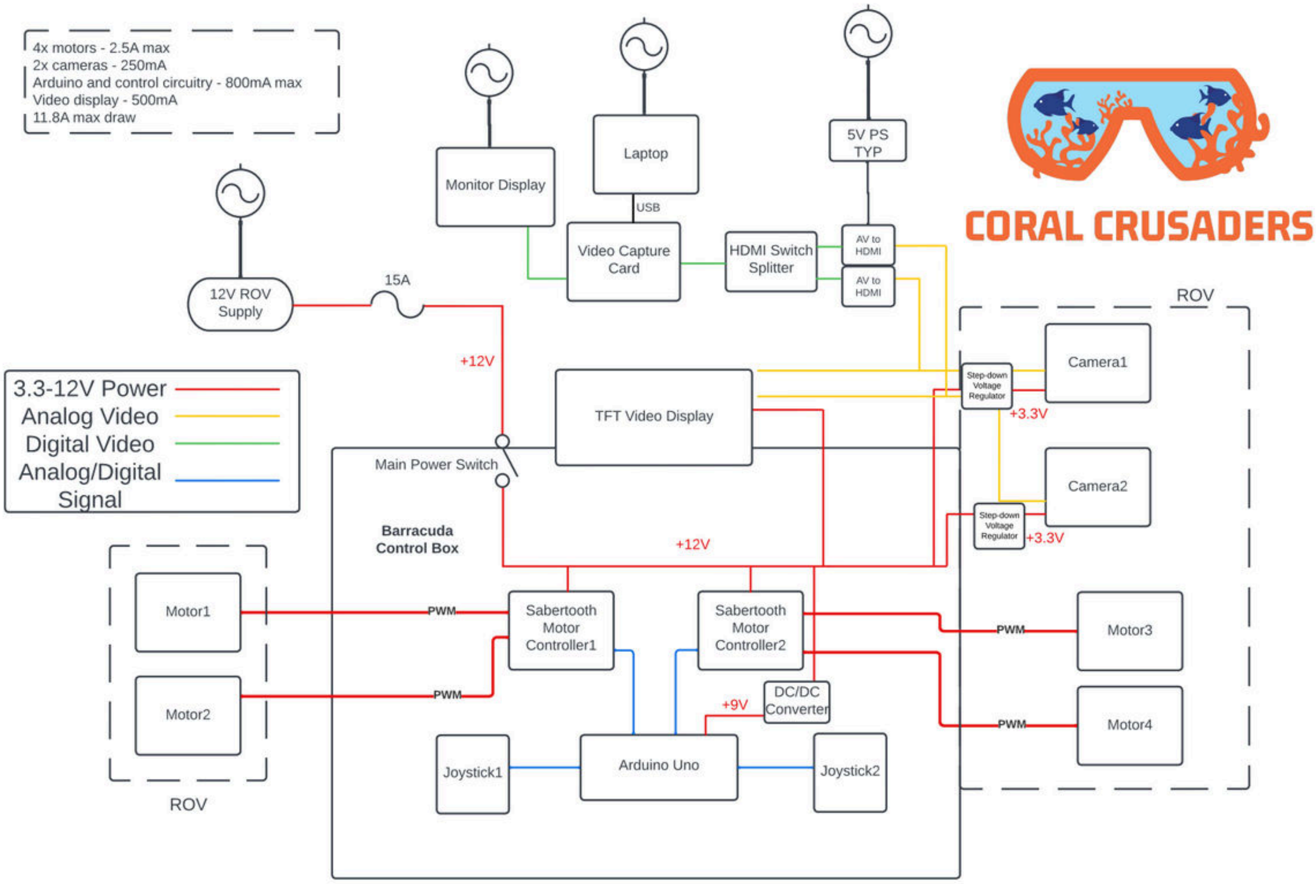
Team Tasks Snippet on OneNote

We all split up tasks - whether it was to build the control system, come up with a new frame design, or calculate buoyancy.

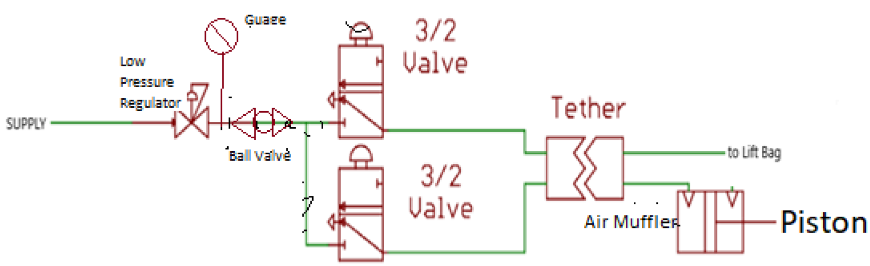
Communication was key, and we did so through E-mail and text.

5| System Integration Diagram (SID)

5.1| Control System Integration Diagram



5.2| Pneumatic System Integration Diagram



6| Design Rationale

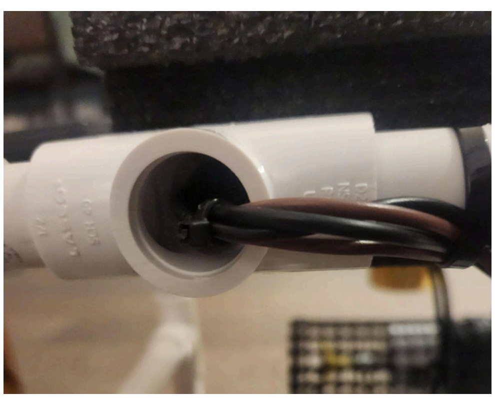
6.1| Frame

The cuboid PFC frame is 36 cm long, 25 cm wide, and 30 cm tall. It overall utilizes 3m of ½" diameter PVC, 27 T-pieces, and 4 motor sleeves. Overall this frame weighs around 1.7kg.

Cuboid Frame

PVC was chosen for multiple reasons. Firstly, as a starting team, PVC is easy to find and build with, as well as being cheap to buy. Additionally, it is easy to make changes to. We had to go through multiple iterations of PVC frame design to make one that could hold 2 tools and 2 cameras.

The frame has been constructed to allow wires to cleanly enter the tether and allows for convenient wire removal if a camera dies.



Wires Run through Frame

Clean Tether Connection

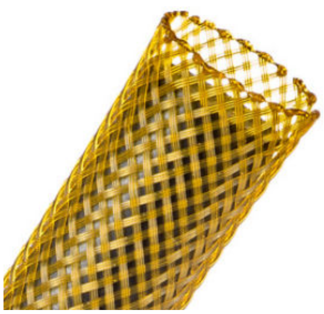
6.2| Tether

The tether consists of 2 camera wires, a motor cable, and 1cm diameter solid cylindrical polyethylene foam for buoyancy. This foam is run throughout the length of the tether, creating slightly positive buoyancy.

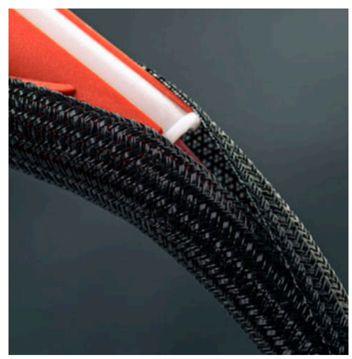
Cylindrical PE Foam Credit: homedepot.com

| Sheath

To cleanly contain all the wires, we started off using regular expandable TechFlex that came with the Barracuda Kit. However, the problem appeared right when we started wiggling all the wires through. It was hard and took more than half an hour just to get the worse inside the sheath. What made it worse was that there was no way to ever change out the wires within the TechFlex, in case a camera malfunctioned.



Expandable TechFlex



Split TechFlex Credit: techflex.com

Therefore, we bought some split TechFlex, which instead of being expandable, had an opening running down, allowing for easy changes to be made. Additionally, it allowed us a chance to add on, if we ever wanted to add an electronic tool or use pneumatics.

6.3| Control Box

As a new team, Coral Crusaders wanted to start simple. Instead of going for an ROV with onboard electronics (which allows for more electronic capabilities), we started with the MATE Barracuda kit.

This control box included two joysticks, an Arduino Uno, and 2 sabertooth motor drivers.

Barracuda Box Credit: seamate.org

| Box Revisions

After soldering and setting up the kit, we made several important modifications.

1. LCD module
    a. The kit didn't have a place to put the LCD module, so we had to improvise and put the LCD where the watt meter was, and zip-tie the watt meter between the joysticks.
2. Switches and Buttons
    a. To increase control capabilities, we added a reset button, LED light, and programmable switches. The LED allows for troubleshooting, and switches can be used for things like slow/fast mode when maneuvering.

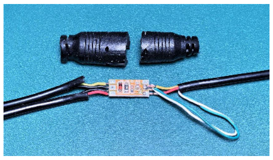
Modified Barracuda Box

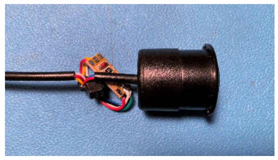
6.4| Video System

Our video system consists of a TFT display, a monitor, and 2 mini CCTV cameras.

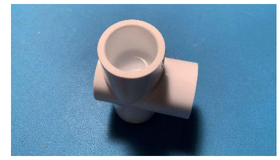
| Cameras

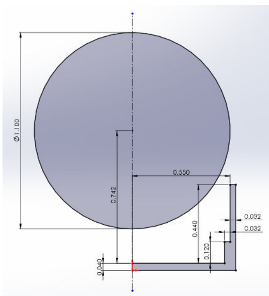
To make the cameras fit in a ½" PVC Cross, we needed to unsolder and resolder the step-down voltage regulator closer to the camera itself. Then it was fitted in a PVC cross with one cut end. Then 3D-printed epoxy plugs were inserted in the sides, and epoxy was poured to waterproof the camera. Additionally, an acrylic disk was adhered to the lens to further waterproof the camera.


Voltage Regulator


Soldering


Fitted in Cross


Epoxy


Solidworks Camera Cap


Finished Camera

To further protect the camera, we 3D printed lens caps. Solidworks was used for CAD designs.

We ran into some problems, however. Two of our cameras died due to a ground wire problem. As a solution, we switched to Siamese cables. While Siamese cables are thicker and take up more space within the TechFlex, they proved to be a stronger solution and the problem hasn't persisted.

The two cameras are placed on the front and bottom of Sylvia Earle. Many of the tasks in this year's competition involve a bottom camera to run transects and capture images.


Camera Cap and Siamese Cable

| System

As the CCTV cameras are analog, the signal must be converted to digital to display on a monitor. Thus we used an AV to HDMI converter to do so. Additionally, we utilized a video capture card to convert HDMI to USB so we were able to view the video on a laptop.

AV to HDMI Converters

6.5| Tools

| Hooks

Tools consist of a variety of hooks. The hooks are from bicycle racks and are sealed in PVC with epoxy and a 3D-printed plug. These hooks are versatile, with the double hook being most useful for the bottom tool. Because the hooks are angled, both of their ends can be seen by the down-camera so it can be easier to grab things. In addition, two hooks increase the chance of grabbing things by twofold.

Hooks

| Fry

The simpler - the better. The tool to carry the fry consists of a can with two strings attached - one to the top of the can, and one to the bottom. The top string is used to bring the can down, but the bottom string is used to bring the can up. When the bottom string is pulled up, the can flips, dumping all the fry out. These strings have slim floatation attached - enough to keep the strings upright in the water, but not so much that it could impact rotation. Ballast was also used to ensure that the rotation was proper and that it would not accidentally get pushed over on the floor of the pool.

Fry Container

| Push and Ruler Tools

The pusher tool was made out of a can lid. Its purpose is to make the last task of pushing the docking station button easier. The ruler tool is simply a ruler created for the task of measuring the coral dimensions. We used geometry to figure out the difference between the measured diameter on the screen versus the actual coral diameter.

Push and Ruler tools

m(cm)	d(cm)	m(cm)	d(cm)
1	1.02597	17	25.95512
2	2.105192	18	28.13237
3	3.239632	19	30.39124
4	4.43124	20	32.73293
5	5.68195	21	35.15856
6	6.993668	22	37.6692
7	8.368271	23	40.26588
8	9.807602	24	42.94955
9	11.31346	25	45.72111
10	12.8876	26	48.58144
11	14.53173	27	51.53134
12	16.24751	28	54.57158
13	18.03654	29	57.70287
14	19.90035	30	60.92589
15	21.84045	31	64.24128
16	23.85825	32	67.64964

Measured vs. Actual Diameter Chart

| Locking Mechanism

We thought of many locking mechanisms such as using screws or bolts, but we found that spring clips worked amazingly. The spring clip will automatically lock the tool into place inside the PVC. To take it out, you can use another tool to push the spring clip down, and then remove it.

Locked-in Tool

6.6| Floatation

The volume of floatation was calculated prior to the first wet test. Using Excel and existing density metrics, we found the volume of PE foam needed to keep Sylvia Earle neutrally buoyant.

Parts		Number		lb/part	Total lb	Volume/part	Total Volume	Notes				
PVC Pipe	Length		Length of parts	0.0126607 lb	1.513 lb	0.250319 in^3	29.91311584 in^3					
	2 in	12	24 in									
	2.5 in	8	20 in						Additional Metrics			
	3.25 in	10	32.5 in						0.0488	lbs/in^3	PVC density (1.3-1.45 g/cm^3)	
	3.5 in	8	28 in						0.2503	in^3	volume of 1/2" PVC pipe per inch	
									0.0127	lbs	weight of 1/2" PVC pipe per inch	
	7.5 in	2	15 in						0.03866	ABS density (0.9–	lbs/in^3	
		Total Length	119.5 in						0.2765	Steel rebar densi	lbs/in^3	
									0.00126	PE foam density	lbs/in^3	
PVC Tee		27		0.073 lb	1.971 lb	1.441 in^3	38.907 in^3		0.03613	Water density (1	lbs/in^3	
Cross		0		0.066 lb	0 lb	1.36 in^3	0 in^3	*includes camera cross				
Tether Grip		1		0.027 lb	0.027 lb	0.692 in^3	0.692 in^3					
Motor		4		0.441 lb	1.764 lb	8.631 in^3	34.524 in^3					
Motor sleeve		4		0.068 lb	0.272 lb	1.448 in^3	5.792 in^3					
Camera		2		0.1 lb	0.2	1.8 in^3	3.6 in^3					
PVC coupler												
Motor coupler		4		0.015 lb	0.06 lb	0.156 in^3	0.624 in^3					
Prop		4										
Nut												
Screw		4		0.007 lb	0.028 lb	0.022 in^3	0.088 in^3					
									Density			
Total					5.835 lb		114.1401158 in^3		0.051121 lb/in^3			
	Neutral buoyancy calculations				0.0618 lb		49.06995749 in^3	PE foam volume and weight				
					5.8968 lb		163.2100733 in^3	ROV volume and weight WITH PE FOAM				
									0.03613 lb/in^3			

Flotation Spreadsheet

To keep with our clean design, we chose to make rectangular prisms of foam with circular cutouts for PVC pipe. To cut this, we used a sharp toilet paper roller.

The first time we put Sylvia Earle in the water, it was slightly positively buoyant, but near perfect. We strapped on some foam with zip ties and added 2 bars of 1.25cm diameter steel rebar as ballast to the bottom, and it was able to achieve neutral buoyancy.

The benefit of adding more foam and more weight as well is to increase the distance between the center of buoyancy and the center of mass. The increased distance ensures that the ROV can go back to stable equilibrium (upright in the water), thus being more stable than if the centers of buoyancy and mass were close together.

A downside could be increased weight, but considering that our ROV is compact and has a lightweight frame, ballast is not a problem.

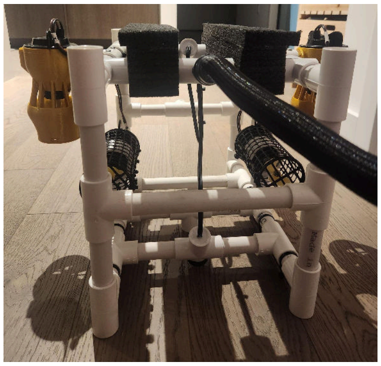
Steel Rebar Ballast

PE Foam Floatation

6.7| Propulsion

Sylvia Earle has 4 bilge pump motors for propulsion. This is the maximum amount of motors that can be supported by the two sabertooth motor drivers. 6 thrusters would have been ideal - to perform all 6 degrees of freedom, but alas we tried to make do with what we had.

Even with four thrusters, the placement options were endless. In the first iteration, the two vertical motors were on the inside of the frame, but after finding a convenient way to place foam on the ROV, we moved the vertical motors to the outside.

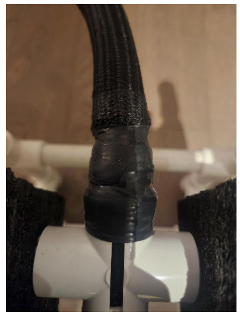


Final Motor Placement

Vectoring was always an option. We chose not to vector any of the motors for the following reasons. First, the regional pool is very deep, which means fast up/down movement is critical, so the vertical thrusters are best not to be vectored. For the horizontal thrusters, we found it better to control without vectored movement. Plus we did not have enough time to practice in the pool with it, so non-vectored thrusters were a safer option.

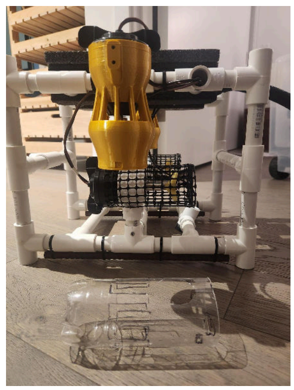
6.8| Safety Features

Sylvia Earle has a strong strain relief, utilizing multiple layers of sheathing and permanent self-bonding silicon tape which can hold at least 5 times the weight of the ROV out of the water. We tested this out by attaching a suitcase scale to the ROV and by pulling the ROV up by the tether. The scale read 18kg while the tether did not seem stretched or abnormal at all.



Strain Relief

The motors are shrouded as per MATE standards (no holes greater than 12.5mm wide).



3 Motor Shrouds

The first motor shroud we tried out was with plastic bottles. The Coral Crusaders love a good ICE drink, and it happened that the bottle fitted the motors perfectly. However, it was a struggle to cut the right-sized holes. So the second solution we used was garden mesh. We fitted the mesh around a 3-D printed plate and attached it to the motor. We also tried using 3-D printed shrouds (Credit to sthone and djsn on thingiverse.com for the design).

7| Finances

7.1| Budget

Budget of Coral Crusaders Expenses	
Category	**BUDGET**
Consumables	$50
Control System	$1,000

Fees	$500
Storage	$50
Pneumatic System	$150
ROV Build	$400
ROV Tools and Props	$100
Tether Build	$200
Tools	$50
Travel (Flight, housing, food)	$4,000
Video System	$250
GRAND TOTAL	$6,750

7.2| Cost

Summary of Coral Crusaders Expenses			
Category	**Contribution**	**Expense**	**BALANCE**
Consumables		$51.82	$51.82
Control System		$997.12	$997.12
Fees	$770.00	$298.93	-$471.08
Storage		$32.59	$32.59
Pneumatic System		$209.00	$209.00
ROV Build		$494.08	$494.08
ROV Tools and Props		$283.72	$283.72
Tether Build		$226.39	$226.39
Tools		$50.45	$50.45
Travel	$1,000.00	$4,320.43	$3,320.43
Video System		$303.83	$303.83
GRAND TOTAL			$5,498.34

A more detailed itemized spreadsheet is found here. It is too large to fit in this documentation.

Note that everything the vast majority of things are bought since we are a new team.

All funding was supplied by Coach Mike and parents. We obtained a $1000 travel grant from MATE for winning the regionals, and $770 worth of pool time from the Redmond Pool. We did not get any sponsors.

8| Challenges

Coach Mike had often said that “the first year is always the hardest”, and yes there is a large kernel of truth to that.

The first big challenge was Covid and commitment. At the start of Covid, we were three - Dylan, Dhruv, and Kounish. We had previously planned to compete in the 2022 MATE competition, but this proved to be a stretch considering the lack of strong commitment and the pandemic. Kounish also decided to take a break from underwater robotics. However, this year we made it our goal to get a robot in the water no matter what. Even if we had a crooked ROV with malfunctioning motors, we were going to compete regardless - just for the experience. Our goal of getting the ROV in the water turned into us competing at the world championship!

With that mindset, we still had to face the problem of a lack of team members. Despite taking the initiative in multiple member-searching quests, they all ended up unsuccessful. Regarding outreach, Dhruv reached out to his peers in Redmond High School and advertised to his VEX robotics organization about UWR technicalities. In addition, as a long-time volunteer at the Seattle Aquarium, Dylan used their monthly volunteer mail to educate about UWR, and the unique opportunity MATE provides, while searching for new team members interested in the ocean. The company format of the MATE competition allows for members of all skill sets to participate in a challenge. Despite this roadblock, we were able to work together to win the Pacific Northwest Regional as a first year team.

Another challenge was that Coral Crusaders had little prior experience with soldering and control boxes. Thus we had to embark on a long learning curve as we encountered problems from cold solder joints to blown fuses and burnt Saberteeth. But, Coach Mike readily assisted us, and we learned from those mistakes.

Lastly, after the regionals, there was a big question mark on team roles. Since the team comprised of only three, it was hard to assign large company titles such as CEO, CTO, and CFO when everyone contributed to everything. Thus, we found the solution of making our company a limited partnership, which accurately portrays our team.

9| Lessons

Always have a goal in mind. Without a goal, there is nothing to reach and nothing to challenge. At the start of the year, our vision was blurry. We did not have a clear goal - were we planning on attending the 2023 competition, or was it going to be another year flying past? But we aimed high, and here we are, winning the regional, and attending Worlds with Sylvia Earle.

There will always be something to improve - you will never be done. Every time we look at Sylvia Earle, we always ponder the millions of ways she could be improved. Whether it was half a year ago, or half a day ago, it always seems like there was a never-ending list of improvements. But coming out of this experience, we learned to appreciate what we have and how far we have come.

Another thing we learned was an appreciation for mistakes - and we made a lot of them. The earlier you make mistakes, the earlier you learn from them and can improve. Some mistakes can be more costly than others - but the lessons they teach are invaluable.

10| Future Improvement

There is always something to improve. After the competition, we plan on getting our gripper to work. We had aced the fluid power quiz, and prepared a pneumatic system with a grabber tool (grabber tools for seniors with less reach), but did not have time to set up a complete system before the competition. Therefore, we will be competing without a gripper - so next year, we definitely want to have that.

Another thing we are aiming for is a 6-motor design. Extra maneuverability will without a doubt come in handy for skilled tasks. This also means we will need to revamp the control box, or better yet, build some onboard electronics.

And finally - we will need to find more people. The great thing about the MATE competition is that every team is a company, and every company has people of all different areas of expertise. Having each person assigned to a specific job would make things run much smoother and output better results than if one person was juggling many assignments.

11| Acknowledgements

We would like to thank Coach Mike for continuously supporting us on this journey while sharing wisdom and experience. We would be unable to make it to the regional, much less the world championship, without your lessons, patience, and belief in us.

Additionally, the parents have been gracious in supporting this year's financials. Without their help, we would not be able to afford to build Sylvia Earle since we were a first-year team and lacked the time to reach for sponsors.

Thank you MATE II for this unique competition.

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