## Engineering Report: Leviathan AUV University of California, Riverside



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## 1. Objective:

The objective of the Leviathan AUV was to create a new submarine which could house electronics, batteries, and other subsystems, made to complete as many challenges as possible for the Robosub 2020 competition.

## 2. Team:

2020-21 UCR Robosub Roster

- Saurabh Kamble [Mechanical Co-Lead]
- Wilfredo Teran [Mechanical Co-Lead]
- Roger Tirtawidjaja [Project Lead]
- Ryan Deuling
- Zinal Patel
- Jose De Leon
- Rebekah Woo


## 3. System Requirements:

a. Competition Rules: 2021 Robosub Competition Rules
b. System Requirements: Leviathan AUV System Requirements

## 4. Materials/Component List:

- McMaster Parts List
- Chassis
- 6061 Aluminum
- Leviathan Parts List
- End cap
- Flange
- Acrylic
- Cylinder
- End cap
- O-Rings
- Thrusters
- T100 Thrusters
- T200 Thrusters
- Electronics Rack
- Wooden Dowels: four $3 / 8$ in dowels \& two $3 / 16$ in dowels
- 3D Printed Parts
- Rail end caps (2), front/rear camera mount (2), vertical handle, electronics mount.
- Threaded Inserts for plastic
- Stainless steel Socket Screw M4-0.70 x 10mm (Amazon)
- Electronic Components
- PCB's (4)
- Cameras (2)
- NVIDIA Jetson
- Buck Converter
- Batteries
- Battery Scaffold
- Scaffold legs (2), battery plates (2), lithium batteries (2)
- Planned: Torpedo Launching Mechanism
- 12 g CO 2 cartridge, angled torpedo, torpedo end cap, springs, servo mount latching mechanism, and eyebolts.


Figure 1. An Exploded view of the Leviathan Chassis via SOLIDWORKS


Figure 2. An Exploded view of the Electronics Rack via SOLIDWORKS

## 5. Procedure and Deadlines:

a. Gantt Chart
b. Quarterly Timeline

## 6. Design:



Figure 3. Side and Front Views of the Leviathan Current Design


Figure 4. Top View of the Leviathan Current Design

### 6.1 Intent

The Leviathan AUV was designed mainly on a three cylinder and eight thruster design. The idea behind having eight thrusters on it was to have more degrees of movement, while the three cylinder design was to have the most flexibility for sub-systems. The three cylinders were meant for housing electronics, batteries, and another subsystem to power the submarine if necessary. The geometry of the submarine was to make it as square as possible for the easiest center of gravity and center of buoyancy, while trying to make the submarine as compact as possible. We aimed for the submarine to do as many of the competition tasks as possible, but it later got refined to: gate, buoys, path, with surfacing as the stretch goal and a later planned torpedo and drop weights for next year.

### 6.2 Machining

While designing the submarine, it was intended for almost every metal part to be cut from uniform thickness aluminum. The metal was to be purchased as a rectangular plate and laser laser cut to fit all of our needs. The pieces were designed to have the least post-machining as possible.

The end cap flanges for the acrylic cylinders were intended to be machined using previous machining techniques involving a lathe, but were later bought pre-made to secure consistency and quality. The actual end cap attaching to the flange was laser cut along with the rest of the metal parts, to save on costs.

Post-machining included threading holes and drilling some holes on parts. 3D printed guides were made to help drill the holes evenly and correctly.

The acrylic cylinders were going to be purchased, along with other materials including but not limited to: bolts, rubber lining, and square tubes.

### 6.3 Three Cylinders

The three cylinder design was intended for housing electronics, batteries, and pneumatics. With the center cylinder holding the electronics, it includes but it is not limited to PCB's, cameras, and the NVIDIA Jetson. One of the side cylinders is meant to hold the batteries. The opposite side cylinder houses pneumatic systems, which includes but is not limited to an air tank, solenoid, and regulator. The middle cylinder was intended to be as forward as possible to ensure the front camera has the most sight, and to leave room for the bottom facing camera to see without obstructions.

The cylinders are held in place by aluminum handles meant to swivel along a bolt attached to the main rib plate. The middle cylinder is held in place by L-brackets, while the side cylinders are held down by the chassis itself.

The middle cylinder is held by L pieces inserted on the end of the square tubes, which are held down by a quick release pin, on one end. On the other end, it is held by an $L$ bracket which is bolted to the square tubes. The side cylinders are fixed by having the end caps flushed with the side plates.

The acrylic cylinders were proposed to be smaller than the original Seadragon electronics cylinder, but to use the same thrusters as it. This was because the previous team commented on the amount of unused space the previous submarine had in the end.


Figure 5. SOLIDWORKS 2020 screenshot of the metal chassis along with acrylic tubes.

### 6.4 End Caps

The end caps of the cylinder are based on the designs of our previous end caps. However, instead of it all being one piece, it is separated into two pieces: one which has the o-rings meant to stay on the inside, and an outside plate meant to be taken on and off. One of the main problems from the last submarine was constantly reapplying o-rings and lubricant for it, causing consistency issues and time lost in preparation. With the new design, it relies on the compression fit from the outside plate to the interior o-ring through a series of screws to ensure a water tight fit. The o-rings on the interior have been increased from two to three to ensure a tight seal. The design is meant for a torque wrench for consistency while mounting, and to prevent stripping of the threads.


Figure 6. End-cap assembly consists of 6061 aluminum circular plate as well flange seal from BlueRobotics.

### 6.5 Chassis

The top and bottom plate of the chassis fixes the rib plates's position, while also adding structure. The long rectangular hole in the plates is to allow for read switches to be placed on the middle cylinder, and also allowing visibility for the middle cylinder from the top. It is held down by screws through the rib plates. The top and bottom plate is not level to the rib plates so it does not get scratched when laying it down.

The two side rib plates of the chassis are the main mounting points of the submarine. On it, it has slots open for all of the cylinders, holes for the top and bottom plates, and rectangular cut outs for the square tubes. As well as mounting points for various l-brackets, it also has grooves for wires to go through, screw holes for the side cylinder holders, and also the hardpoint where the feet of the submarine is going to be mounted to. Along with mounting points, it also ensures the Leviathan is aligned and structural.

Attached to the two side rib plates are mounting pieces for the two side acrylic cylinders. These are mounted with bolts on the end of the mounting piece to the side rib plate. It is designed so it would rotate along a bolt when inserting or taking out an acrylic cylinder. The side piece has a handle on it to make it easier to grab, but is not intended to hold the weight of the submarine.

Each piece in contact with the acrylic cylinders are lined with rubber strips with one side being adhesive, which faces the metal side, on the opposite face in order to create friction and not scratch the surface of the acrylic.

The square tubes on the submarine is mainly where the thrusters and the planned handles are mounted to. It allows hard points for the drop weight system to be mounted to as well, and also serves as the mounting point for l-brackets to ensure the cylinders do not move. It allows for more mounting points and the hollow nature of the square tubes ensure that they can fill up with water, adding weight to the submarine so it can sink, and drain itself when taken out.

On the ends of the square tubes are triangular planned handles meant as the main carrying point of the submarine for transport. The triangular nature of it allows it to be easier when lifting the Leviathan
up and down. There is a slight groove on the inside part of the handle to create a slightly more ergonomic fit to the hands. The handles are mounted via nuts and bolts.

Instead of machined handles, a long PVC tube is going to be used to lift the submarine by going through the two holes above the square tubes. This will be taken out of the submarine normally and only be used for transporting the Leviathan.

### 6.6 Wings

The wing mounts are designed to hold the eight thrusters, and are placed at the very end of the square tubes. The thrusters themselves are mounted to aluminum square plates from screws, which has mounting holes to mount on the actual top and bottom plate of the wing mounts via screws. Said top and bottom plate clamps down on both square plates and thus each top and bottom plate holds two thrusters each.

The wing mounts are designed to extend the thrusters enough so that the thrusts do not interfere with each other. They are also designed with the intent of not creating thruster wash with each other, and thus the direction of thrust of all the thrusters are not in line with each other. The placement of the thrusters are all in the same plane as the center to eliminate potential moments being made by the thrusters.


Figure 7. SOLIDWORKS screenshots of the wing mount assembly which consist of two T200 thrusters from BlueRobotics.

### 6.7 Electronics Rack

The purpose of the electronics rack is to maintain all of the electronic components of the Leviathan in a safe and organized manner. The location of the rack is inside the main tube. The rack assembly consists generally of a push-pull assembly. This design facilitates the process of removing electronic components for the Electrical team during mock obstacles testing.

General assembly parts include two rail end caps which serve as a base support for supporting the $3 / 8$ in dowels are tangent to the main tube cylinder. The interior components of the rack is the push/pull assembly that can be removed from the autonomous robot at any point by unscrewing the back end cap. An integration of the camera mount with the electrical components (e.g. Jetson, buck converter, and PCBs) is feasible with the front camera mount part. This part possesses two circular slots for the wooden dowels as shown in the illustration below. These wooden dowels provide an axial degree of freedom to adjust the horizontal distances between PCBs if necessary (cables). Overall, the main purpose of the electronics rack is to provide structural support and to facilitate the integration of computer vision, PCBs, motor/thruster controllers, microcontrollers, and cameras into the assembly. The camera mount holds two cameras, one facing forwards, and the other one facing directly downwards which aims to target the location of the drop weights as well as guide the AUV for the pathmarker. The location of the drop weights is still to be determined. In the rear side of the rack, a vertical handle is attached to the back camera mount by the mechanism of magnets. This once again will allow for the whole interior structure to be removed, or inserted from the main tube. The current design of the assembly allows for plenty of space of cable allocation and most importantly air flow.


Figure 8. Isometric View of the Electronics Rack (Version 3)


### 6.8 Battery Scaffold

The goal of the battery scaffold is to constrain the battery packs axially and radially in order to prevent power failures due to turbulence during water testing or competition rounds. The proposed design's purpose is to hold both battery packs at a tight tolerance which fits into the tube using PVC tubes to prevent it from sliding axially.

Figure 9. Isometric View of the Battery Scaffold

### 6.9 Torpedo Launcher Mechanism

Objective: Launch an active or inactive projectile at specified underwater targets with varying degrees of difficulty. The projectile should not at any time have a momentum high enough to bruise a human being.

In the design process for the torpedo mechanism, lots of research went into the fundamentals of existing methods of projectile transport and were then further narrowed down into a method which would achieve our goal as well as being viable for our team to design and manufacture. The design consists of a projectile or torpedo which is independently powered with
 pressurized CO2. The triggering mechanism operates similarly to a spring action rifle.

The dimensions of the torpedo projectile (outer diameter, penetrating surface area, and density) were determined and verified by a MatLab script written to run and study the dynamic kinematics of the torpedo when launched underwater. The torpedo also has a hollow slot to hold a $12 \mathrm{~g} \mathrm{CO}_{2}$ cartridge within it. The torpedo's thrust is a result of the CO 2 cartridge being punctured which releases CO 2 gas at 90 PSI acting as a propulsion method for the torpedo. The tail end of the torpedo features angled fins to induce a rotational motion during its underwater "flight". This is done to prevent the torpedo from deviating from the intended flight path due to buoyancy or resulting hydrostatic pressures.

$$
\begin{gather*}
F_{a p p}=F_{1}+F_{2} \\
F_{1}=k_{1} x \\
F_{2}=k_{2} x \\
F_{a p p}=k_{e q} x=F_{1}+F_{2} \\
F_{a p p}=\left(k_{1}+k_{2}\right) x \tag{1}
\end{gather*}
$$

Equation 1 above shows the relationship between the spring constant, compression distance and applied force when two
 springs are arranged in the parallel orientation. The torpedo's CO 2 cartridge is punctured by a separate spring-trigger mechanism. It was experimentally derived that the cartridge requires $42 \mathrm{lbf}\left(\mathrm{F}_{\text {app }}\right)$ to be punctured. The calculations were then done to find the ideal springs and their compression which in parallel would exert a force of 42 lbf to puncture the cartridge via impact. With a proper understanding of the relationship of this system, the team was able to choose springs from the McMaster-Carr inventory which fulfilled the mathematical equation for springs set in parallel.

The puncture plate is released by a servo arm that rotates in and out of the puncture plate's path. The servo's position and enclosure dimensions are set to both fit within the frame of the submarine as well as keep the parallel springs adequately compressed in order to puncture the compressed CO2 cartridge.


Figure 10. Isometric view of the CO2 torpedo launching mechanism on the left. In addition, an isometric exploded view is shown on the right, which consists of the angled torpedo, screw plate with puncture screw, springs, and endcap base.


Figure 11. The updated version of the servo mount assembly is shown on the left. The specific servo model is DSSERVO DIGITAL SERVO. The torpedo launcher mechanism is axially expanded in the acrylic barrel which is concentric to the 'TubeRib' hole.

### 6.10 Torpedo Launcher Mechanism (pneumatics):

The pneumatic selected for this system is a single-acting piston with a spring return. Prior to submerging the AUV, the pneumatic would be hooked up to an air compressor tank, with a pressure less than the 247 psi maximum pressure the manufacturers recommend. It would start with the switch in the closed position, leaving the cylinder to be fully compressed and with an atmospheric pressure. During the torpedo challenge, the pilot would navigate the AUV to get within 6 inches of the target and would send a signal for the switch to go into the open position. The air lines would be flooded with a significantly higher pressure, pushing the piston to reach its maximum stroke length of 1.5 inches and propelling the torpedo forward with the intent to hit the target.

After performing cost analyses on the two torpedo propulsion systems, the decision to move forward with the $\mathrm{CO}_{2}$ system was made as the costs are significantly less.


Figure 12. Exploded view of the Pneumatics Torpedo Launcher Mechanism. Solenoid valve will result in a thrust force applied onto the torpedo.

### 6.11 Ballast Design

Objective: to increase the overall buoyant force of the autonomous underwater vehicle by increasing the volume displaced by the Leviathan. More specifically, the ballast tubes will seal-in enclosed air in the two bottom side holes of the chassis. Considering the submarine's chassis consists of 6061 aluminum alloy, the overall weight is marginally larger than the current sub's buoyancy force without the ballasts implemented.

As shown in the appendix, an approximate length of 65 cm long ballast was able to increase the overall buoyancy of the sub to be 3.76 percent slightly buoyant. However, in the future we usually try to aim for $5-10 \%$ slight buoyant sub in order to ensure battery power efficiency is not compromised during competition live testing. The volume of the ballasts can be altered by selecting a low density material (e.g. PVC tubes) to ensure no more mass is added to the AUV resulting in a higher weight force. The specific ballast dimensions are currently being determined based on the availability of PVC tubes in nearby hardware stores. In previous years, the purpose of the ballast was to increase the overall AUV's weight force since most of the chassis consisted of large acrylic plastic tubes. This year's design, the purpose of the ballasts is the opposite. The possible location for these ballasts is right below the main tube as shown in Figure 13. The addition of the ballast can also be used as a support mechanism for the marker dropper conceptual design.

$$
\begin{gathered}
V_{s, m}=\frac{\left(\pi d_{s, m} h_{s, m}\right)}{4} \\
F_{B, 1}=\rho_{f} \bullet V_{\text {tot }} \bullet g \quad(2) \\
\% \text { Buoyancy }=\frac{\left|F_{b}-W\right|}{W} \times 100 \%
\end{gathered}
$$



Figure 13. SOLIDWORKS screenshot of the possible location of the ballasts in order to increase the AUV's overall buoyancy as well to ensure stability.

## 7. Resources:

a. Blue Robotics Thrusters
i. T100
ii. T200

## 8. Appendix:

Manual buoyancy calculations:
Internal $V$ olume (tubes) $: 2 V_{s}($ side - tubes $)+V_{m}($ main - tube $) \rightarrow V$ olume formula for cylinders $: V_{s, m}=\frac{\left(\pi d_{s, m}{ }^{2} h_{s, m}\right)}{4}$;
$\Rightarrow$ Side tube dimensions : $d_{s} \simeq 0.17 \mathrm{~m}, l_{s}=0.3 \mathrm{~m}$; Main tube dimensions : $d_{m} \simeq 0.17 \mathrm{~m}, l_{m}=0.43 \mathrm{~m}$;
$\Rightarrow$ thus, internal volumes can be determined as follows : $V_{s} \simeq \frac{\pi \cdot(0.17 \mathrm{~m})^{2} \cdot(0.3 \mathrm{~m})}{4} \simeq 6.8094 \times 10^{-3} \mathrm{~m}^{3}$;
$\Rightarrow V_{m} \simeq \frac{\pi \cdot(0.17 \mathrm{~m})^{2} \cdot(0.43 \mathrm{~m})}{4} \simeq 9.7601 \times 10^{-3} \mathrm{~m}^{3} \rightarrow V_{\text {internal }} \simeq 2\left(6.8094 \times 10^{-3} \mathrm{~m}^{3}\right)+\left(9.7601 \times 10^{-3} \mathrm{~m}^{3}\right) \simeq 2.38 \times 10^{-2} \mathrm{~m}^{3}$
$\Rightarrow V_{\text {elec rack }}=708.14 \mathrm{~cm}^{3} \cdot\left(\frac{1 \mathrm{~m}}{100 \mathrm{~cm}}\right)^{3}=7.0814 \times 10^{-4} \mathrm{~m}^{3} ; \rightarrow V_{\text {bat scaffold }}=731.79 \mathrm{~cm}^{3} \cdot\left(\frac{1 \mathrm{~m}}{100 \mathrm{~cm}}\right)^{3}=7.3179 \times 10^{-4} \mathrm{~m}^{3}$
$\Rightarrow V_{\text {total }}=V_{\text {internal }}-\left(V_{\text {elec rack }}+V_{\text {bat scaffold }}\right)=2.194 \times 10^{-2} m^{3} \rightarrow$ Estimated buoyancy : $F_{B, 1}=\rho_{f} \cdot V_{\text {tot }} \bullet g$
$\Rightarrow F_{B, 1} \simeq 215.232 N ; \rightarrow W_{\text {sub }}=m \bullet g \simeq 238.952 \mathrm{~N} ; \rightarrow V_{\text {ballast }} \simeq 1,667.38 \mathrm{~cm}^{3} \sim 1.667 \times 10^{-3} \mathrm{~m}^{3} ;$
$\Rightarrow V_{n e w ~ i n t ~} \simeq 2.5274 \times 10^{-2} \mathrm{~m}^{3} ; \rightarrow F_{B, 2} \simeq 247.94 \mathrm{~N} ; \rightarrow$ thus, $F_{B, 2}>W_{\text {sub }} \rightarrow$ by $\left(\frac{247.94-233.952}{238.952}\right) \times 100 \%=3.76 \%$

## 9. Draft Space:



