Abstract:

As a part of the SeaPerch competition, we created an ROV that could complete the obstacle and waterway challenges as fast as possible. The challenges required the ROV to navigate through hoops and to transport sunken and floating debris. Our approach, to reduce development and time costs, consisted of an iterative process that first optimized stability and then efficiency in the Seaperch games. Stability is critical to drivability, and we spent much our time implementing techniques so our ROV would travel straight along the surge axis. We developed a frame 25.4 centimeters long. With its length, we placed ballast at the front and our two horizontal motors at the very back. We also designed a tether position that avoided any weight at the back that could shift our center of gravity. The python software that we wrote refined stability too. It calculated the location and needed amount of weights and flotation. The techniques solved the problem where the torque output of the back motors would overwhelm the ROV's balance. We then implemented a series of changes to solve the water games. We created a large opening that held floating debris. We attached a hook and passive claw intake. The intake would simply press into an object and held the debris through its elasticity. The mechanisms were successful as none required extreme precision from the driver. Other novel ideas that helped to make the ROV effective included a tachometer and a modularity. We used a tachometer to record the RPMs of several motors and chose the two with the closest values. The tachometer solved our problem where one motor was faster than the other. Our modular design was helpful as well. Modularity refers to printing several parts that attach to form the whole chassis. It increased the speed at which we could build and test ideas because it reduced the amount of 3D printing material needed. We believe our ROV could have future commercial applications. With appropriate scaling and autonomous algorithms, it could clean sunken trash in a lake.

Task Overview:

The tasks for the ROV are split up into 4 different sections: the recovery challenge, the obstacle course, the speed challenge, and the waterway clean-up. The recovery challenge involves collecting 3-ring triangles and placing them into a designated recovery bucket in the greatest quantity in the shortest time. With this challenge, our ROV needs the ability to lift the weight of the triangles, and thus, the ROV should be positively buoyant. In the obstacle course, the ROV must pass through a series of hoops differing in direction, surface, and complete the course again but in the opposite direction, all in under 5 minutes. The control of the maneuverability and speed, as well as tether management, are important for this challenge. For the speed challenge, the ROV will have to race against another robot to reach a pool wall as fast as possible. Here, we are focused on being able to drive the ROV in a straight line to minimize the distance traveled. For the waterway clean-up, there are four tasks to be completed: the active mine, the disposal vault, the garbage patch, and sunken waste. In the first task, the ROV must disarm the Active Mine by either rotating or removing the Arming Device. Task two involves opening the Disposal Vault Gate, depositing the mines and sunken trash into the vault, and closing and relatching the Vault Gate. Then, as part of the garbage patch task, the ROV must retrieve items from the Garbage Patch Containment Ring and transport it to the pool deck. In the sunken waste portion, the ROV must retrieve sunken waste and mines from the Waste Platform and deposit the items on the Disposal Vault Platform. Well thought-out claw and hook designs are especially necessary in these tasks since the success of the ROV depends on being able to grasp differently shaped objects. Recovering items from the garbage patch is especially important to earn the most as each object is worth 10 points. In each challenge, ensuring drivability is critical. To help pass through the hoops, our ROV must be no wider or taller than 30.5 centimeters and for the waterway challenge, our intake designs should not require the driver to be extremely accurate when grabbing the debris. We should prioritize stability because it would make driving easier. The ROV should be negatively buoyant for the garbage patch to bring the object down. It should be positively buoyant for the waste platform to carry the object to a higher level.

Design Approach:

To successfully build our ROV, we followed the engineering design process. We first defined the problem. We must build an ROV that would sufficiently complete the obstacle and mission courses designed by the Seaperch program. We then researched. From last year, we know how critical stability is to the ROV's success. A ROV has movement about six degrees of freedom: three translations- surge, heave, and sway, and three rotations- roll, yaw, pitch (Christ, 2007). For ease of driving, we designed our ROV to move straight along the surge axis. To solve both the waterway challenge and stability problem, we used an iterative process that consisted of two main steps and further sub steps: first, to maximize stability, and second, to maximize the efficiency at which we could transport debris. Figure 1 illustrates our iterative process and the sub steps involved.

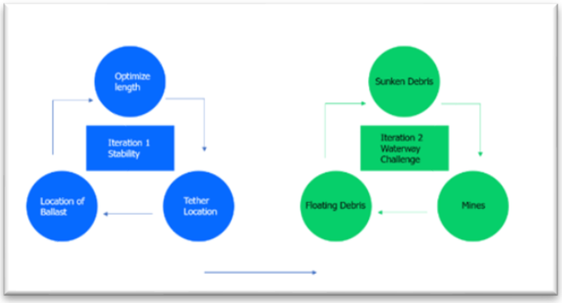


Figure 1: The chosen iterative process

As we brainstormed and evaluated, we decided to use a square frame for the ROV as it was simple and because it was mostly hollow, it would not create much drag (Buoyancy, n.d.). However, from last year, we know the torque from the motors often overwhelms the ROV's balance and causes it to pitch upward (General Thrust, n.d.). We decided to experiment with long and short frames in which the length was maximized and minimized to the extreme to see if we could minimize the length without the ROV porpoising. Our frames can be seen in Figure 2. We moved onto developing a solution and printed our CADs. We used our motors and control box from last year to quickly prototype.

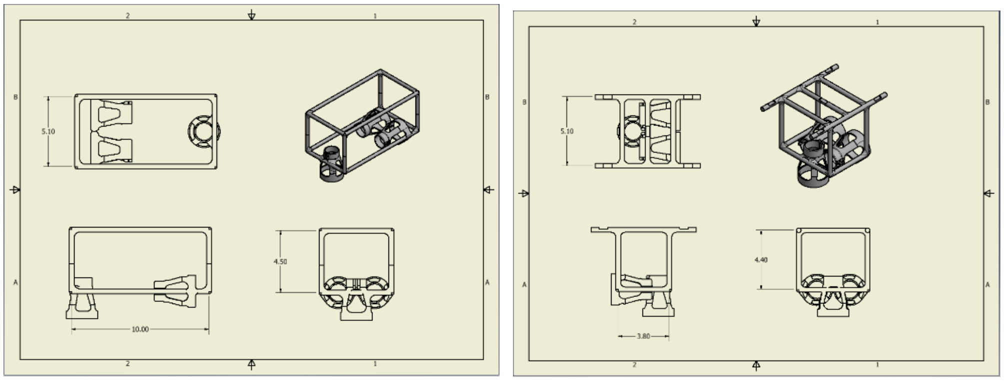


Figure 2: Isometric and base views of the experimental long (left) and short (right) ROV frames.

In the testing phase, the long frame porpoised less compared to the short frame but still slightly. To completely remove the upwards pitching, we added two ¾ gram weights to the front and moved the motors to the very back. By placing the motors at the back, we maximized the distance between weights and the torque output from the motors. We also wrapped the tether around the front to prevent any weight that could shift the center of gravity back.

Figure 3: Ballast placement (left), tether placement (middle), motor placement (right).

With stability solved, our next step in the iterative design process was to revise the ROV so that it would effectively intake and carry debris. We removed the front side supports for easier driving. Our ROV could now approach floating debris at an angle. We also noticed the bottom of the ROV would hit the floating object. We moved the vertical motor back 5.1 centimeters. As for the sunken trash, we created a passive claw intake and hook. Our first hook required too much precision from the driver because the distance between it and the vertical motor was only 2.8 centimeters. We increased the height of the hook, so the distance is now 8.3 centimeters. After securely attaching our passive intake, the ROV could hold the sunken water bottles and cans. Figure 4 illustrates our iterations to improve our speed in the Waterway Challenge.

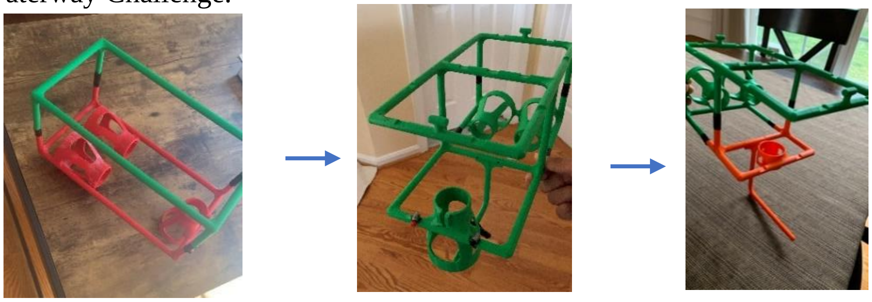
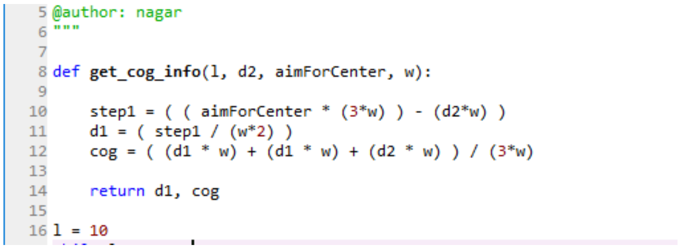


Figure 4: Initial long ROV frame (left), Waterway ROV (middle), Revised Waterway ROV (right)

Our ROV consists of many unique ideas that we used to our advantage. We used kickboards for buoyancy. It is easily mountable to the ROV and it does not become waterlogged. To calculate the general amount of buoyancy needed as well as the location of the center of gravity and buoyancy, we wrote software in python, another one of our novel ideas. This allowed us to assess how much life board we needed and where to place components of the ROV, specifically the motors, to ensure that the center of gravity remained in the middle of the ROV (What is buoyant force, n.d.).



```python
@author: nagar
"""


def get_cog_info(l, d2, aimForCenter, w):

    step1 = ( ( aimForCenter * (3*w) ) - (d2*w) )
    d1 = ( step1 / (w*2) )
    cog = ( (d1 * w) + (d1 * w) + (d2 * w) ) / (3*w)

    return d1, cog

l = 10
```

Figure 5: A snippet of our software

Our third novel idea was to employ a modular design. This enabled us to edit parts of the ROV without needing to reprint the entire body, and it allowed us to experiment with different back motor heights. Modularity removed our production bottleneck where we could not print and test parts fast enough. Our fourth original idea was using a tachometer to determine the speeds of the motors and chose ones that were closest together. Our initial back motors were causing issues in how straight the ROV was able to maneuver. So, we tested the RPMs of several motors, and we chose the closest two RPMs out of our selection. It changed from a 2000 RPM difference between the two back motors to around 150.

Figure 6 illustrates our final ROV ready for the regional competition. The final dimensions are 25.4, 12.9, and 11.4 centimeters for the length, width, and height respectively. The ROV is stable and moves straight along the surge axis through the following techniques: ballast at the front, tether position, long frame, and our software that finds the optimal locations for ballast and motors. In other words, the techniques maximized the distance between our ballasts and motors while ensuring the center of gravity remained in the middle. Our driver can easily carry the floating debris through the ROV's large opening which allows for the ROV to approach the trash at most angles and heights. The ROV efficiently gathers sunken trash through a hook and passive claw intake. Our kickboard as floatation is effective as well because it does not become waterlogged and is easily mountable.

Figure 6: Final ROV

Results:

We ran multiple tests throughout our design process. The first test conducted analyzed the difference between a longer and shorter frame. We observed that the shorter one pitched upwards more often than the long one. Thus, we chose the long frame as our base design. To further increase stability, we added weights and wrapped the tether around the front in our next design since the original tether position shifted our center of mass.

Figure 7: The short ROV frame in water-testing

We also tested the long ROV's ability to hold floating objects. We noticed that the front side supports required the object to enter at a certain angle; thus, we printed a new ROV that removed these supports. We then conducted a third test with our new ROV that compared the height of our back two motors. Figure 8 illustrates both positions of our back motors, one being closer to the bottom of the ROV. The position with the motors closest to the center drove at a faster speed. The results surprised us because we had hypothesized that the bottom motors would increase the distance between the center of gravity and buoyancy, allowing for more stability, but that was shown to be incorrect (Buoyancy, n.d.). We speculate that the upper position is allowing the center of torque to act through the center of gravity (General Thrust, n.d.).

Figure 8: Different Motor Heights

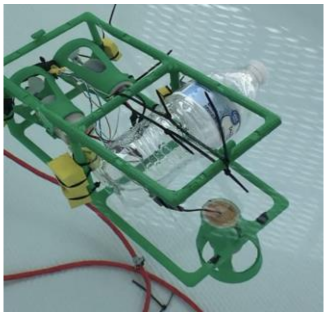


Figure 9: Testing the Waterway ROV's effectiveness at collecting floating debris

The fourth test conducted determined how effective the new robot was at collecting game objects. We placed a half-filled water bottle into a tub and the ROV attempted to grasp and carry it. By doing this, we found out that if we kept the vertical motor on, half of the ROV's body would be out of the water and it would be able to access the objects. We also observed the bottom half of the ROV would hit floating debris. We printed a new piece that moved the vertical motor back 5.1 centimeters so the object could enter at most angles and now heights.

The fifth test refined our ROV's ability to hold sunken trash. Our ROV attempted to pick up sunken waste and we observed the hook was too close to the vertical motor. It didn't allow the game objects to pass through into the ROV since it was so close to the body. We printed a new hook that increased this distance. To hold sunken water bottles and cans, we attached a paperclip bent into a semicircle to the bottom of the hook. The paperclip flexes outwards to grasp the circular objects and using the vault's hoop, it lets the object loose.

Throughout our iterations, we conducted tests to quantify the ROV's ability to move straight along the surge axis. We placed the ROV two centimeters high at one end of our water tub and drove it to the other end. We measured how far the bottom of the ROV was from the inside of the tub and recorded the difference between the beginning height and the end height. Figure 10 illustrates the differences among our iterations. From figure 10, we concluded that our iterations were effective at reducing porpoising because the difference in heights approached zero.

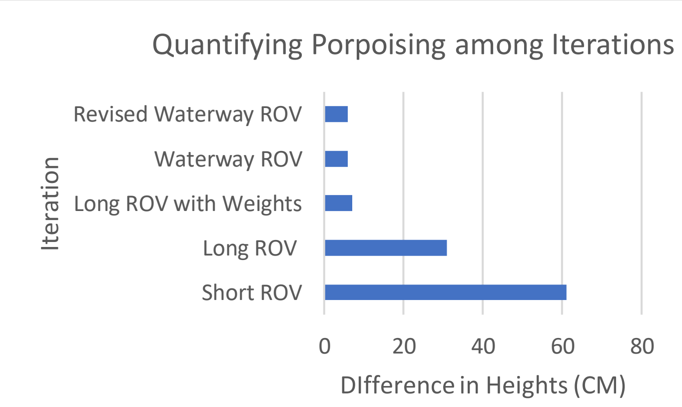


Figure10: Bar graph of conducted test

Reflection:

Despite the current situation, our team managed to construct a ROV that we were pleased with. A prominent reason for the ROV's efficiency was following the design and iterative processes. We researched thoroughly to refine the stability of the ROV. We brainstormed and evaluated approaches with the length of the ROV and the buoyancy to best limit porpoising, eventually deciding on a long ROV frame with ballasts at the very front. We then conducted tests to find the most efficient intakes for transporting debris, which we accomplished by creating a large, open 'mouth' to hold floating objects. The hook and passive intake that we employed allowed for easy movement of the sunken trash. Our ROV, after multiple rounds of researching, prototyping, experimenting, and observing, could optimally complete the obstacles. We structured our progress in the iterative process to be taken one step at a time, which provided orderliness within the advancement of the ROV. The design remained simple, shown through our square frame, which enabled us to prioritize other factors such as the object intake.

Not all of our success can be attributed to the design process. It was also creative ideas that contributed to an effective ROV. One major bottleneck had been printing. Since printing an entire ROV frame for each test wasted time and materials and couldn't be done at our expected pace, we engaged a modular design in which we could easily replace specific parts of the ROV. This allowed us to conduct experiments while using less materials, and it benefited us significantly in the time aspect of our project. Not only did we do well with managing our time, but our focus on the stability and drivability of our ROV was instrumental. The ROV was able to drive in a straight line along the surge axis through a long frame that distanced the motors and ballasts. Our software written in Python was very helpful as well. It automated the process of calculating the amount of flotation and weights, and locations for the center of gravity and buoyancy.

However, there were some parts of the process that could have been completed more effectively. Our ability to grasp the sunken waste was adequate, but it could have been easier for our driver to ensure a higher chance of success. We are considering attaching a fourth motor for an active claw design, but there are pros and cons to it. The claw would improve our speed in collecting sunken trash, but it would add complexity. Our future plans also include adding ducts to produce greater thrust, and therefore reduce our times in the speed challenge. We are also looking into a closed hydrodynamic design, comparable to the Trident ROV (Mitchell, n.d.). It would reduce drag greatly. We should have taken further steps in minimizing our research and design costs. While we did notably reduce our printing time, we still want to find faster ways to create the components, along with finding a more cost-effective way to test different frames. We will experiment with computational fluid dynamics for this.

With that said, we believe that we accomplished our goal in building a successful ROV. It could have commercial applications. A hobbyist not looking to spend over 50 dollars could want the ROV as it is very cheap to manufacture. Our ROV could also be used, after appropriate scaling, to clean sunken waste in lakes with autonomous algorithms. Our ROV, due to its stability, could serve as a base design where other teams add mechanisms, such as an arm, to solve a wanted task. Our research with pitch can help other teams and the academic community.

Acknowledgments:

We would like to express our gratitude for our teacher, Mr. Quast. We are extremely grateful for his persistence to continue the Seaperch season. We would also like to thank him for providing the tools needed to build and test ROVs. We would like to thank Ms. Carroll as well. Her motivation to continue PWCS robotics despite the current situation is inspiring. Finally, we would like to thank our parents. Your encouragement was much appreciated.

References:

Buoyancy, Stability, and Ballast 1 [Digital image]. (n.d.). Retrieved January 5, 2021, from http://www.cornerstonerobotics.org/curriculum/lessons_year3/eriii9_buoyancy1.pdf

General Thrust Equation. (n.d.). Retrieved January 5, 2021, from https://www.grc.nasa.gov/www/k-12/airplane/thrsteq.html

Mitchell, S. (n.d.). OpenROV Trident. Retrieved January 5, 2021, from https://seabits.com/trident/

Robert D. Christ and Robert L. Wernli Sr., *The ROV Manual: A User Guide for Observation-Class Remotely Operated Vehicles*, Elsevier Ltd., Oxford UK,First edition, 2007.

What is buoyant force? (n.d.). Retrieved January 5, 2021, from https://www.khanacademy.org/science/physics/fluids/buoyant-force-and-archimedes-principle/a/buoyant-force-and-archimedes-principle-article#:~:text=The%20reason%20there's%20a%20buoyant,the%20downward%20force%20from%20water.

Appendix A: Budget

Component	Vendor	How was your component used?	Cost
3D Printed Frame (184 grams)	MakerBot	Connects and protects major components of the ROV	$9.20
Kickboard	TYR Sport	Serves as flotation	$2
Total Cost of Seaperch Components			$11.2

Years participating in SeaPerch

Times at the International SeaPerch Challenge

Our SeaPerch is unique because: (100 words MAX)

SeaPerch Design Overview: (100 words MAX)

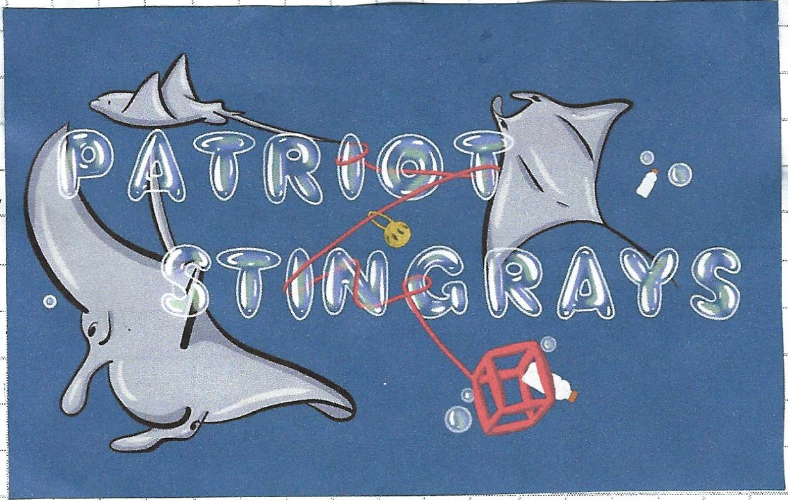
Our biggest takeaway this season is: (100 words MAX)

Contents

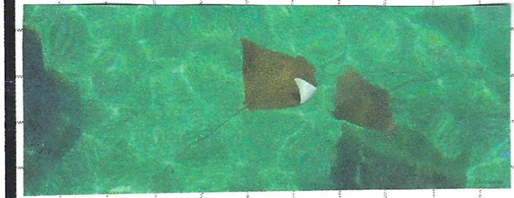
LOGO DESIGN

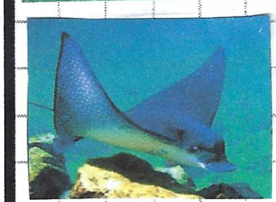
To start off the notebook, we will outline its purpose. The notebook involves aspects of the design process that we feel we did not explain adequately inthe technical design report.

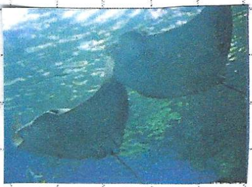
The first step to designing the logo was researching. We started by looking at the components of a good logo. Clean and symbollic were the agreed key factors. We then chose logos that we liked and tried to emulate the style we saw. While doing this, we chose the mascot, stingrays, and the subsequent team name.



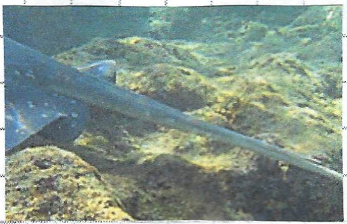
The logo has a clean and cartoon-like style.







We chose stingrays as our mascot because we believed that they best expressed the goal for our ROV. They are able to smoothly and gracefully propel themselves through water, which were traits that we focused on while building our ROV. Their large and flexible fins help them balance. They are able to swim by moving their bodies in a wave-like motion and undulating their fins. They can also flap their fins, giving them the illusion of flying through the water. This represented what we wanted our ROV to act like.



A stingray's tail

While normally not agressive, they have a stinger they can use. When provoked, they will prevail as triumphant. Because of this, stingrays best modeled not only our ROVs abilities, but our team as well.

OWNER / DESIGNER Anika	DATE 3/24	☐ UNIT ☐ PROJECT
WITNESS / TEACHER Naman A	DATE 3/24	PROPRIETARY INFORMATION

LOGO DESIGN (CONTINUED)

After we decided on our mascot, we formulated rough sketches of possible logos. As a team, we looked and agreed on which one we liked the best. We made our decision based on originality and which design was the most attainable. We wanted to produce a quality logo, so we selected a design which we believed we could realistically create with our lack of experience in digital art. We chose sketch 3.

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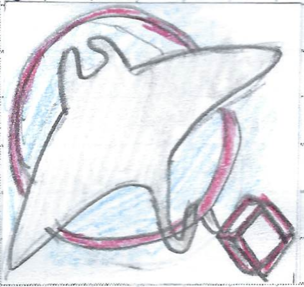

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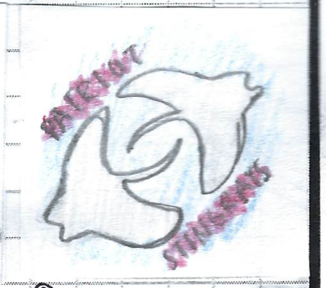

③

④

The white letter outlines

We then began the designing process. We used the Autodesk Sketchbook program to make the logo. None of us were familiar with graphic design, so it was a learning experience as we made the logo. Our beginning stages involved experimenting and playing with the program. The first thing we did after familiarizing ourselves with the program's basic functions was to start the outlines of the sketch. In order to fit with the water theme, we made the letters of our team name look like bubbles. We started with just a white outline of all the letters. Then, we added a transparent white layer filling the letters, green and purple shading, and finally, white highlights.

Transparent white layer

Purple/Green Shading

White highlights

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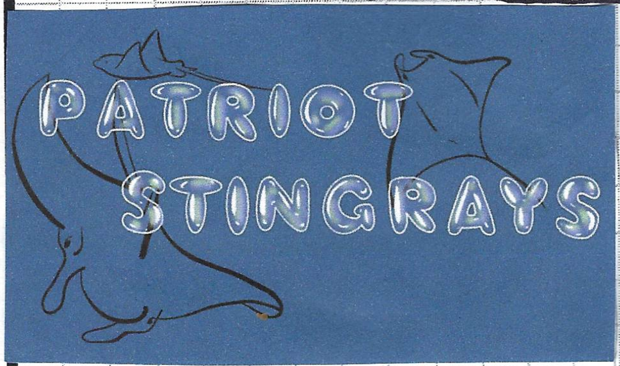
WITNESS / TEACHER Naman	DATE 3/24	PROPRIETARY INFORMATION

LOGO DESIGN (CONTINUED)



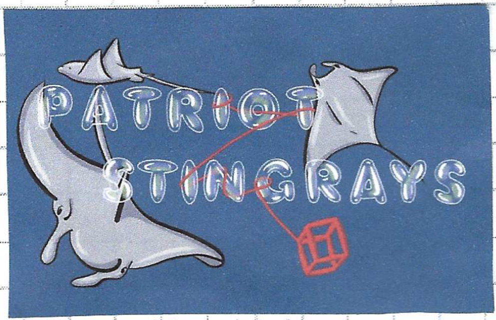
Stingrays are outlined.

Stingrays are colored.

We moved onto drawing the stingrays. We put a total of three, each showing a different perspective and depth. We started with a black outline (top left) of each of the three stingrays. Then, we filled it in using silver to match our school colors of blue, red, and silver (top right). Lastly, shading and highlights were added to complete the stingrays. (bottom)

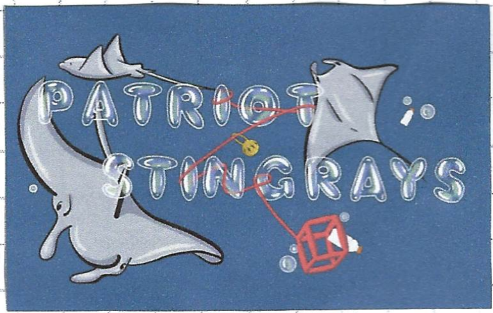
Shading/highlights are added.

We focused on the ROV. Since our ROV was a simple box shape, we depicted that in the logo. We used our school's theme color of red, and created a hollowed cube. We decided to make the tether long and loopy, so we wrapped it through and around several of the letters before connecting to the ROV.



The ROV is added

Lastly, we completed the finishing touches. We added game objects, such as water bottles and a mine, and scattered them throughout the logo. We drew some bubbles in as well through the same process as the letters.



Game objects and bubble are added.

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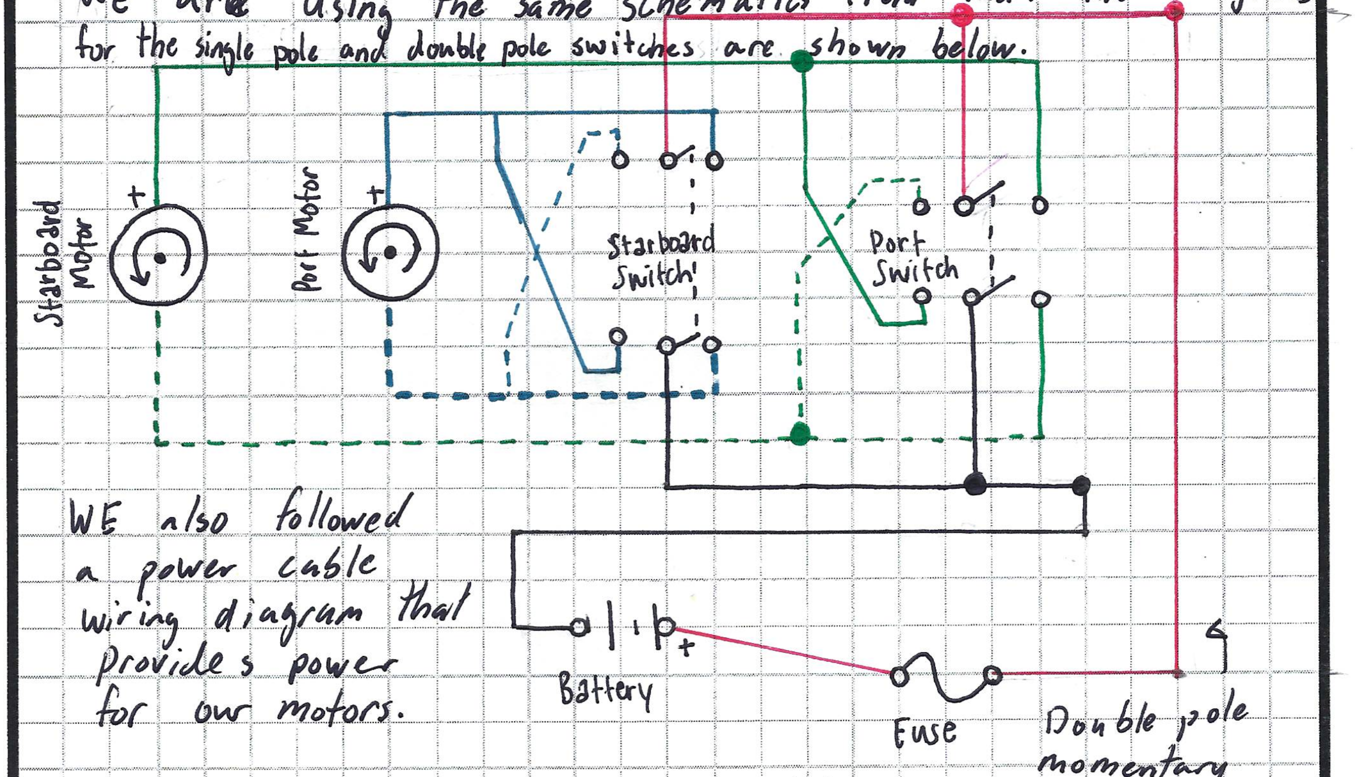
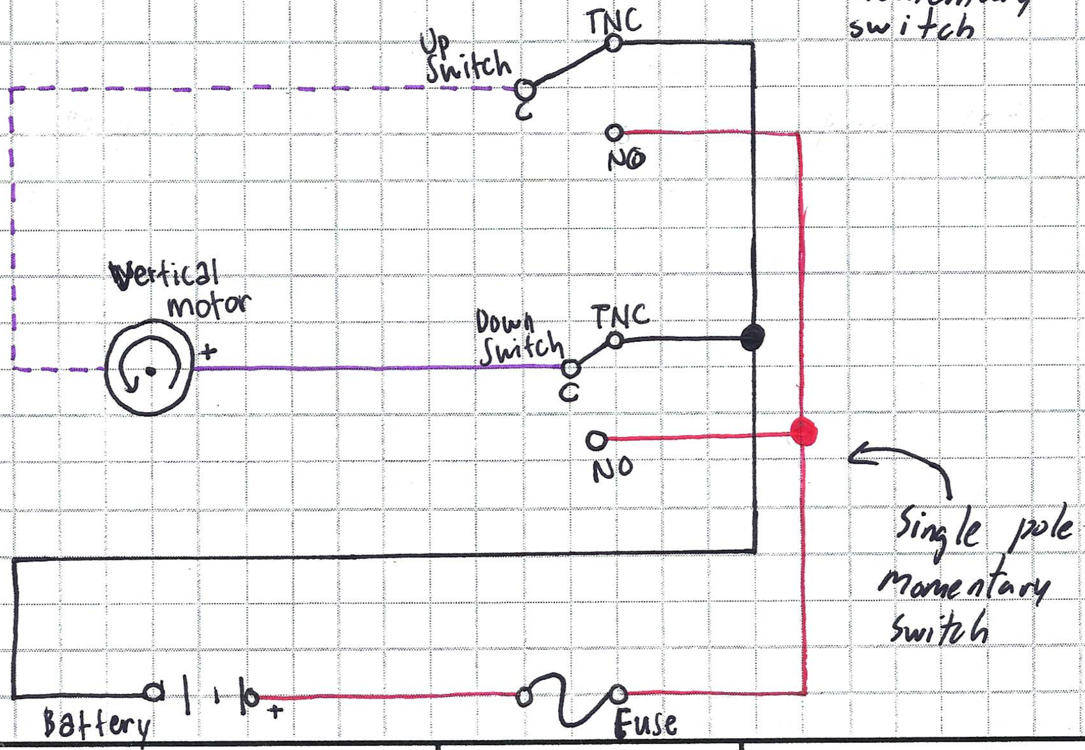
WIRING

We are using the same schematics from last. The diagrams for the single pole and double pole switches are shown below.



WE also followed a power cable wiring diagram that provides power for our motors.

Double pole momentary switch



Single pole momentary switch

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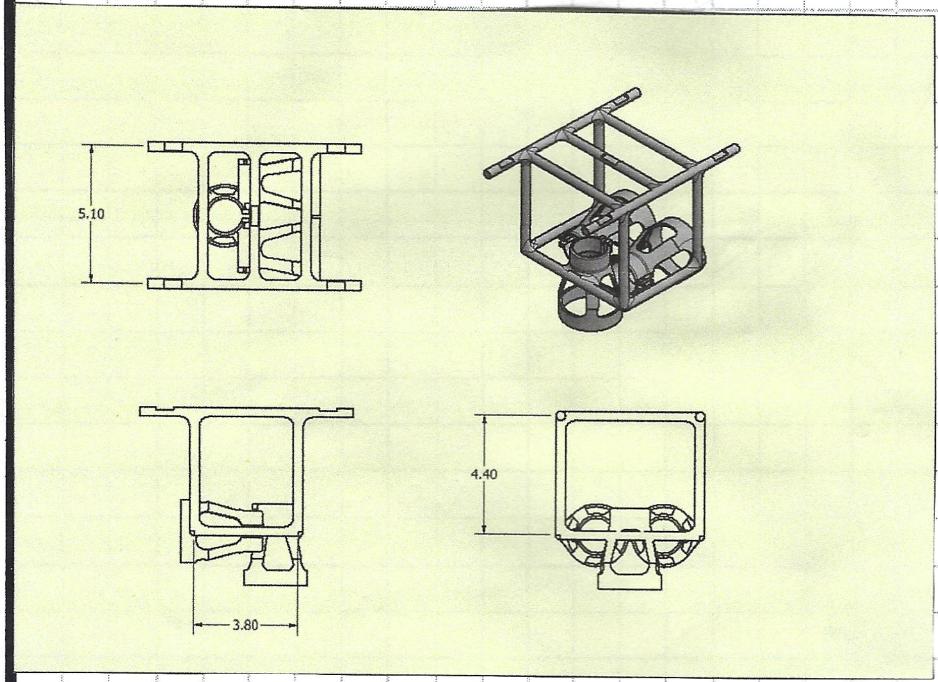
PROPRIETARY INFORMATION

	Entries	Page

FRAME DESIGN

Our 3D models for our frames are shown on the following pages. We first experimented with the length of the ROV.

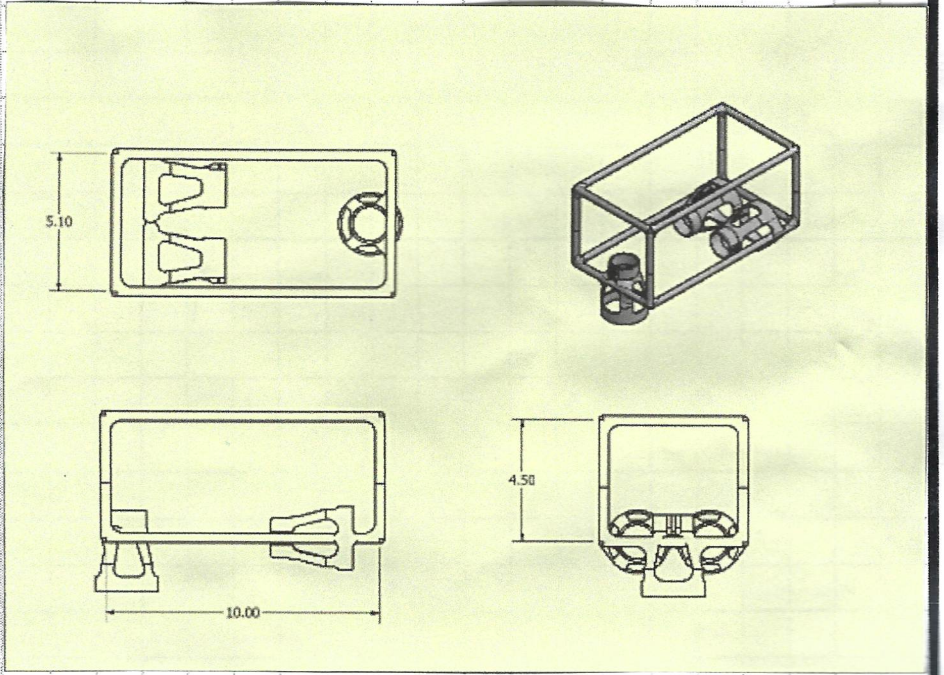


We printed a frame that was as short as possible, shown to the left.

N.A

We also printed a frame that was as long as possible, shown to the right.

N.A



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WITNESS / TEACHER Namah Agarwal	DATE 3/24	PROPRIETARY INFORMATION

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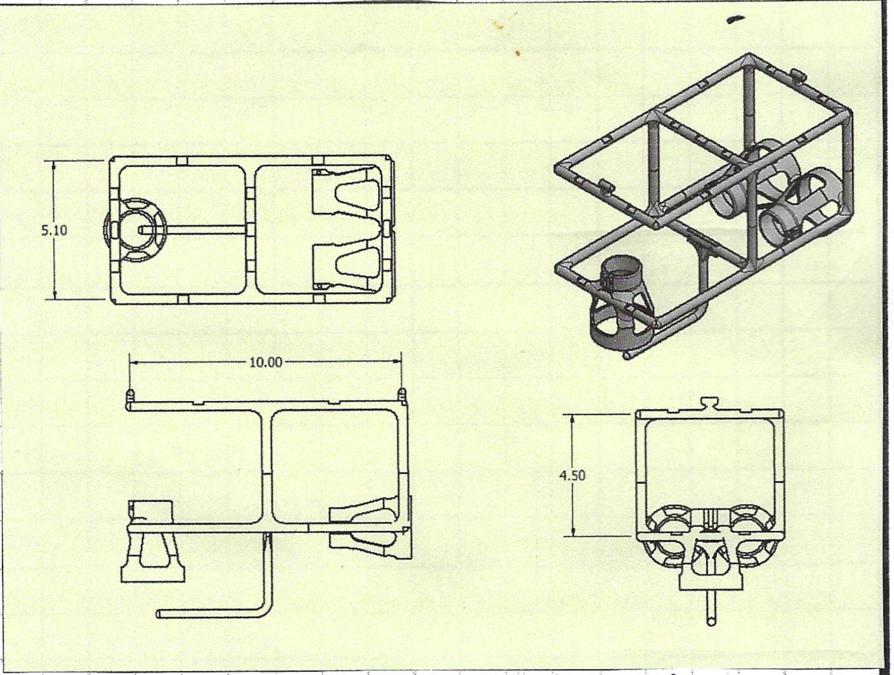
FINAL FRAMES

Based off the long frame, we implemented the changes to increase our efficiency; opening 'mouth' and mounting bracket for the hook.

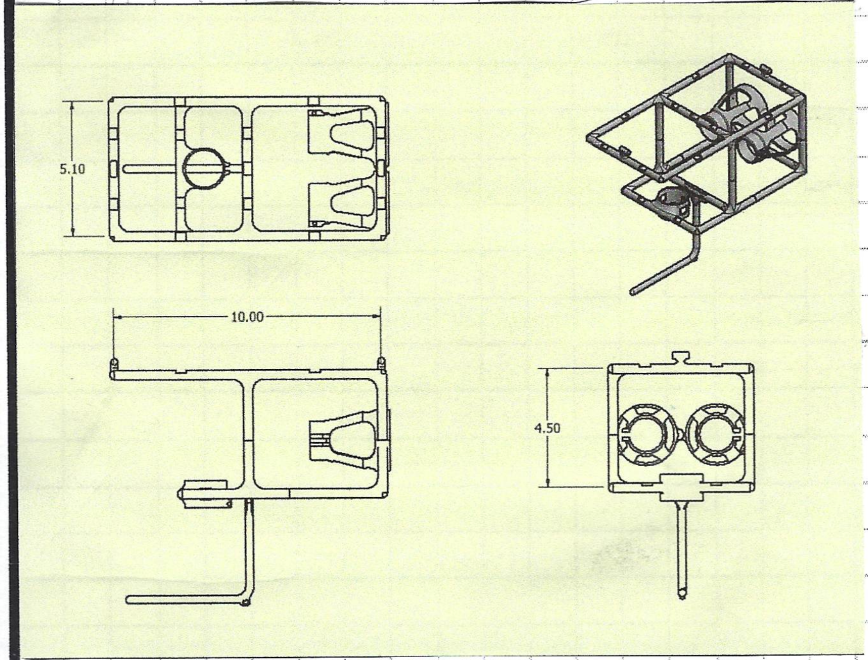
We removed the front side supports. Our final ROV, shown below, is more efficient at catching floating objects because we moved the vertical motor 5.1 centimeters back.

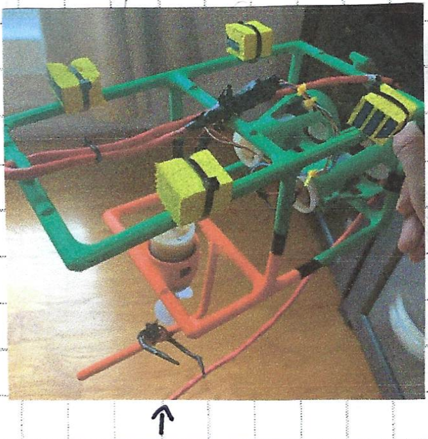
N/A



3rd Iteration ROV (above)

Final ROV (below)





↑
Final Rov Printed (above)

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