Final Design Review (FDR) Report

Zero-Waste Ocean Floor Hydrophone Mooring

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June 9, 2023

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Statement of Disclaimer

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Abstract

Maddie Schroth-Glanz, from the Statistics Department of Cal Poly, requires a system that assists in the deployment and retrieval of a marine hydrophone used to record ocean mammal vocalization patterns, specifically in large whales. This report discusses the final design, including changes to the design after the Critical Design Review, and the tests that were done to ensure the final design achieves the specifications of the project. We will discuss everything from material purchases to manufacturing and assembly for all subsystems of the project, and then discuss how our testing justified the design choices we made. Finally, the report will discuss recommendations and further steps that can be taken to improve upon and complete this project. The appendices include a user manual, risk assessment of the final product, final budget, software, the design verification plan and report, and the test procedures that were followed.

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1 Introduction

Professor Maddie Schroth-Glanz of the California Polytechnic State University, San Luis Obispo Statistics Department is conducting research on intra-species communication between whales on the California coast. To allow for collection of data of whale vocalizations, she requires a hydrophone mounting system that can be deployed from the surface, drop to 80-meter depths, collect data for up to 6 months, then be retrieved using a high-frequency signal-activated pop-up system.

Since the Critical Design Review (CDR), the Mechanical Engineering team has finalized all design choices. The biggest design choice that was finalized after the CDR was the linear actuator driven release mechanism. Due to incomplete work from the Computer Engineering (CPE) team, our team decided to create a circuit that will allow us to test the release mechanism. While this does not accomplish the goal of creating an acoustically triggered release mechanism, our scope for this project did not include signal processing for release. An in-depth breakdown of this system can be found in Section 3.4 of this document.

This document covers the manufacturing and assembly process of the final design in Section 3. The outcomes of testing this final design are discussed in Section 4.2.

2 Design Overview

Most of our design has remained the same since the Critical Design Review in mid-February. However, the design for our release mechanism has been finalized after delays due to finding a linear actuator that is able to work at 80 meters deep in water.

2.1 Design Description

The design can be broken down into several subsystems: the frame (1), the spool (2), the release mechanism (3), the capsules (4), the weights (5), and the buoy (6). A full system photo can be seen in Figure 2.1, as well as a close-up of the smaller components. The release mechanism includes a ratchet-style bar, which prevents the spool from rotating until the actuator pulls the trigger. We used eight 10lb weights which attach via carabiners to the 120m spool of rope. The electronics will be housed in the pressure resistant capsules when they are developed by a future project. See our CDR report for a more detailed description of each component [1].

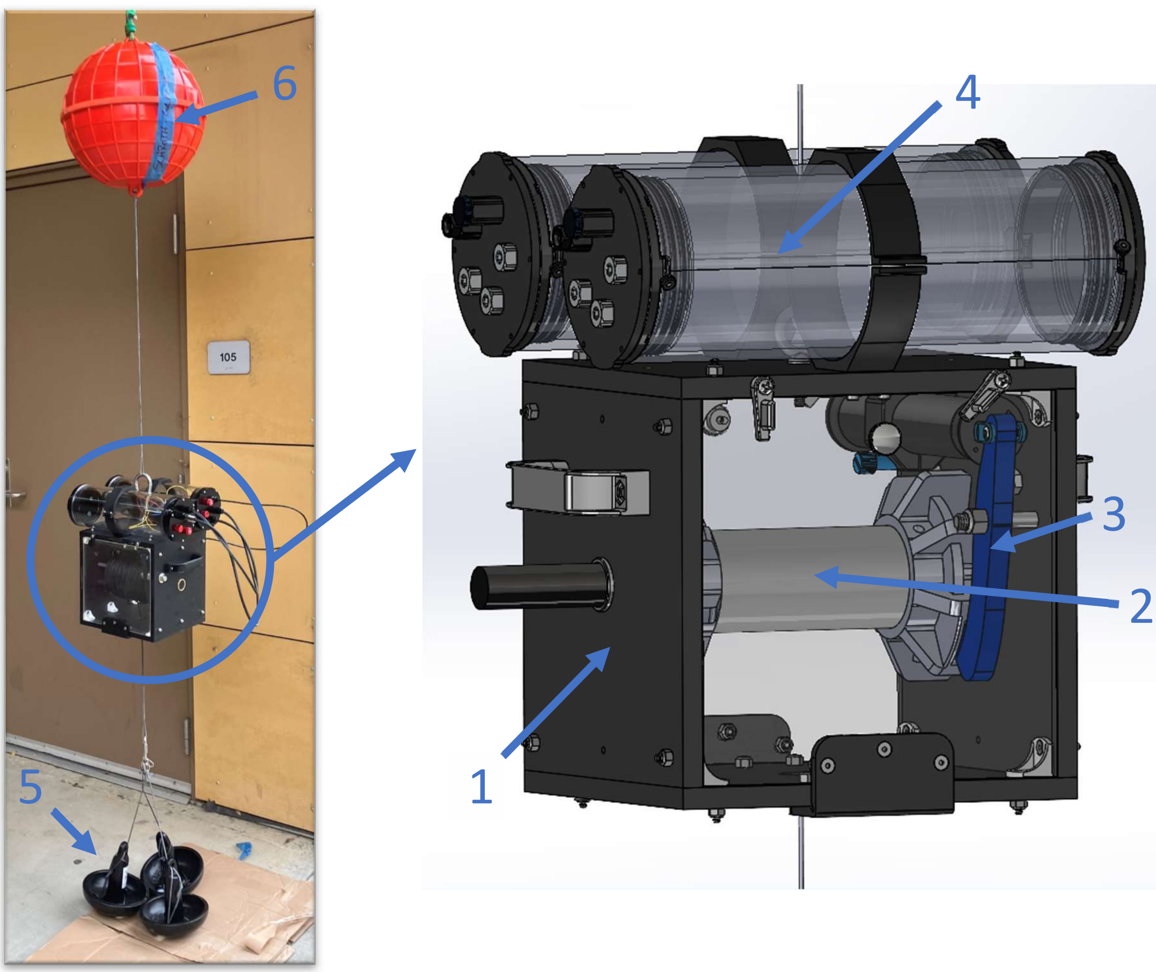


Figure 2.1: Full system design with close-up view of frame and inner components.

2.2 Design Changes Since CDR: Release Mechanism

One design that has been solidified since the CDR is the release mechanism. Figure 2.2 shows the release mechanism design, including the linear actuator (1), pivoting bar (2), and the spool endcap (3). The bar pivots about a ¼" bolt that attaches to the frame (4). Our release mechanism prevents the spool from rotating (clockwise in the orientation shown in Figure 2.2) during deployment, keeping the line to the weights in constant tension to prevent tangling. The release bar geometry was designed so that the force on the release bar contact face (the top of the feature highlighted in red in this image) would be in line with the pivot point. This causes the bar to remain in pure tension during deployment, applying no forces to the shaft of the linear actuator. The pivot point was placed such that when the linear actuator pulls the top of the bar inward with a 13mm travel, the release bar's tooth (shown in red) will pull out of the spool end cap with just a few millimeters to spare, allowing the line to unspool as the device floats to the surface.

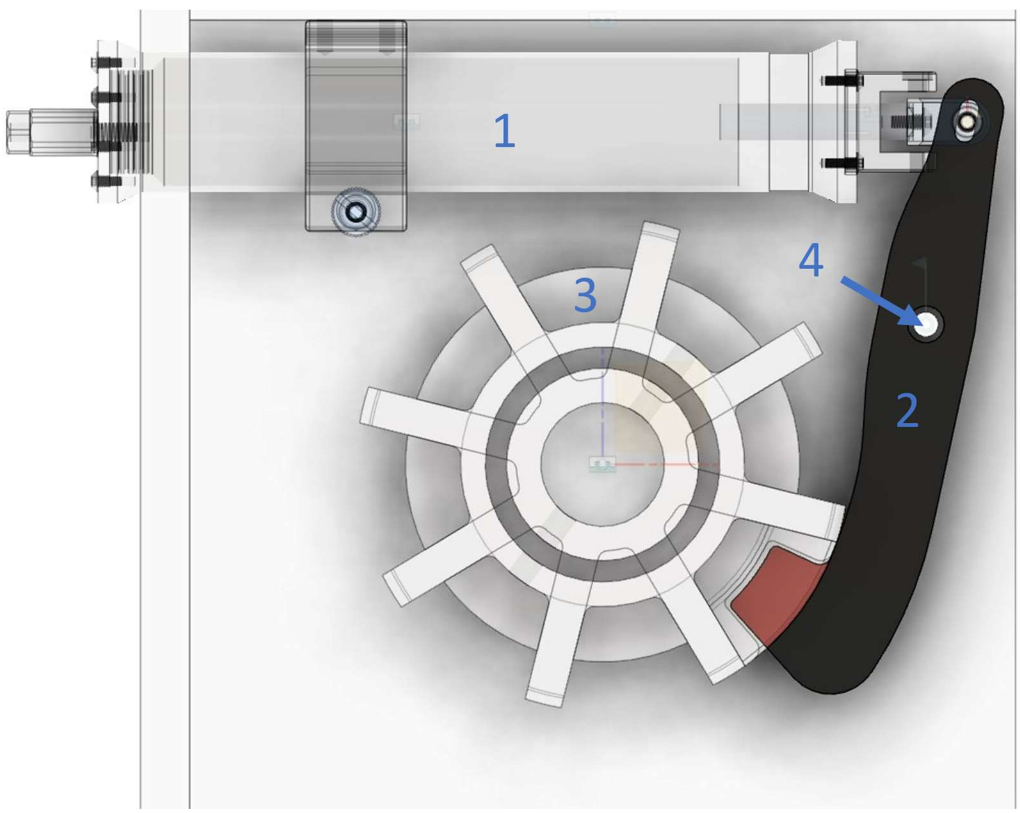


Figure 2.2: Release mechanism design.

3 Implementation

3.1 Procurement

Our materials were bought, 3D printed, or used from the past senior project group. A final project budget can be found in Appendix C that covers everything that we purchased this year for both the structural prototype and the verification prototype, with a final cost of $1400. Appendix C also has the full cost budget that covers all parts used in the final prototype, if another one is built in the future. The prototype costed us $950. If a complete new prototype was to be built, it would cost about $1500, which includes the cost of the capsules, PVC pipe, and Dyneema rope [2].

The Dyneema rope, Blue Robotics capsules, and the PVC pipe were used from the past project. The 3D printed parts – endcaps and hand crank – were printed at Innovation Sandbox and Mustang ’60 respectively. Due to these being parts we already have and that it was free to print the parts, these did not cost anything to us.

Most other parts were ordered from McMaster-Carr, except for the weights, which were purchased from Dick’s Sporting Goods, and the linear actuator, which was purchased from Blue Robotics. The total cost of the McMaster-Carr order was around $400, and the weights were bought on a sale and cost $150. The linear actuator was the most expensive part purchased this year at $600. Blue Robotics lists the actuator as a “Newton Gripper”, but we realized that it could serve the purpose that we want it to if it is modified a little bit.

Table 3.1: Final project budget summary.

Subsystem	Price
Frame	$100
Spool	$25
Release Mechanism	$650
Buoy	$0
Weight	$175
Capsules	$0

3.2 Manufacturing

There were only several components that require manufacturing in our design. These were the main frame panels, the acrylic opening panels, the shaft, spool extender (PVC), and the release mechanism bar. Although, some holes that were made for the 3D-printed parts did not print perfectly, so they had to be machined as well. This included the hole for the quick-release pin in the hand crank and the holes for the press fit pin through the end caps. This was done on the drill press with the desired bits according to the type of fit. All manufacturing was done either in Mustang ’60 or the Aero Hanger.

3.2.1 Frame Panels

The main frame panels, made of HDPE, were cut to size on a table saw and then milled to place the holes on the frame correctly. Figure 3.1 shows one of the panels on the mill. One error that occurred was when cutting the panels to size on the table saw. The measurement of the edge of the blade to the stop was not exactly 9” so the panels were cut short in one direction, and then when adjusting for the next dimension, were cut slightly too large. Luckily, the side that were cut short were able to be placed so that they have the same width and no overhangs, and same with the sides that are cut long. The panels were then drill pressed because the set up on the mill did not allow for the holes to be drilled all the way through. However, we could use a center drill to locate the holes using the mill for accuracy and then complete the holes on the drill press.

Figure 3.1: Set-up of one panel on the mill.

3.2.2 Acrylic Panels

The acrylic panels were laser cut. These were left to manufacturing last due to a hold-up on the design of the release mechanism. The size of the linear actuator meant that an additional cutout was required to allow the acrylic panels to open correctly, which was a simple change on the drawings. Cutting these on the laser cutter meant that the profiles of the cutout and outside were easy to make, instead of having to mill those shapes ourselves.

3.2.3 Shaft

The shaft was cut to a rough size on a chopsaw and then placed on a lathe to turn it down to fit the bushings and face it to the correct size. The finished version is shown in Figure 3.2. The frame was put together to get an accurate reading of the dimensions that the shaft needed to be lengthwise, as shown in Figure 3.3. In addition to the Delrin shaft, the PVC had a hole drilled into it to stop the end of the rope from sliding around and out, as well as holes in the ends to allow for a pin to be inserted through the endcap, PVC, and shaft to prevent unwanted spool rotation. The steel pins were cut to length to fit within the end caps.

Figure 3.2: Shaft after finished on the lathe with bushings on.

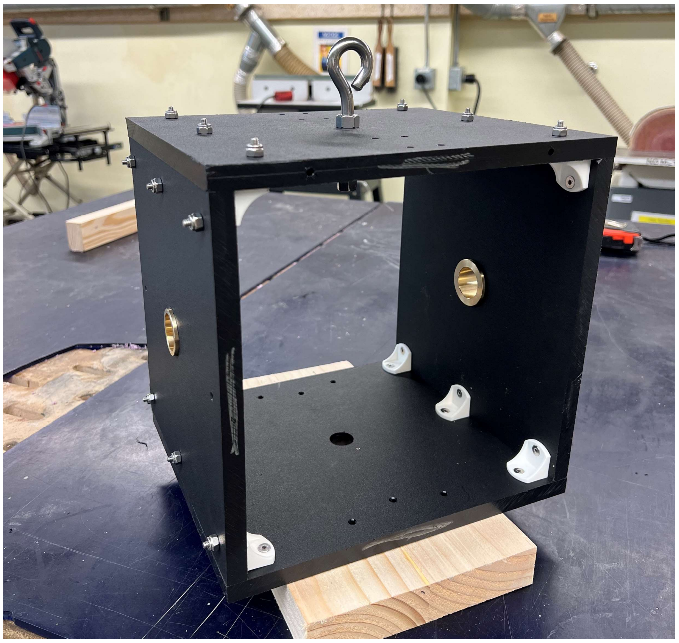


Figure 3.3: Preliminary assembly of frame.

3.2.4 Release Mechanism

The release mechanism bar had several more steps to manufacturing than the other components. First, the shape of the bar was laser cut to use as a guide for the router. Two sizes of the bar were cut in case the thinner version was too thin, but our first draft proved to be sufficient. Next, our piece of stock was roughly cut to the size of the part using a vertical bandsaw. The guide was then taped onto a piece of the leftover HDPE piece from the frame panels' stock (initially we used pins, but tape proved much more effective). Both of these steps are shown in Figure 3.4. The piece was then cut to the correct shape on the router. Finally, the part was placed on the mill to drill the pivot hole and slot for the linear actuator to slide along. This milling operation is shown in figure 3.5. All manufacturing for this part occurred in the Aero Hangar, and the shop techs were incredibly helpful in providing knowledge about how to best operate the machines used for these steps.

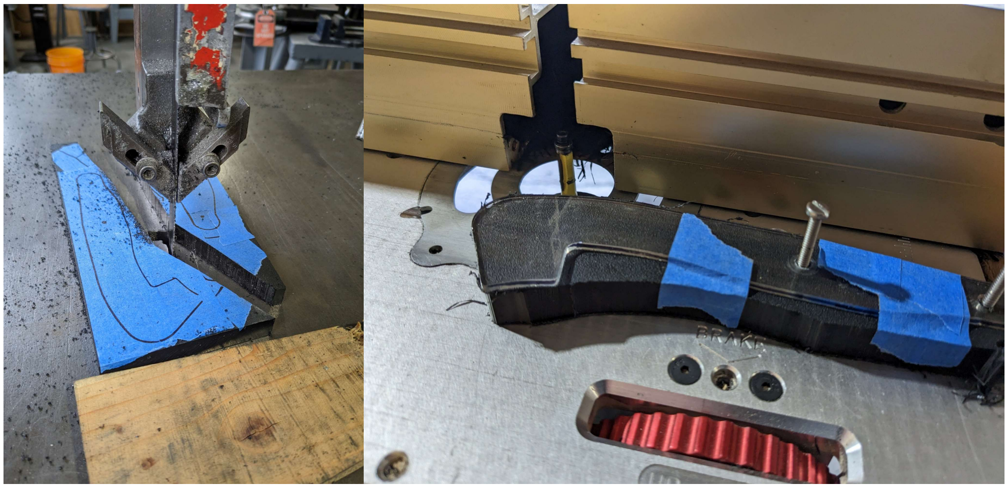


Figure 3.4: Bandsaw and router machining operations for release mechanism ratchet bar.

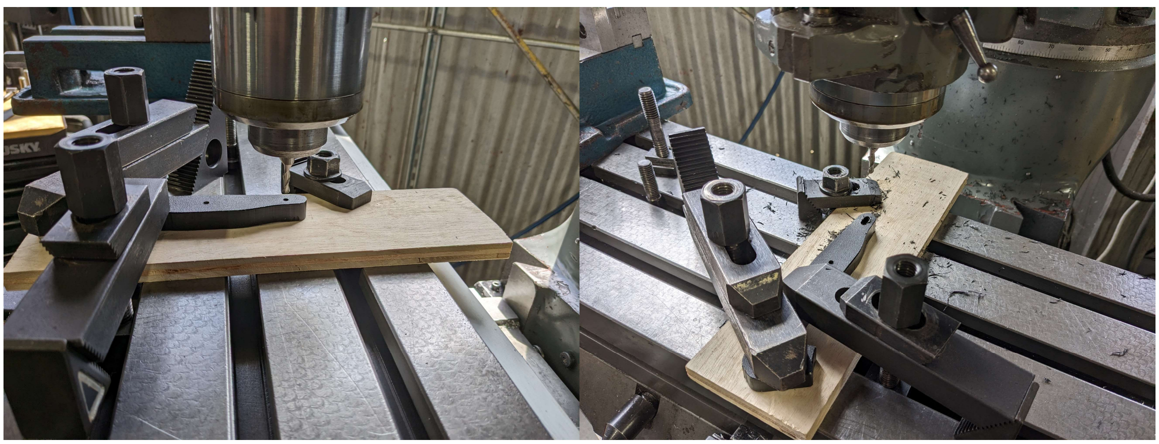


Figure 3.5: Milling operation for release mechanism ratchet bar, before and after.

3.3 Assembly

The assembly started with attaching the eyebolt, stoppers, and actuator mount to the top panel and the hinges to the bottom panel. The side panels had bushings fit into the center holes, and one had the release mechanism bar attached. Unfortunately, the bushings were not press fit into the panels, but because the shaft has a step, it keeps the bushings in place. The end caps and PVC extender where also assembled with the shaft by steel rods. Then, the top, bottom, and one of the side panels were attached via three angle brackets in each corner, with the top and bottom having the other side prepared for the final side to be attached. The shaft was inserted into the bushing on the assembled side, and the other side was slid onto the shaft and screwed onto the angle brackets. The acrylic panels were then attached to the other side of the hinges along with the handles. Figure 3.6 shows the progress up to this point. The main handles for the full system were attached at this point as well.

Figure 3.6: First steps of final assembly of prototype.

The electronics were assembled as noted in the following section, 3.4. They were then placed in the capsules and the capsules were then screwed onto the top panel. This allowed the linear actuator to be placed in the mount. This mount was tightened only after an extension and retraction of the end was completed to locate it. Figures 3.7 and 3.8 show the assembled prototype respectively without and with the hand crank.

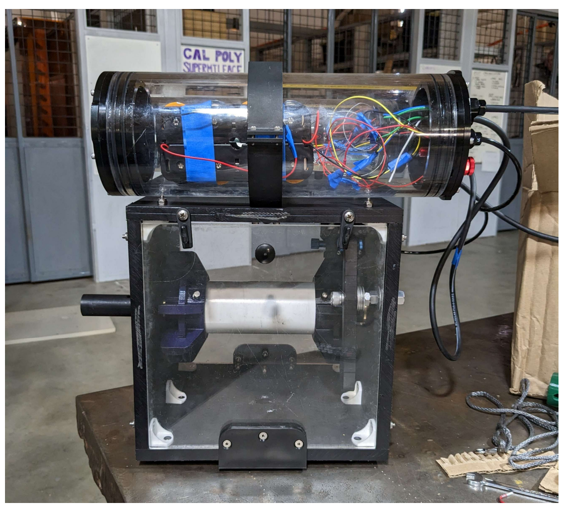


Figure 3.7: Assembled prototype without rope, weights, or buoy.

Figure 3.8: Assembled prototype with hand crank.

The rope was then tied to the hole in the PVC and carefully spooled. The end of the rope was fed through the hole at the bottom panel. Each weight had a separate length of rope tied to the eye and a carabiner using a bowline knot. Each of the weights' carabiners were placed on a bigger carabiner attached to the end of the spooled rope. The ends of the rope were all held under a flame to singe the ends so that they do not unravel. The buoy was attached via a carabiner and a length of rope, then tied with a bowline knot to the eyebolt.

3.4 Software & Electronics

Initially, the assigned CPE team to the project oversaw all portions that relate to triggering the release mechanism. As the project suggests, the trigger was supposed to be an acoustic signal sent by a deck box from the boat. However, the acoustic signal processing system they were developing was not completed. To ensure that the mechanical system works properly, an alternative trigger system was developed to control the linear actuator using an Arduino Mega 2560. The mechatronics classroom in Building 192 was used to facilitate this process.

The linear actuator from Blue Robotics is a servo-style actuator in the sense that PWM signals control the behavior of the actuator. It requires anywhere from 9 to 18 volts and has a peak current draw of 6 amperes. By giving the actuator a certain PWM period, it exhibits behavior as outlined in the table below.

Table 3.2: Behavior of linear actuator with respect to PWM signals sent.

Behavior	Period [µs]
Extends	>1530 to 1900
Retract	<1470 to 1100
Neutral	1500

The Arduino Mega 2560 is a microcontroller board that is used to control the actuator, print LCD messages, and take input from an infrared remote through an infrared receiver. The infrared remote sends a signal to the infrared receiver which outputs a unique code for each button on the remote. By tying the remote buttons to specific numbers, the remote can be used to control the state of the microcontroller pins. The board sends PWM signals to the linear actuator depending on what button is pressed and also uses several I/O pins to send data to the LCD screen. These messages and what states they correspond to are shown in Table 3.3 below.

Table 3.3: IR remote inputs and corresponding behavior.

Button on Remote	Actuator Behavior	Board Behavior	LCD
1	Extend	State 1: Lock	“Extending!”
2	Retract	State 2: Release	“Retracting!”
3	Retract after 5 minutes	State 3: Timed Release	“Timer Started: 5 min”
Power	Idle	State 3a: Cancel Timer	“Timer Cancelled”
None Pressed	Idle	State 0: Initialization	“Welcome!”

Programming the Arduino was a streamlined process, with servo control libraries written for Arduino that allowed PWM control to be as simple as a single line of code. The IR Remote code, as described above, required buttons to be tethered to certain numbers. As a result, each state is tethered to a specific number with the exception of the home state. A finite state machine is provided below in Figure 3.9, which describes the transitions between each state.

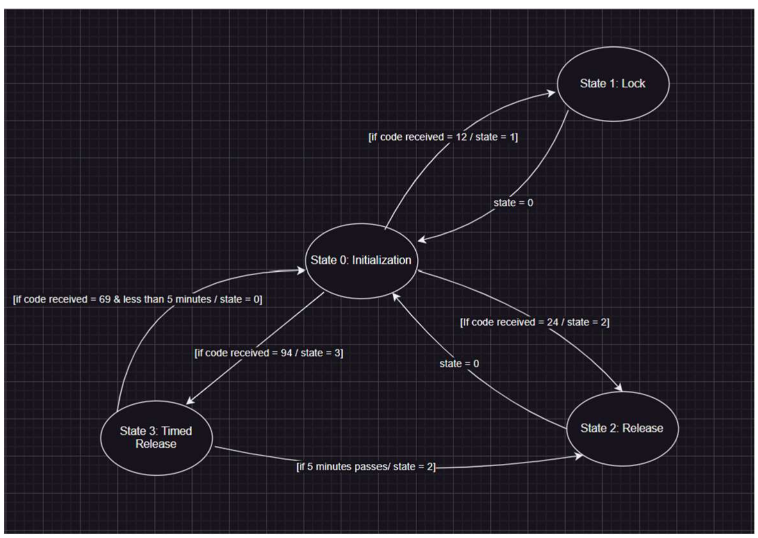


Figure 3.9: Finite state machine for circuit.

All of the code used for the Arduino is attached in Appendix D, which was written in the Arduino IDE utilizing a modified version of C++.

The circuit for this system involves the 12-V battery tray made up of 8 D-cell batteries, the linear actuator, the Arduino board, IR Receiver, a 16-pin LCD screen, 2 resistors, and a 9-V battery to power the Arduino board. The circuit schematic is provided below.

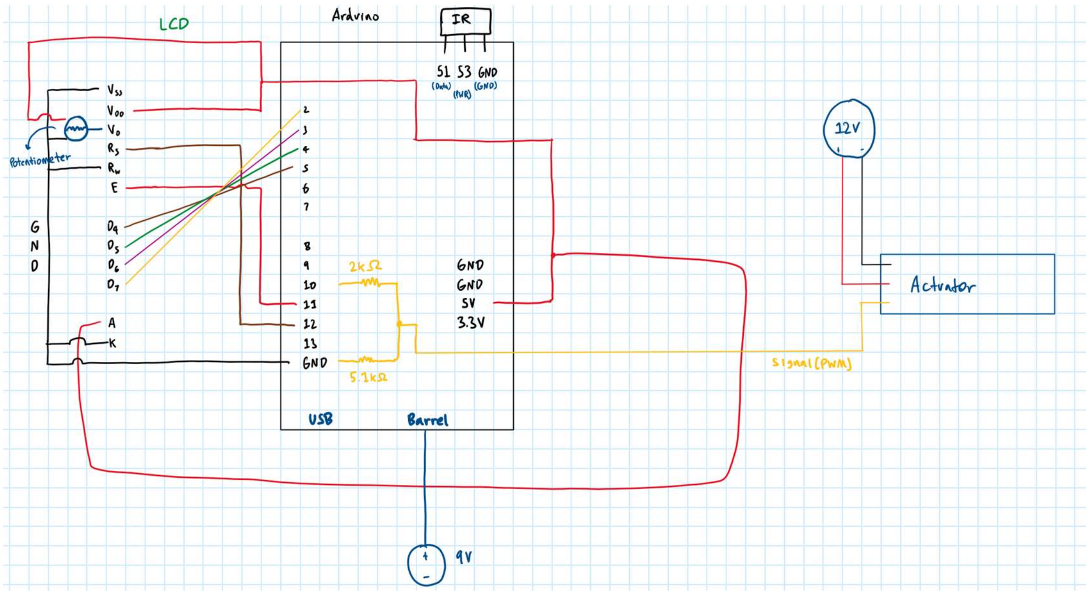


Figure 3.10: Circuit schematic.

While a breadboard was used for the circuit during the prototyping and testing phase, the circuit connections have to be mechanically and electrically secure during testing of the verification prototype. In order to ensure this security, we used an Arduino Prototype Shield, which gave us access to all the pins we needed from the microcontroller board, but had solder holes on the shield itself. This allowed us to solder the circuit directly on the shield, which reduced the amount of jumper wires needed. A picture of the breadboard circuit and prototype shield circuit are provided.

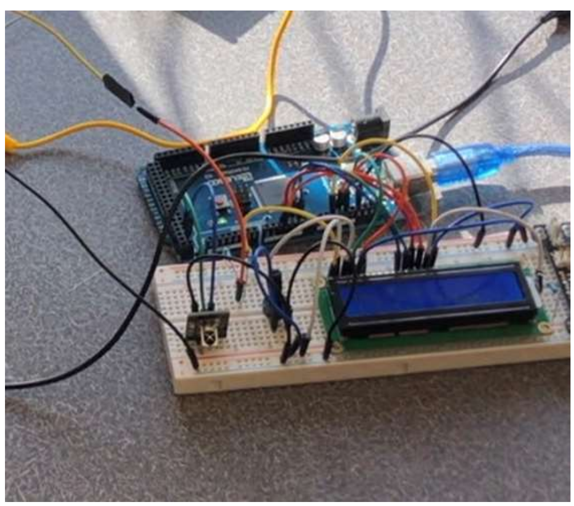


Figure 3.11: Breadboard circuit.

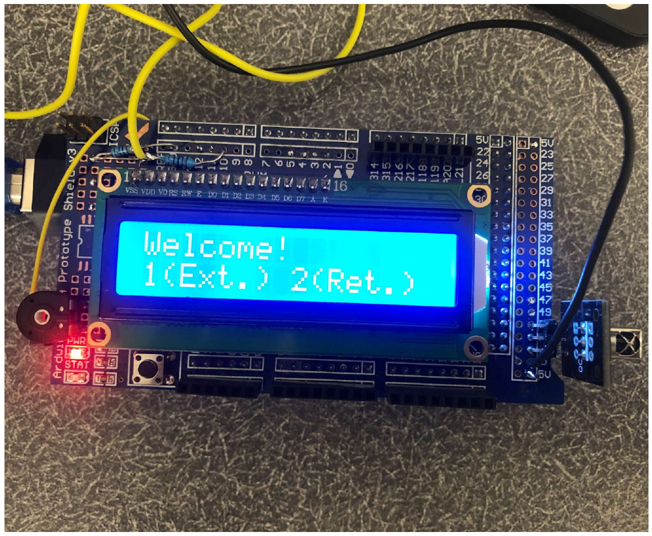


Figure 3.12: Soldered Prototype Shield Circuit.

The process for moving the circuit onto the prototype shield involved stripping stranded wires, entangling the stranded wire ends, soldering, and covering the soldered joint with heat shrink. For joints that could not be heat shrunk, we used electrical tape to ensure they would not be at risk to short.

4 Design Verification

4.1 Specifications

Table 4.1 shows each of the specifications that have been outlined in previous reports, and how each were tested to ensure they will meet the desired requirements. Most of the specification with inspection being their compliance method were simple tests that do not need any further explanation (such as verifying our device can be carried by hand in specification 1). The analyses done for certain specifications were either completed by hand or simulated using certain programs such as MATLAB and Excel. Most of the physical tests were conducted after initial prototypes of their respective components were completed.

Table 4.1: Specifications table.

Spec. #	Specification Description	Compliance Method	Description of Method
1	Weight	Inspection	Known/estimated weights can be used to calculate total weight.
2	Static length	Inspection	Should be determined by intended position of the hydrophone.
3	Active length	Inspection	Should be determined by expected depth and expected effects of currents.
4	Redeployment time	Testing	Redeployment process can be tested by timing/estimating the process to re-spool the system and re-engage the release mechanism.
5	Cost	Analysis	Cost analyses on each subsystem or the system has been done.
6	Drop speed/duration	Analysis	Total forces on the system were analyzed to determine the speed the system will drop at, then how long it will take to reach the ocean floor.
7	Corrosiveness	Analysis/ Inspection	Known corrosiveness rating can be used for the different materials in the system.
8	Waste left	Inspection	Ensure rope can lift weight from underwater.
9	System power requirement	Analysis	Power requirements of all components have been analyzed to ensure proper power supply.
10	Impact strength	Testing	Drop tests of different components in air or water to simulate potential impacts while underwater.
11	Static strength	Testing	Stress tests on the rope and other components to simulate the tensile stresses system will undergo while underwater.
12	Retrieval of Weight Force	Testing	Tests on the weights in water to simulate the resistance the person retrieving the weights would feel.

To anticipate and prevent system failures, a Failure Modes and Effects Analysis (FMEA) was put together to consider all potential types of failure. This FMEA can be viewed in the CDR Report, and it indicates the importance of each failure mode, how it will affect the systems operation,

and what tests can be done to ensure the failure will not occur [1]. These tests and analyses, along with those explained in Table 4.1, justify the chosen design.
These tests have also been documented to prove that the specifications listed above have been met, and these tests are outlined in the DVPR in Appendix E. Further detailed explanations of these tests will be discussed in the next section. The DVPR also documents the dates that tests were started and completed alongside their results recorded.

4.2 Testing and Results

Table 4.2 summarizes our tests, their corresponding specifications or purpose, and their results. A more detailed table appears in Appendix E of this report. Our testing plan included seven tests, six of which were completed during our project. The following subsections (4.2.1 through 4.2.7) give detailed summaries of each test, and full descriptions of each test can be found in Appendix F.

Table 4.2: Testing summary.

No.	Test Name	Specification or Purpose Spec	Result	Target
1	Respooling	Redeployment Time	Pass (15 minutes for spooling)	Less than 30 minutes
2	Shock Loading	Static Strength	Pass	No permanent damage
3	Drop	Impact Strength	Pass (3° at 4 drops)	Less than 5° deflection after 3 drops
4	Weight Recovery	Retrieval of Weight Force	Pass (5 min recovery at 75lbf)	Less than 75 lbf
5	Dryland Release	Actuation of Release (Preliminary) Linear Actuator Test	Pass (2 seconds)	Within 2 minutes
6	Submerged System	Low Depth Water Actuation of Release (Intermediary) Pool Linear Actuator Test	Failure	Within 2 minutes
7	80m Depth System	Actuation at 80m of Release (Final) Ocean/Hyperbaric Linear Actuator Test	Incomplete	Within 2 minutes

4.2.1 Test 1 – Respooling Test

This test was conducted to gauge how long the redeployment process would take. This is a priority for the sponsor, as time out on the water is valuable, which means the time span of this process is good to know for planning collection trips. This test was to be conducted 5 times, then average time and standard deviation was calculated. Initially, the respooling test was done with the rope passing through the open acrylic panel, but it was realized that that was not accurate to how the respooling would realistically take place. Figure 4.1 shows the initial test completed using this process. The rope is instead passing through the hole in the bottom of the frame while being respooled during the retrieval process, so the previous test data was scrapped, and 5 new tests were performed. As expected, these new tests took longer as feeding the rope back onto the spool as it is passing through the frame hole is more difficult than just through the open acrylic panel.

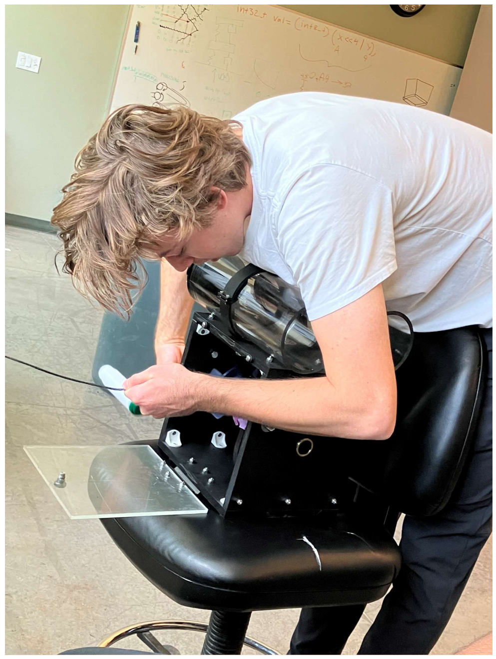


Figure 4.1: Evan completing the respooling test.

The result of this test was fast enough to keep the deployment time near our goal of about 30 minutes. The 5 tests resulted in an average time of 883 seconds (14 min, 43s) with a standard deviation of 161 seconds (2 min, 41 s). With the other steps of the redeployment process – retrieving the weights, resetting the release mechanism, and checking for damage – taking less then ~15 minutes (weight retrieval time is explained in section 4.2.4), it would be expected to take 30 minutes total for redeployment if everything goes smoothly. With the steps outlined in the user manual, a smooth retrieval/redeployment process can be done.

4.2.2 Test 2 – Shock Loading Test

The shock loading test replaced the static strength test that was in our CDR report. This was because we found that the static strength test that we were planning on the shaft was not relevant to how our system is set up, and that a shock loading test on the full shaft subsystem would be more useful to us.

The main purpose of this test was to see if the PVC spool expander was able to withstand a shock load of 80lb. This test was conducted with the rope fully spooled around the PVC to simulate the actual case that would happen. A shock load would be very unlikely to occur when the spool is unraveled because the weights are the cause of the maximum shock thought to occur and having no tension in the line would not create a shock.

For our test, we set the frame of the prototype across two tables and then dropped the weights by pushing them off a chair that was standing to the side. Figure 4.2 displays our set-up. The test was done in 10lb increments, starting with 10lb and ending at 80lb. The 80lb test was done three times. There were no cracks visible after checking, meaning that the spool subsystem will withstand a shock of at least 80lb. We do not expect this to happen but if it does, it will either be in deployment or storage if someone accidentally drops the weights while the frame is suspended.

Figure 4.2: System set-up for shock loading test.

4.2.3 Test 3 – Drop Test

The drop test was completed during winter quarter with our structural prototype. The purpose of this test was to see if multiple impacts on the frame would damage the structural integrity of the frame. The result was after the fourth drop, about a 3–5 degree deflection can be caused by medium pressure to the edges. After the fifth drop, about a 10 degree deflection can be caused by the same pressure. This is after starting with 0 degrees of deflection with this amount of pressure. After inspecting the corner brackets, we noticed that some were cracked as shown in Figure 4.3. The corners of the frame were also dented, but not in a way that would decrease the functionality of the prototype. We suggest to check each bracket if the frame is accidentally dropped and to change the bracket if one is cracked. The bracket should not be overtightened, which can also cause cracks in the bracket.

Figure 4.3: Cracked corner bracket.

4.2.4 Test 4 – Weight Recovery Test

During device retrieval it is necessary to pull the weights up from the ocean floor after the system and buoy have been acquired. This test was performed to find a relationship between the amount of force used to retrieve the weights and the amount of time it would take for said retrieval. We developed an estimate of 2-5 minutes based on a simple drag model.

This test is performed by resting the weights on the ocean floor (40ft underwater for our test at the pier). They are connected to a force gauge via a line that passes through a pulley, as shown in Figure 4.4. During the test, one or more testers started moving, pulling one end of a force gauge until it stabilizes at a given target force value. Once their speed and the measurement stabilized, another observer started a timer. This observer stopped the timer after the testers had pulled the weights up by 30 feet. The time taken and the constant force applied were recorded for each test. Figure 4.5 shows images of our testing setup, and Table 4.3 shows our raw data. From our data, we used a simple drag model to approximate the amount of time it would take for the weights to be pulled up from our design target of 80 meters.

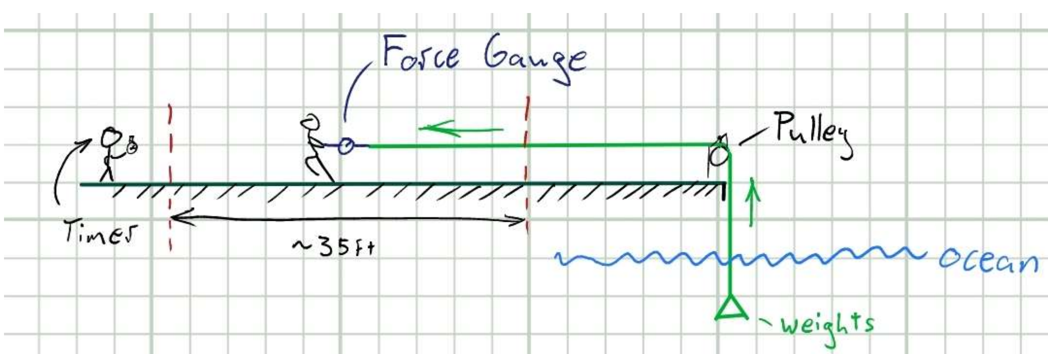


Figure 4.4: Sketch of testing setup.

Figure 4.5: Pictures of testing setup.

Our drag model makes the following assumptions. First, our weights experience forces only from their weight, buoyancy, drag, and the force applied to the line. Second, within a short distance of travel the weights will arrive at a constant speed for a given applied force. Third, the density of ocean water is approximately equal to the density of pure water. Fourth, the force our tester applies and the velocity the test is performed at are constant for the duration of a given test. Finally, we assume the water density, the cross-sectional area of the weight cluster, and drag coefficient do not vary with the depth nor the speed the weights will travel at across all these tests and the weights' future retrieval during use. These assumptions allow us to use the following equations to determine a relationship between applied force and recovery time:

$$F = F_d + W - F_b \text{ and } t = \frac{d}{\sqrt{V^2}}$$

where F is the applied force during testing, F_d is the drag force the weights experience, W is the weight of the weights, and F_b is the buoyant force the weights experience. The relationship between distance, time, and velocity is written strangely, but this will be useful in deriving the uncertainty in our recovery time.

Since we are assuming our drag coefficient and ocean density will stay constant, we can show the following using the above force balance equation:

$$F = \left(\tfrac{1}{2}\rho A_{\perp} C_d\right) V^2 + (W - F_b), \text{ or}$$
$$V^2 = \left(\frac{2}{\rho A_{\perp} C_d}\right) F + \left(\frac{2(W\text{-}F\_b)}{\rho A_{\perp} C_d}\right)$$

where ρ is the ocean water density, $A_{\perp}$ is the cross-sectional area of our cluster of weights, and C_d is the drag coefficient. The velocity is assumed to be constant throughout this experiment, so we take the velocity to be the average, or the distance traveled over the time recorded. Although the equation admittedly looks more complicated than the previous line, it shows a linear relationship between force and the square of the velocity of the simple form $y = mx + b$. Statistical analysis techniques allow us to perform a linear regression for this relationship using our testing data, yielding a statistical uncertainty for the square of the velocity. The formula used to find this uncertainty at any arbitrary input is shown below.

$$U_{y,\text{statistical}} = \pm t s_{yx} \left(\frac{1}{n} + \frac{(x - \bar{x})^2}{\sum_{\text{i}=1}^{\text{n}} (x_i - \bar{x})^2} + 1 \right)^{\frac{1}{2}}$$

For our use case, y is our desired output (the square of the velocity), and x is our input (the force applied to the line connected to the weights).

In addition to this statistical uncertainty, we can find the measurement uncertainty by propagating our time and distance uncertainties.

$$U_{V^2,\text{measured}} = \left[\left(U_t \frac{\partial (V^2)}{\partial t} \right)^2 + \left(U_d \frac{\partial (V^2)}{\partial d} \right)^2 \right]^{\frac{1}{2}}, \text{ where } V^2 = \frac{d^2}{t^2}$$

Once both the statistical and measurement uncertainties were found, we combined them by root sum square to get the total uncertainty for the velocity squared. One final error propagation takes this uncertainty to find the range of time values for a given force value when recovering the weights from our target depth of 80 meters.

$$U_{\text{t}} = U_{V^2} \frac{\partial (\text{t})}{\partial V^2} = U_{V^2} \left(\frac{80 meters}{2 (V^2)^{\frac{3}{2}}} \right), \text{ where } t = \frac{80 meters}{\sqrt{V^2}}$$

Table 4.3 shows our measurements, the average velocity of the weights during the test, and the estimated time it would take to bring the weights up from an 80 meter depth. Figure 4.6 shows our trendline used for the time prediction as well as our predicted time given an arbitrary force input. From our analysis it is clear that recovering the weights will take at most 5 minutes, with diminishing returns as more force is applied past 200lbf. We are confident that a winch mounted to the boat used for retrieval will be able to recover the weights in 2-5 minutes as long as the winch is strong enough to start pulling up the weights.

Table 4.3: Measured and calculated values for weight test.

Measured						Calculated			
Distance [ft]		Time [s]		Force [lbf]		Velocity Squared [ft^2/s^2]		Recovery Time [min]	
30	±2	25	±0.2	72	±4	1.4	±0.4	3.8	±3.3
30	±2	17.1	±0.2	80	±4	3.1	±0.8	2.5	±0.9
30	±2	16.3	±0.2	82	±4	3.4	±0.9	2.3	±0.7
30	±2	15.2	±0.2	85	±4	3.9	±1.0	2.1	±0.6
30	±2	12.5	±0.2	88	±4	5.8	±1.5	2.0	±0.5
30	±2	12.3	±0.2	92	±4	5.9	±1.6	1.8	±0.4
30	±2	10.9	±0.2	100	±4	7.6	±2.0	1.6	±0.3
30	±2	11.5	±0.2	100	±4	6.8	±1.8	1.6	±0.3
30	±2	9.4	±0.2	110	±4	10.2	±2.8	1.4	±0.3

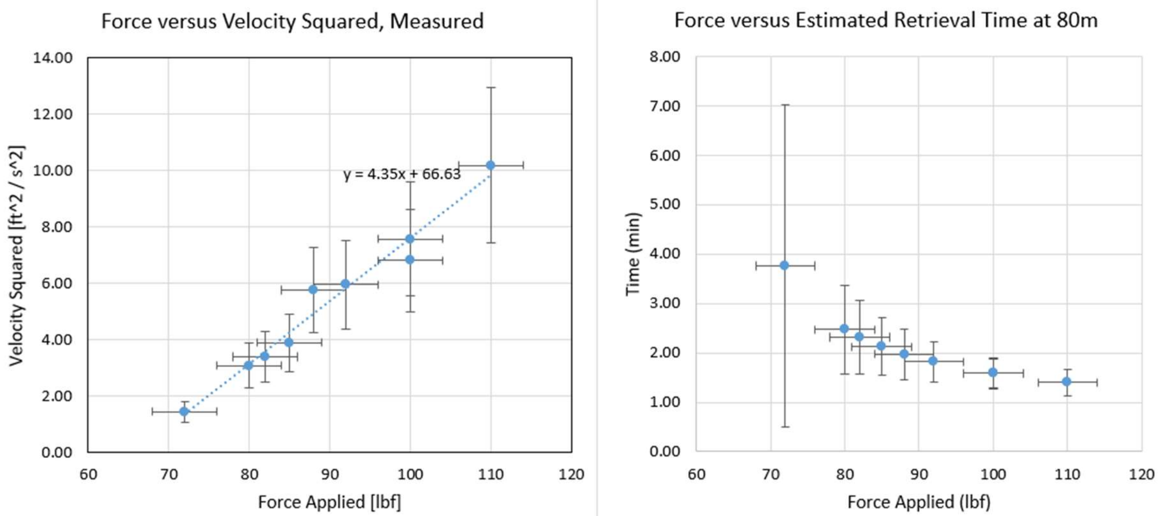


Figure 4.6: Plots of force applied versus measured velocity (left) and versus estimated recovery time (right). The linear model is matches well within our error bars.

4.2.5 Test 5 – Dryland Release Mechanism Test

This test was completed to test both our electronics set-up for testing as well as a preliminary check of if the release mechanism works on land. As described earlier in section 3.4, an IR remote system was developed in order to easily lock and release the system. For this test, we only needed the linear actuator to retract and extend for release and re-engaging the release mechanism respectively. With working electronics to control the actuator, we created a similar set up to how the shock loading test was done and activated the release several times with the full 80lb weight. This also tested the strength of release mechanism bar as well as the linear actuator force. The system worked well and passed all of the tests completed.

Figure 4.7: Dryland release mechanism test.

4.2.6 Test 6 – Submerged System Test

This test is a less intense and easier to run version of test 7, which would be to run our system at its 80m use case. This test was much easier to schedule since it only required one pier technician to assist with a winch rather than two technicians to spend multiple hours setting up, driving, and cleaning the Cal Poly boat. Since this test applies less pressure to the system, failures at this depth would occur much more slowly and infrequently, letting us isolate issues more effectively.

To perform the submerged system test, we attached the full system to a winch at the Cal Poly Pier, initiated the delayed release on the microcontroller after 5 minutes, and lowered the system to the ocean floor, about 35ft underwater. The microcontroller allowed the linear actuator to retract 5 minutes after activation, and the system floated to the surface as expected. Figure 4.X shows the start of the experiment with the whole system being lowered to the water. However, upon retrieval the capsules were seen to have water in them, indicating that there had been a breach. We recovered the electronics by washing them in freshwater to displace as much saltwater as possible, sprayed them with Contact Cleaner, and then let them dry in rice for two days to soak up any moisture left. The electronics remained functional after the recovery process, but the test indicated our capsules were not ready to be deployed at this shallow depth, let alone our 80m target. Further testing must be performed to determine the source of the leak.

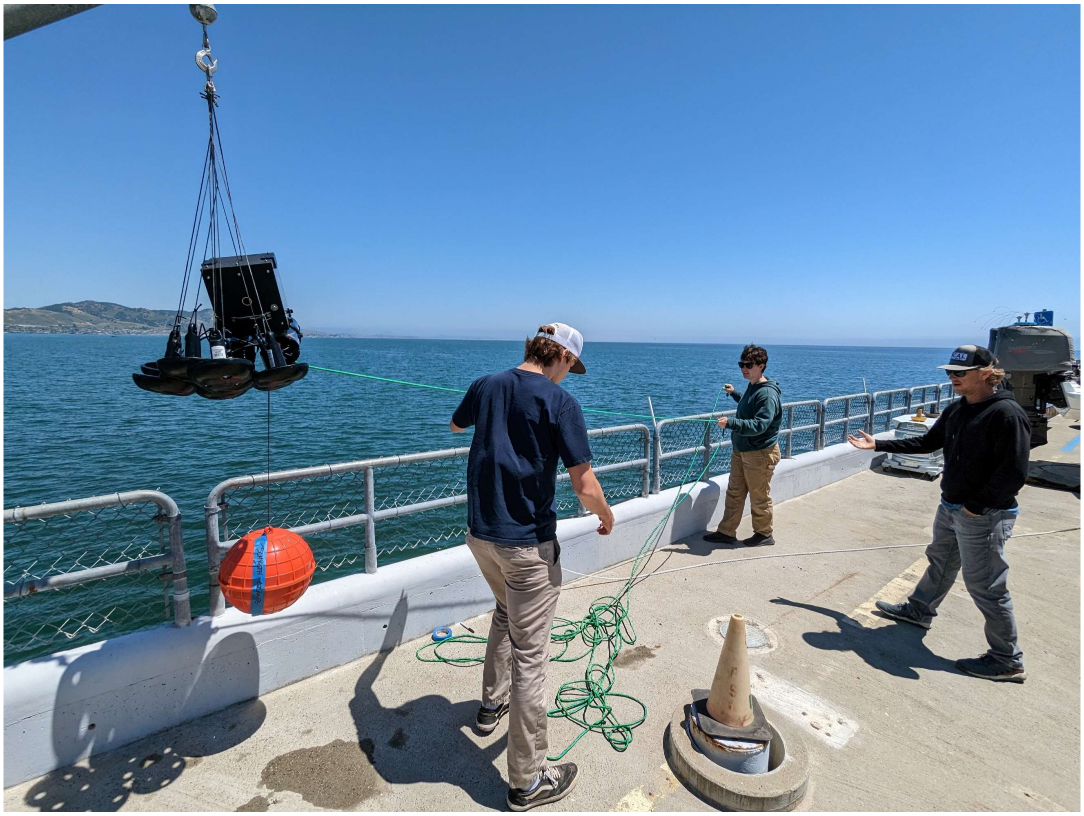


Figure 4.8: Lowering of the system for the submerged test.

4.2.7 Test 7 – 80m Depth System Test

This test would entail deploying our full device from the CalPoly boat to a depth of 80 meters to simulate its actual use case. Since our electronics capsules failed and the pier was unable to schedule time for us to deploy on the boat within our testing timeframe, this test was not performed.

5 Discussion & Recommendations

5.1 Discussion

Due to the nature of this project being an underwater system, we learned a lot about designing in different environments. For example, we had to select materials that would not corrode due to the salt water, take into consideration fouling and how to mitigate it, and find a linear actuator that works at an 80-meter depth in water. We also learned how quickly a project can go from the research and ideation phase to building the prototype.

One design change that we would recommend would be to create a mechanism that lightly presses the rope into the spool so that it does not unravel too quickly and cause tangling, as this occurred frequently during our dryland testing (though more testing is needed to determine if the spool's momentum will cause it to rotate too far while in the water). If we had to build this prototype again, we would use shorter fasteners or brackets that would allow us to leave the nuts on the interior of the frame, giving us a flusher exterior surface. If we had to do the project again, we would refine our project scope to only consider traditional "pop-up" release mechanisms instead of brainstorming original no-waste designs. This would have given us more time to ideate on how to design the different systems, locking these designs in sooner. One of the most stressful parts of this project was designing the release mechanism, which did not get fully specified until partway through our manufacturing time. More purposeful ideation would have helped us make more progress on this and other systems sooner.

5.2 Recommendations and Next Steps

This prototype, once finished, will be able to be deployed for up to 6 months at up to an 80-meter depth. The system should be checked prior to each deployment. This includes checking the rotational direction of the spool, running the activation, checking for damage, and pressure testing the capsules. When deploying the system, the buoy and frame should be placed into the water first, with the weights following. When retrieving the system, the release mechanism will be triggered, allowing the buoy and frame to surface. The buoy and frame should be pulled into the boat before putting the line around a winch and winching the weights up. One thing to always be cautious of is the amount of line that the system has. If the line is not spooled at the same time as the weights are being pulled up, the user and surrounding people should make sure not to get caught in the line. After spooling the line, the release mechanism should be put back into its locked position. The user should be cautious about getting fingers pinched during this process. A user manual that goes over deployment, retrieval, and maintenance is included as Appendix A.

If this prototype was to be produced again, we would recommend that the matching HDPE frame panels be milled at the same time, ensuring their dimensions and hole locations match. We also recommend that during the machining of the release mechanism bar, the hole and slot be machined before the profile of the bar is, as it is much easier to mill these features before the part must be clamped along its curved edge.

In order to move the project forward, an interdisciplinary team may be the best option, as an acoustic release is the only remaining portion of this project to be developed. Signal processing skills will be necessary, but the team should also be able to understand how the mechanical system functions and take into account power requirements to run this project long term. In addition, making a custom printed circuit board (PCB) would be recommended for the final electronics design. Essentially, a future team would need to develop a PCB that can generate the PWM signals required based on acoustic communication. We'd recommend a team comprised of EE, CPE, and ME mechatronics students.

6 Conclusion

The prototype was mostly successful in the functions that we designed it for. The release mechanism did work on a timer and the prototype was fully retrieved when we conducted the low depth water test. However, the capsules did leak which could be an error in how we put them together or a result component damage while sitting in storage for months. This, along with the unavailability of the boat, meant that we were not able to conduct a test at the target depth of 80 meters. Based on the results of the release mechanism, the component that we were most worried about working, in other tests, we are confident that the release will work at depth.

While the focus of our project was to hold a hydrophone at a depth until retrieval and have the whole system zero-waste, the connection to between the frame and the buoy could be modified to hold other ocean testing instruments. Once the acoustic trigger is added to the system, it could be used for a large variety of ocean measurement instruments. In addition, by swapping out the capsules or actuator, this system could be deployed at deeper depths. Increasing the capsule size to allow for more power storage could also extend the deployment time available.

We hope that a future team will pick up where we are leaving off. We are confident in the mechanical system we designed, and with some pressure capsule troubleshooting and the development of the acoustic triggering system we are certain that this project can be completed.

References

[1] E. Brown, G. J. Ellsworth, C. Schofield, J. Somasundaram, "Critical Design Review Report," Mechanical Engineering Dept., California Polytechnic State University, San Luis Obispo, CA, USA, 2023

[2] R. Lawson, J. Lyons, L. de Torres, C. Otero, S. Danthinne. "Senior Project Report for Acoustic Release and Receiver System." Mechanical Engineering Dept., California Polytechnic State University, San Luis Obispo, CA, USA, 2020.

Appendices

Appendix A – User Manual

Frame Disassembly for Spool Removal

This process will outline how to take apart the frame partially to allow for spool removal. Other frame components can be removed without frame disassembly, but this process could allow for easier maintenance. *Italicized text refers to potential safety hazards to consider.*

Tools Required: 3/32” Allen key, 11/32” wrench/hex driver.

1. Detach the carabiner from the end of the spool line. This will allow the spool line to be pulled through the frame opening and *prevent unwanted spool rotation when working inside the frame.*

2. Ensure the spool is fully spooled at this point so that rope tangling will not occur. Ensure the release bar is in the unlocked position. If it is not, activate the release so that the bar will not impinge spool removal.

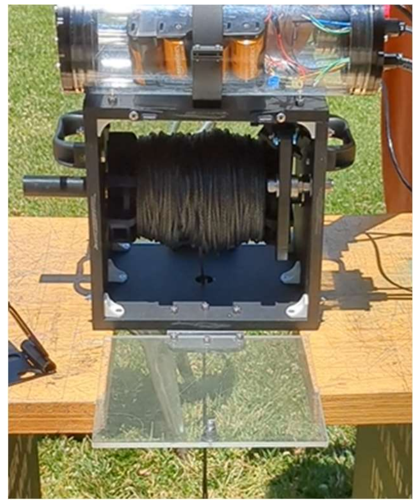


Figure A.1: Frame system with acrylic panels open.

3. Open acrylic panels. Having both open will allow for easier access to the screws. *Be careful of pinch points while working inside of the frame*.

4. Remove the panel opposite the release mechanism (side with the shaft protruding on the outside). Using the Allen key and wrench, remove the 6 screws that connect the white plastic corner brackets to that side panel, highlighted in the picture on the right (2 cannot be seen but are the two on the top side that are attached to the side panel.

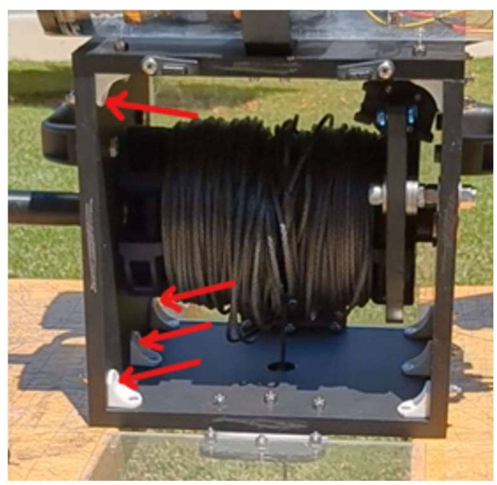


Figure A.2: Labeled screws for removal. Note that there are two more screws (6 total) that need to be removed, all attached to the left side panel in this image.

5. Remove the side panel from the frame. The spool will now be loose and can be removed as well. Keep in mind that the bushings are loose in the side panel, so they may come off with the spool shaft or may fall off.

System Retrieval/Deployment Process

This process outlines the steps to ensure a successful redeployment. To speed up redeployment time, it is recommended that at least two people participate. This procedure can be completed by only one person, just expect it to take about twice as long. If the system is being deployed for the first time, start from the deployment section. *Italicized text refers to potential safety hazards to consider or steps required to perform a task safely.*

Tools Required: Battery tester, Crank for spool shaft, Activation system, Winch (recommended) for weight recovery.

Recommended Supplies for Maintenance: Batteries (C for actuator), Cleaning rag, White plastic brackets, Capsule O-rings and O-ring pick, Silicone Grese, Alcohol wipes, extra screws/nuts and associated Allen keys/wrenches.

Retrieval

1. Send activation signal to the system to initiate retrieval (more detailed steps can be outlined once activation mechanism is made).
2. When the system surfaces, remove it from water using provided handles or by the buoy line. *Do not lift the device by the capsules or spool line.*
3. Pull up on the spool line to test the mobility of the weights. At this point, if the weights are stuck, attempt to get them moving before using a winch or other means for retrieval.
4. Set up system and attach crank handle to prepare for respooling. Set up winch (or whatever method desired) to prepare for weight retrieval. It is important to re-spool the line as it is being pulled up to prevent tangling in the line.
5. Initiate weight retrieval and begin respooling. *Refer to the spooling process manual for the proper procedure for respooling.* Also, inspect the line for defects (abrasion, compression damage, pulled strands) as it is coming in. Any defects will need to be addressed before redeployment.
6. Once weights have surfaced, *secure them somewhere to prevent any potential unexpected spool rotation during maintenance.*
7. At this point, inspect the overall system for any damages/failures that need to be addressed. If any parts have visible damage, redeployment is not recommended until they have been replaced/fixed (it is important that this is done upon retrieval in case of any potentially compromising damages in the system).
8. With one acrylic panel open, rotate the spool so that the release bar hook is aligned with the designated slot in the shaft endcap. Use one hand to hold the endcap opposite of the release mechanism in place. *Do not hold the endcap on the same side as the release mechanism as the activation of the release mechanism will create pinch-points.* ***Ensure that your fingers are at least 6 inches away from all moving parts of the release mechanism during activation. This includes the front of the actuator and the body of***

the release bar. Activate the closure of the release mechanism to put the release bar back into the locked position.

9. Remove the vent plug from the capsule with the actuator batteries, then remove the endcap. *Do not blindly reach into the capsules as there is loose wiring that can cause shock or may be sharp.* Re-inspect the inside of the capsule for any signs of leakage. *If there is any sign of a leakage, take precautions outlined in the Battery and Capsule sections of the Maintenance Guide before moving forward.* Use the battery tester to check the batteries. Battery replacement is recommended for every redeployment, but if the batteries are still at least 75% full, they can be reused.
10. To reinstall the endcap, inspect the O-rings for any damage. If no damage is found, skip to step 12.
11. Remove the damaged O-ring from the end cap. Clean the endcap with an alcohol wipe. Apply silicone grease to the new O-ring. Install new O-ring onto endcap (see maintenance section).
12. Clean off the inside of the capsule with a microfiber towel, **DO NOT** use alcohol wipes on the acrylic tubes as they will cause micro-cracks in the acrylic. Then reinsert the endcap into the capsule and reinsert the vent plug as well.
13. If redeployment is not planned, the weights can be disassembled for easy movement of the system. This is done by opening the pear-shaped carabiner and sliding off the small individual carabiners, then moving them with their attached weights aside. The buoy can also be detached by the carabiner connected to the eyebolt of the frame. The system should also be washed off with fresh water to prevent any buildup/growth on the system when in storage.

Deployment

1. Ensure spool is wound in the correct orientation (crank was wound in the counterclockwise direction). If not, the spool will have to be re-spooled to ensure the release mechanism works properly. If the spool is properly wound, ensure that the release bar is in the locked position and the actuator is secured in its housing.
2. Inspect the weight system and the carabiners for any visual damage/deflection. Rope or carabiners may need to be replaced to ensure all weights can be retrieved properly.
3. Inspect the buoy system. Ensure that the rope and carabiners are in good shape. Replace parts if structural damage is found.
4. Inspect the capsule system, including the cables connecting the capsules. If any unknown substances are present inside of either capsule or if the capsules have not been opened in over a week, refer to steps 9-12 of the retrieval process to check the O-ring seals, the status of the batteries, and clean out the capsule. If there is damage to the cables, they must be repaired before deployment as water will leak into the capsules through holes in the cables. If any penetrators (metal parts that allow the cables to pass through the endcaps) are loose, tighten them.

5. Inspect the frame, especially the corner brackets/fasteners, for any visible damage. If any of the corner brackets/fasteners are damaged, replace them with spare components. If the HDPE panels are damaged, determine if the damage will affect the structural integrity of the frame or the release mechanism's ability to work properly. If so, this damage must be repaired before deployment.
6. **Refer to the bearing section of the maintenance guide to ensure that the bearings are ready for deployment.**
7. Clean off any visible debris/fouling/corrosive buildups inside of the frame. Exterior buildup is not necessary to clean, but it is recommended as it may help slow the process of buildup forming on the overall system. Refer to the appropriate section of the maintenance guide for the type of buildup that requires removal.
8. Run the activation of the release mechanism to ensure that it is working. *This is to be done without weight on the spool, so ensure that the weights are either removed or secured before this is done.* If any notable flaws in the release mechanism are seen, they must be addressed before deployment. If not, proceed to return the release mechanism back into the locked position.
9. When the boat is in the desired location for deployment, position the buoy, hydrophone, and frame system along the side of the boat so that they can easily slide off without getting caught. *Move the weights to the boat's edge and ensure there are no tangles in the line, or that the line is not wrapped around anything on the boat. Do not stand between any part of the system and the edge of the boat, especially the lines connecting the buoy or weights to the device.*
10. While keeping the weights on the boat, slowly lower the rest of the system into the water. Once it has left the boat or is floating in the water, carefully release the weights off the side of the boat (or lower them in with a winch) and let the system sink to the bottom.
11. Make a note of the GPS location of deployment for future reference.

Spooling Process

This process outlines the correct way to wind up the spool. It is recommended that the line is to be laid out flat in about 5-10m segments while spooling, or being pulled up from the ocean, to prevent tangling in the line. Line tangles can cause a delay in the spooling process or cause damage to the line. *Italicized text refers to potential safety hazards to consider.*

1. Attach the provided crank to the shaft section protruding from the side of the frame. This is done by sliding it onto the shaft, then aligning the holes in the crank and the shaft for the quick-release pin to go through.
2. Open one of the acrylic panels. Examine the inside of the frame to ensure there are no obstructions to the spinning of the spool.
3. If the spool is partially wound, ensure that the line is organized neatly on the spool (as shown in the image on the right). If not, it is recommended that the spool be unwound completely to ensure that the line will not tangle when unspooling.
4. Secure the system so that it will not wobble/slide as the crank is being rotated.
5. Use one hand to hold the line slightly taut directly in front of the spool. This hand will be used to guide the line across the spool while being wound. Use the other hand to hold the crank handle.
6. Start to rotate the crank **counterclockwise**, guiding the line as it winds around the spool. *Rotate the crank at a reasonable pace so that the spool is not spinning fast enough to cause injury. This is about 2 rotations per second.*
7. The line does not need to be as neat as possible but try to avoid wrapping nearby loops on top of each other as they could slide along the spool and tangle. Make sure the line is wrapping as tight as you can get it.
8. Once the line has been spooled up so that the desired length of line remains outside of the frame, try to keep the line as you align the designated slot on the endcap up with the release bar.
9. While holding the endcap opposite of the release mechanism or the crank in place *and keeping all fingers at least 6 inches away from the release bar*, activate the release mechanism to lock the spool from rotating.
10. Close the acrylic panel and remove the crank.

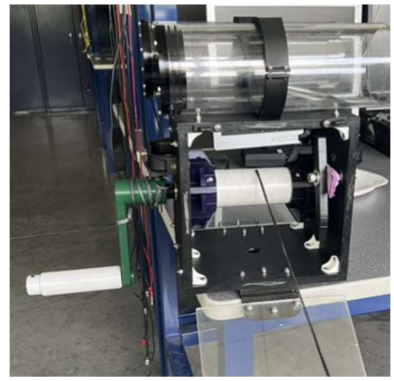


Figure A.3: Crank attached, acrylic panel open, and placed on a sturdy spot.

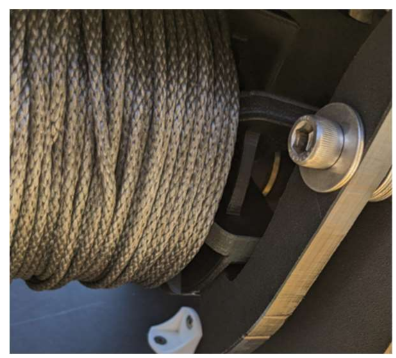


Figure A.4: Neatly spooled line.

Figure A.5: Final spooled-up system.

Maintenance Guide

This guide provides information on the required upkeep of the system to ensure that it will work correctly. The required tools, replacement parts, and procedures to complete maintenance are listed for the important components of the system. *Italicized text refers to potential safety hazards to consider or steps required to perform a task safely.*

Batteries

<u>Required Tools:</u> Battery tester

<u>Supplies:</u> Replacement batteries (C-cell), gloves, electronics cleaning spray, rag

To ensure that the release mechanism will have enough power to activate, the batteries must be checked before every deployment. Using a battery tester, check the voltage of every battery and ensure that there is at least a total of 12 volts between them. The actuator will work between the range of 9-18 volts, so anything under 12 volts is risky. Ensure that the mechanical switch is in the off position before removing any of the batteries from their slots.

In case of a capsule water leakage or battery acid leakage, you will need to remove and clean/replace all the batteries. *Make sure you wear gloves for this*. Carefully remove the batteries from the capsule, and if there are no signs of damage or leakage on them, then they should be cleaned off with electronics cleaning spray and a rag. If there are signs of damage or leakage, then they should be carefully removed and properly disposed of. The battery holders should also be cleaned with an electronics cleaning spray and a rag for both of these situations. Make sure everything is completely dry before reassembling the capsule.

NOTE: Battery acid is harmful and should not be handled without gloves. Also, keep the batteries and your hands away from your eyes and mouth when handling leaking batteries. Wash your hands thoroughly after handling leaking batteries. If any battery acid gets on your skin during handling, rinse under cold water immediately for about 15 minutes. If battery acid gets in your mouth or eyes, poison control should be contacted immediately.

Bearings

<u>Required Tools:</u> None

<u>Supplies:</u> Lubrication (if desired)

The bearings need to be free of debris or corrosion to work properly. This means proper inspection should be done upon retrieval and deployment. The bearings are a close fit to the shaft, so not much, if any, water will get between the shaft and the bearings, but if the gap seems to be significant for whatever reason, lubrication may be needed. Lubrication would help prevent any unwanted buildup between the shaft and the bearings. This lubrication would need to be viscous and not dissolve in water. Lubrication is not required for the bearings to spin but may be required for the bearings to work after a long period underwater. Bearing can also be replaced if too much corrosion/damage occurs. Follow the Spool Removal Process section of the manual for replacement of the bearings.

Capsules
<u>Required Tools:</u> O-ring pick, vacuum pump
<u>Supplies:</u> Replacement O-rings, silicone grease, alcohol wipes, microfiber towel, elect

Every time the capsules need to be opened, the endcap seal is broken and the O-rings wear. To redo the seal, the O-rings must be cleaned and regreased, or replaced if damaged or overused. This is also true for the endcap penetrators, if any are removed, the O-ring must be cleaned and regreased or replaced before being reinstalled. Make sure to use the alcohol wipes for the O-rings and endcaps, and the microfiber towel for the acrylic tubes. **DO NOT** use alcohol wipes on the acrylic tubes as they will cause micro-cracks in the acrylic.

Ensure that the cable jackets are undamaged before submerge ing the system in water. Any cracks or holes in the cable jackets will allow water to leak into the cables and eventually into the capsules. Damage can be repaired by filling the cracks or holes with epoxy and then covering it with electrical tape. If the damage seems to have reached the wiring inside of the cable, then the cable may need to be replaced. The process for replacing the cable and installing new penetrators can be found on the Blue Robotics website.

To ensure the capsules have not lost their watertight seal, a vacuum test may be administered. Using the designated vent plug adapter on a vacuum pump tube, the adapter can be inserted into the vent plug. You will want to create an approximately 10 psi vacuum inside of the capsule, and then turn off/stop pumping the vacuum and examine the leak rate of the air. This means the vacuum must have the ability to seal when powered off, or a one-way valve with a pressure gage. You will then wait about 30 minutes, and if there is any leakage of air, then there is likely a leak in the capsule. At that point, refer to the previous protocol for resealing the O-rings and penetrators, or checking the cables and acrylic tubes for any damage.

More details on how to perform maintenance or replace parts on the capsules can be found on the manufacturer's website: https://bluerobotics.com

Carabiners
<u>Required Tools:</u> Wrench/pliers for the locking screw (if they cannot be screwed by hand)
<u>Supplies:</u> None

For the carabiners with lever openings, ensure that they are not bent/damaged to the point that they cannot remain closed. For the carabiners with locking screws, ensure that the screws are closed and not loose. If they open, the carabiners/rope attached to it could slip loose, so replace carabiners that may be loose or unable to close/remain closed.

Carabiners may also corrode, as they are made with metal. Ensure that they do not lose structural integrity due to corrosion and do not become rough/sharp as they could damage the rope connected to it. Either of these situations would require the carabiner to be replaced. When replacing a carabiner, it is not crucial for the replacement to be identical, but it should be the same size or larger and made of 316 Stainless Steel.

Endcaps and Shaft
Required Tools: Hammer/Punch
Supplies: None

If damage was seen on either the shaft (including PVC) or the endcaps, then that part would likely need to be replaced. Any crack or bend in the shaft could cause the system to fail and would require a replacement. If there are scratches, dents, or buildup on the shaft, then buffing out or cleaning off the damage will be enough to allow the system to still work. If there is any severe damage on the shaft where it protrudes out of the frame (for the crank attachment), this damage can likely be ignored because any failure will not affect the performance of the system. If it is a split that runs parallel to the axis of the shaft though, this could grow and cause damage to the shaft inside of the bearings/frame, so this should be addressed.

If damage is seen on the endcaps, this can most of the time be fixed with glue or just left as is without compromising the system. As long as the endcaps will not fall off or start to rotate freely due to the damage, minimal measures may be taken. The other crucial feature is the slit for the release bar on the endcap next to the release mechanism. If this slot has any damage of any kind, the endcap should be replaced. A new endcap may be printed, or, if the slot on the other endcap is intact, they can be switched.

To take apart the spool, the spool removal process must be followed. Then, using a hammer and a punch, the stainless-steel pins can be hammered out and then the spool system will pull apart by hand. *Only do this if you are familiar with a hammer and a punch.* Use caution when using a hammer, as the endcaps are brittle and can crack easily.

Plastic Corner Brackets and Frame Fasteners
Required Tools: 3/32” Allen key, 11/32” wrench
Supplies: Replacement corner brackets

The corner brackets are susceptible to cracking when too much bending or impact force is put on the fasteners. To avoid this, do not over tighten the fasteners. When a corner bracket is cracked, like in the figure on the right, the bracket should be replaced. This is done by simply removing the screw and locknut on both sides of the bracket with the correct Allen key and wrench, then reattach the screw and locknut with a new bracket. Make sure to tighten the nut no more than ¼ turn past contact with the frame panel.

Release Mechanism and Bar
Required Tools: 5/16” Allen key, 9/16” wrench, 4mm Allen key, 3mm Allen key, flathead screwdriver
Supplies: Replacement Bar

The release mechanism is the most crucial aspect to the system performing the way it should, so any damage, deflection, buildup, or other things that may impede the system needs to be addressed. For the release bar, any damage or deflection means the bar must be replaced.

Having a back up bar made would be safe to have on a redeployment mission. To replace the release bar, the screw attaching the bar to the actuator must be removed using a 3mm Allen key. Then, the 3/8” bolt must be removed using a 5/16” hex key and a 9/16” wrench. Keep note of how the washers are organized on the bolt before removing it. Release bar can then be replaced, and screws reattached. Test alignment of the new bar with the endcap slot before activating the mechanism to prevent any damage to the endcap or the actuator.

The first thing that should be checked when inspecting the actuator is to see if it has become loose in its mount. If so, the release mechanism may not lock the spool properly. If this is happening, put the release mechanism in its locked position, slide the actuator so that the release bar sits inside of the slot on the endcap, then re-tighten the blue screw on the mount with a flathead screwdriver. If there is any damage to the exterior of the actuator, it will likely be fine, but if the damage is on the pin-side of the actuator, it could impede its motion. Run multiple tests of the actuator’s motion before redeploying. If the actuator stops working, troubleshooting processes can be found on the manufacturer’s website (Blue Robotics) listed in the Capsules section of this maintenance guide. Removal of the actuator can be done by first removing the screw attaching the actuator to the release bar using a 3mm Allen key, then removing the blue screw on the mount using a flathead screwdriver (or by hand). You will then be able to slide one side of the mount out and remove the actuator. If the mount needs to be removed, the two screws attaching it to the frame can be removed using a 4mm Allen key.

Rope/Line
Required Tools: Scissors, lighter/heat gun
Supplies: Extra rope

If any damage is seen on the rope, the chances of the rope breaking will increase. As the rope being intact is necessary for the system to work properly, any damage must be addressed. Damage that does not occur near the end of the spool line can be dealt with by either cutting out the damaged section and tying the ends together, or by tying a loop in the line so that the damaged section is on the loop. For any damage near the end of the spool line, if it does not shorten the line too much then the line can be cut just before the damage to remove the damaged section. It is important to record how much is cut off/looped for all of these cases so that the spool line does not get too short after multiple repairs. Any damage to shorter sections of line (the individual weight lines or the buoy line) can be fixed by simply cutting a new section of rope and replacing the entire existing rope.

Whenever rope is cut, both ends (unless one section is being thrown out) should be fused with a lighter/heat gun so that they do not start to fray. This is done by holding the recently cut end over the flame/heating zone for about 10 seconds, or until the entire end has started to melt/fuse.

Whenever rope needs to be tied, ensure that the proper knot is used. Improper knots or incorrectly tied knots can cause the rope to tangle, become damaged, and/or break. The bowline knot, shown in Figure A.6, is used for all applications on this prototype.

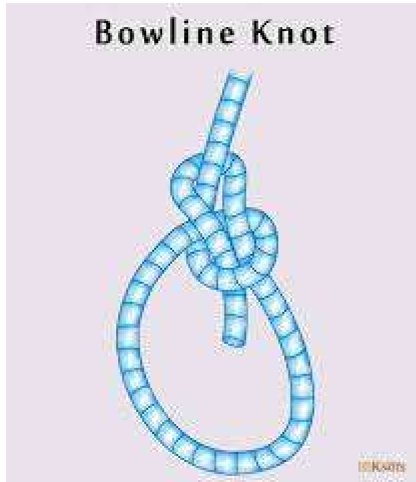


Figure A.6: Knot used for all applications on system.

Appendix B – Risk Assessment

designsafe Report

Application:	F73_WhaleSounds_RiskAssess	Analyst Name(s):	Chloe Schofield, Evan Brown, Jathun Somasundaram, German Jack Ellsworth
Description:		Company:	
Product Identifier:		Facility Location:	
Assessment Type:	Detailed		
Limits:			
Sources:			
Risk Scoring System:	ANSI B11.0 Two Factor		

Guide sentence: When doing [task], the [user] could be injured by the [hazard] due to the [failure mode].

Item Id	User / Task	Hazard / Failure Mode	Initial Assessment Severity Probability	Risk Level	Risk Reduction Methods /Control System	Final Assessment Severity Probability	Risk Level	Status / Responsible /Comments /Reference
1-1-1	passer-by / non-user walk near	mechanical : drawing-in / trapping / entanglement Rope laying out	Moderate Unlikely	Low	standard procedures of operator	Moderate Remote	Negligible	Action Item Chloe
1-1-2	passer-by / non-user walk near	slips / trips / falls : slip On rope	Moderate Unlikely	Low	standard procedures of operator	Moderate Remote	Negligible	Action Item Chloe
1-1-3	passer-by / non-user walk near	slips / trips / falls : trip On rope	Serious Unlikely	Medium	warning sign(s), supervision	Serious Remote	Low	Action Item Chloe
1-1-4	passer-by / non-user walk near	fire and explosions : spontaneous combustion Battery exploding	Serious Remote	Low	other warning	Serious Remote	Low	Action Item German
1-2-1	passer-by / non-user observe / watch	mechanical : drawing-in / trapping / entanglement Rope	Moderate Remote	Negligible	standard procedures of operator	Moderate Remote	Negligible	Action Item Chloe
1-2-2	passer-by / non-user observe / watch	slips / trips / falls : falling material / object Weights	Serious Likely	High	standard procedures	Serious Remote	Low	Action Item Chloe
1-2-3	passer-by / non-user observe / watch	fire and explosions : spontaneous combustion Battery exploding	Serious Remote	Low	other warning	Serious Remote	Low	Action Item German

Item Id	User / Task	Hazard / Failure Mode	Initial Assessment Severity Probability	Risk Level	Risk Reduction Methods /Control System	Final Assessment Severity Probability	Risk Level	Status / Responsible /Comments /Reference
2-1-1	Our team Common Tasks	mechanical : drawing-in / trapping / entanglement rope	Moderate Unlikely	Low	standard procedures of operator	Moderate Remote	Negligible	Action Item Chloe
2-1-2	Our team Common Tasks	mechanical : pinch point frame panels on and off	Minor Likely	Low	standard procedures	Minor Unlikely	Negligible	Action Item Evan
2-1-3	Our team Common Tasks	mechanical : unexpected start rope spool	Catastrophic Unlikely	Medium	special procedures	Catastrophic Remote	Low	Action Item Jathun
2-1-4	Our team Common Tasks	electrical / electronic : energized equipment / live parts actuator	Serious Unlikely	Medium	prevent energy release	Serious Remote	Low	Action Item German
2-1-5	Our team Common Tasks	electrical / electronic : water / wet locations actuator and pool/ocean	Moderate Remote	Negligible	standard procedures	Moderate Remote	Negligible	Action Item German
2-1-6	Our team Common Tasks	electrical / electronic : unexpected start up / motion actuator	Serious Unlikely	Medium	standard procedures	Serious Remote	Low	Action Item Evan
2-1-7	Our team Common Tasks	electrical / electronic : power supply interruption actuator	Minor Unlikely	Negligible	standard procedures	Minor Remote	Negligible	Action Item Evan
2-1-8	Our team Common Tasks	slips / trips / falls : slip rope and water	Moderate Likely	Medium	footwear, standard procedures	Moderate Remote	Negligible	Action Item Chloe
2-1-9	Our team Common Tasks	slips / trips / falls : trip rope	Serious Likely	High	restricted users, standard procedures	Serious Remote	Low	Action Item Chloe

Item Id	User / Task	Hazard / Failure Mode	Initial Assessment Severity Probability	Risk Level	Risk Reduction Methods /Control System	Final Assessment Severity Probability	Risk Level	Status / Responsible /Comments /Reference
2-1-10	Our team Common Tasks	slips / trips / falls : falling material / object weight	Serious Likely	High	standard procedures	Serious Remote	Low	Action Item Jathun
2-1-11	Our team Common Tasks	ergonomics / human factors : excessive force / exertion weight	Moderate Likely	Medium	standard procedures	Moderate Unlikely	Low	Action Item Jathun
2-1-12	Our team Common Tasks	ergonomics / human factors : repetition spooling	Minor Unlikely	Negligible	standard procedures	Minor Unlikely	Negligible	Action Item Evan
2-1-13	Our team Common Tasks	ergonomics / human factors : lifting / bending / twisting weights	Moderate Likely	Medium	standard procedures	Moderate Unlikely	Low	Action Item Jathun
2-1-14	Our team Common Tasks	fire and explosions : spontaneous combustion battery	Serious Remote	Low	standard procedures	Serious Remote	Low	Action Item German
3-1-1	End user Common Tasks	mechanical : drawing-in / trapping / entanglement rope	Moderate Likely	Medium	standard procedures, supervision	Moderate Remote	Negligible	Action Item Chloe
3-1-2	End user Common Tasks	mechanical : pinch point frame panels on and off	Minor Likely	Low	standard procedures	Minor Remote	Negligible	Action Item Evan
3-1-3	End user Common Tasks	mechanical : unexpected start rope spool	Catastrophic Unlikely	Medium	standard procedures	Catastrophic Remote	Low	Action Item Jathun
3-1-4	End user Common Tasks	electrical / electronic : energized equipment / live parts actuator	Serious Remote	Low	other warning	Serious Remote	Low	Action Item German

Item Id	User / Task	Hazard / Failure Mode	Initial Assessment Severity Probability	Risk Level	Risk Reduction Methods /Control System	Final Assessment Severity Probability	Risk Level	Status / Responsible /Comments /Reference
3-1-5	End user Common Tasks	electrical / electronic : water / wet locations actuator and pool/ocean	Moderate Remote	Negligible	other warning	Moderate Remote	Negligible	Action Item German
3-1-6	End user Common Tasks	electrical / electronic : unexpected start up / motion actuator	Serious Remote	Low	other warning	Serious Remote	Low	Action Item Evan
3-1-7	End user Common Tasks	electrical / electronic : power supply interruption actuator	Minor Remote	Negligible	other warning, standard procedures	Minor Remote	Negligible	Action Item Evan
3-1-8	End user Common Tasks	slips / trips / falls : slip rope and water	Moderate Likely	Medium	footwear, standard procedures	Moderate Remote	Negligible	Action Item Chloe
3-1-9	End user Common Tasks	slips / trips / falls : trip rope	Serious Likely	High	standard procedures	Serious Remote	Low	Action Item Chloe
3-1-10	End user Common Tasks	slips / trips / falls : falling material / object weight	Serious Likely	High	instruction manuals, standard procedures	Serious Remote	Low	Action Item Jathun
3-1-11	End user Common Tasks	ergonomics / human factors : excessive force / exertion weight	Moderate Likely	Medium	standard procedures	Moderate Unlikely	Low	Action Item Jathun
3-1-12	End user Common Tasks	ergonomics / human factors : repetition spooling	Minor Unlikely	Negligible	standard procedures	Minor Unlikely	Negligible	Action Item Evan
3-1-13	End user Common Tasks	ergonomics / human factors : lifting / bending / twisting weights	Moderate Likely	Medium	standard procedures	Moderate Unlikely	Low	Action Item Jathun
3-1-14	End user Common Tasks	fire and explosions : spontaneous combustion batteries	Serious Remote	Low	other warning	Serious Remote	Low	Action Item German

Appendix C – Final Project Budget

Materials Budget for Senior Project

Title of Senior Project:	Acoustic Release/Receiver
Team members:	Evan Brown, German Jack Ellsworth, Chloe Schofield, Jathun Somasundaram
Designated Team Treasurer:	Evan Brown
Faculty Advisor:	Eileen Rossman
Sponsor:	Maddie Schroth-Glanz
Quarter and year project began:	Fall 2022
Budget from	CP ME Dept. and Baker-Koob Grant
Materials budget given for this project:	**$ 1,500.00**

Date purchased	Purchaser	Vendor	Description of items purchased	Part Number	Transaction amount
01/31/23	ME Dept.	McMaster-Carr	HDPE Sheet, Black, 24" x 24" x 1/2"	1101, 1102, 1103, 1104	$ 61.41
01/31/23	ME Dept.	McMaster-Carr	Plastic Corner Brackets (16)	1107	$ 5.92
01/31/23	ME Dept.	McMaster-Carr	#8-32x1" 316 SS Screws (3 10-packs)	1108	$ 10.98
01/31/23	ME Dept.	McMaster-Carr	#8-32 316 SS Locknuts (1 100-pack)	1109	$ 13.13
01/31/23	ME Dept.	McMaster-Carr	1.25"x24" Delrin Rod	1201	$ 20.32
01/31/23	ME Dept.	McMaster-Carr	Acetal Ball Bearing with Four-Bolt Flange, 1-1/4" (2)		$ 187.90
01/31/23	ME Dept.	McMaster-Carr	3/8"-16x1.5" 316 SS Screws (2 5-packs)		$ 13.00
01/31/23	ME Dept.	McMaster-Carr	3/8"-16 316 SS Locknuts (1 25-pack)		$ 9.25
01/31/23	ME Dept.	McMaster-Carr	Shipping and Tax		$ 48.17
03/08/23	ME Dept.	McMaster-Carr	HDPE Sheet, Black, 24" x 24" x 1/2"	1101, 1102, 1103, 1104	$ 61.41
03/08/23	ME Dept.	McMaster-Carr	Plastic Corner Brackets (16)	1107	$ 5.92
03/08/23	ME Dept.	McMaster-Carr	1.25"x24" Delrin Rod	1201	$ 20.32

Date purchased	Purchaser	Vendor	Description of items purchased	Part Number	Transaction amount
03/08/23	ME Dept.	McMaster-Carr	Acrylic Sheet, Clear, 12" x 12" x 1/4" (2)	1105, 1106	$ 31.68
03/08/23	ME Dept.	McMaster-Carr	Flanged Sleeve Bearing (2)	1115	$ 17.12
03/08/23	ME Dept.	McMaster-Carr	Black Plastic Hinge (2)	1117	$ 7.54
03/08/23	ME Dept.	McMaster-Carr	Black Plastic Turn Latch (1 10-pack)	1118	$ 10.00
03/08/23	ME Dept.	McMaster-Carr	#10x3/4" 316 SS Thread Forming Screws (1 10-pack)	1116	$ 10.94
03/08/23	ME Dept.	McMaster-Carr	M4-0.7x18mm 316 SS Screws (1 25-pack)	1302	$ 8.79
03/08/23	ME Dept.	McMaster-Carr	1/4" Quick Release Pin (2)	1706	$ 4.92
03/08/23	ME Dept.	McMaster-Carr	1/4"x24" 316 SS Rod	1204	$ 10.42
03/08/23	ME Dept.	McMaster-Carr	Shipping and Tax (Estimated)		$ 30.00
03/08/23	ME Dept.	McMaster-Carr	Acetal Ball Bearings **(RETURN)**		$ (187.90)
03/08/23	ME Dept.	Blue Robotics	Newton Subsea Gripper	1601	$ 647.16
04/28/23	Team	Dick's Sporting Goods	10lb Mushroom Anchor (8)	1501	$ 152.16
04/28/23	ME Dept.	McMaster-Carr	M5-0.8x18mm 316 SS Screws (1 25-pack)	1608	$ 11.94
04/28/23	ME Dept.	McMaster-Carr	M5 316 SS Washers (1 100-pack)		$ 4.77
04/28/23	ME Dept.	McMaster-Carr	3/8"-16x2.5" 316 SS Screws (2)	1603	$ 3.52
04/28/23	ME Dept.	McMaster-Carr	3/8"-16 316 SS Nuts (1 50-pack)	1605	$ 9.52
04/28/23	ME Dept.	McMaster-Carr	3/8"-16 316 SS Thin Nuts (1 25-pack)	1606	$ 5.00
04/28/23	ME Dept.	McMaster-Carr	3/8" 316 SS Oversized Washers (1 50-pack)	1607	$ 8.97
04/28/23	ME Dept.	McMaster-Carr	Black Plastic Pull Knob (3)	1120	$ 4.71
04/28/23	ME Dept.	McMaster-Carr	Black Plastic Pull Handle (2)	1112	$ 36.24
04/28/23	ME Dept.	McMaster-Carr	5/16"-18x1" 316 SS Heax Head Screws (1 10-pack)	1114	$ 5.52
04/28/23	ME Dept.	McMaster-Carr	5/16"-18 316 SS Nuts (1 50-pack)	1113	$ 6.86
04/28/23	ME Dept.	McMaster-Carr	1/8" Rope (25ft)		$ 20.25
04/28/23	ME Dept.	McMaster-Carr	1/4" Pear-shaped 316 SS Carabiner	1503	$ 18.42

Date purchased	Purchaser	Vendor	Description of items purchased	Part Number	Transaction amount
04/28/23	ME Dept.	McMaster-Carr	1/8" Oval-shaped 316 SS Carabiner (8)	1504	$ 14.48
04/28/23	ME Dept.	McMaster-Carr	Shipping and Tax		$ 22.18
			Total expenses:		$ 1,372.94

budget:		$ 1,500.00
actual expenses:		$ 1,372.94
remaining balance:		$ 127.06

Appendix D – Software

Code written for testing and display purposes only. Written for use on an Arduino R3 Mega.

```
// Infrared Module
#include <IRremote.h>                // Library for IR Remote
#define IR_RECEIVE_PIN 51            // Pin 22 receives data from receiver
#define IR_POWER_PIN 53              // Pin 24 controls receiver power
#define EXTEND_BUTTON_1 12           // Remote Button 1 should be an extension
signal
#define RETRACT_BUTTON_2 24          // Remote Button 2 should be an retraction
signal
#define DELAYED_RETRACT_BUTTON_3 94 // Remote Button 3 should be an delayed
retraction signal
#define RESET_BUTTON_POWER 69        // Remote Button PW should activate RST pin
on microcontroller
int in_vals[1] = {};                 // Used for input filtering


// LCD Module
#include <LiquidCrystal.h>           // Library for LCD Screen
LiquidCrystal lcd(12,11,5,4,3,2);    // Pins on LCD (rs, enable, d4, d5, d6, d7)


// Servo
#include <Servo.h>                   // Library for Servo
#define analogPIN 10                 // Signal line pin (PWM)
#define EXTEND    1900               // [Frequency duration in microseconds for
extend]
#define RETRACT   1100               // [Frequency duration in microseconds for
retract]
#define OFF       1500               // [Frequency duration in microseconds for
stopping]
#define DELAY_TIME 2000              // Delay Time for splash screen

Servo gripper;                       // Servo motor object

// Variables
int state = 0;                       // Tracks FSM state
int input_value = 0;                 // Direct remote input
int current_input = 0;               // Current input stored for filtering
int previous_input = 0;              // Previous input
long lastMillis = 0;        // Variable to hold millis value for start of duration
long currentMillis = 0;     // Variable to hold millis value for checking duration
long delay1 = 60000;        // 1 minute delay = 1*60*1000
long delay3 = 180000;       // 3 minute delay = 3*60*1000
long delay5 = 300000;       // 5 minute delay = 5*60*1000
```

```
long duration = currentMillis - lastMillis;

void setup()
{
  digitalWrite(RESET_BUTTON_PIN,HIGH); // Sets I/O pin to high (allows code to
upload)
  Serial.begin(9600);               // Start serial communication with baud rate
of 9600
  pinMode(IR_POWER_PIN,OUTPUT);     // Sets power pin to output
  digitalWrite(IR_POWER_PIN,HIGH);  // Sets power pin to high (5V)
  pinMode(RESET_BUTTON_PIN,OUTPUT); // Sets I/O pin to output
  IrReceiver.begin(IR_RECEIVE_PIN); // Start receiving data from IR Receiever
  lcd.begin(16,2);                  // LCD Screen is initialized with 16 columns
and 2 rows
  lcd.clear();                      // Anything printed on LCD is cleared
  gripper.attach(analogPIN);        // Signal for Actuator is now from pin 10
  //attachInterrupt(digitalPinToInterrupt(RESET_BUTTON_PIN),RESET_ISR,FALLING);
// When pin is falling, ISR is triggered
}

void loop()
{
 // input_value = IrReceiver.decodedIRData.command;
  if (RST_FLG == 1)
  {
    RST_FLG == 0;
    digitalWrite(RESET_BUTTON_PIN,LOW);
  }

  if (state == 0)
  {
    LCD_INIT(); // Sets up LCD splash screen
    //digitalWrite(READY_YELLOW_PIN,HIGH);

    if (IrReceiver.decode()) //If code is received from remote
    {
      delay(700); // Delay (causes any "bounced" input to be ignored)
      digitalWrite(IR_POWER_PIN,LOW); // Turn off receiver incase any noise is
captured
      input_value = IrReceiver.decodedIRData.command; // Input value is set as a
variable

      Serial.println("This is the direct input value:  ");
      Serial.println(input_value);
```

```
      in_vals[1] = input_value; // Takes input value and stores it in one spot to
ensure only one number is taken from remote
      current_input = in_vals[1]; // Takes single array value and stores it for
use later

      Serial.println("This is the current input value:  ");
      Serial.println(current_input);

      if (current_input == EXTEND_BUTTON_1)
      {
        state = 1;
        Serial.println("State 1");
      }
      if (current_input == RETRACT_BUTTON_2)
      {
        state = 2;
        Serial.println("State 2");
      }
      if (current_input == DELAYED_RETRACT_BUTTON_3)
      {
        state = 3;
        lastMillis = millis();
        Serial.println("Timer start");
        Serial.println("State 3");
        lcd.clear();
      }
      // if (current_input == RESET_BUTTON_POWER)
      // {
      //   digitalWrite(RESET_BUTTON_PIN,LOW);
      //   Serial.println("State 4");
      //   Serial.println(current_input);
      // }
      if (current_input == 0 ) //|| previous_input == current_input)
      {
        state = 0;
        Serial.println("State 0");
        lcd.print("Invalid, try again");
        delay(1000);
        lcd.clear();
      }
    }

  }
  if (state == 1)
  {
```

```
    lcd.clear();
    EXTEND_STATE();
    previous_input = current_input;
  }
  if (state == 2)
  {
    lcd.clear();
    RETRACT_STATE();
    previous_input = current_input;
  }
  if (state == 3)
  {
    DELAYED_RETRACT_STATE();
    previous_input = current_input;
  }
  digitalWrite(IR_POWER_PIN,HIGH);
  IrReceiver.resume();
}
void EXTEND_STATE()
{

  gripper.writeMicroseconds(EXTEND);
  LCD_EXTENDING();
  Serial.println("Extending");
  Serial.println("Done!");
  state = 0;
}

void RETRACT_STATE()
{
  gripper.writeMicroseconds(RETRACT);
  LCD_RETRACTING();
  Serial.println("Retracting");
  Serial.println("Done!");
  state = 0;
}

void DELAYED_RETRACT_STATE()
{
  lcd.setCursor(0,0);
  lcd.print("Timer Started");
  lcd.setCursor(0,1);
  lcd.print("5 minute");

  if(currentMillis - lastMillis < delay5)
```

```
  {
    currentMillis = millis();
    digitalWrite(IR_POWER_PIN,HIGH);

    if (IrReceiver.decode()) //If code is received from remote
    {
      delay(1000); // Delay (causes any "bounced" input to be ignored)
      digitalWrite(IR_POWER_PIN,LOW); // Turn off receiver incase any noise is
captured
      input_value = IrReceiver.decodedIRData.command; // Input value is set as a
variable

      in_vals[1] = input_value; // Takes input value and stores it in one spot to
ensure only one number is taken from remote
      current_input = in_vals[1]; // Takes single array value and stores it for
use later

      if (current_input == RESET_BUTTON_POWER)
      {
        Serial.println("Timer Cancelled");
        lcd.clear();
        lcd.setCursor(0,0);
        lcd.print("Cancelled");
        delay(2000);
        lcd.clear();
        state = 0;
        currentMillis = 0;
      }
    }
  }
    //Serial.println(currentMillis);
    //Serial.println("Not retracted yet");
  if(currentMillis - lastMillis >= delay5)
      {
        lcd.clear();
        RETRACT_STATE();
      }

}



void LCD_INIT()
{
  lcd.setCursor(0,0);
```

```
  lcd.print("Welcome!");
  lcd.setCursor(0,1);
  lcd.println("1(Ext.) 2(Ret.) ");
  Serial.print("Ready for input");
}

void LCD_EXTENDING()
{
  lcd.setCursor(0,0);
  lcd.print("Extending!");
  lcd.setCursor(0,1);
  lcd.print("You chose: 1");
  delay(2000);
  lcd.clear();
}

void LCD_RETRACTING()
{
  lcd.setCursor(0,0);
  lcd.print("Retracting!");
  lcd.setCursor(0,1);
  lcd.print("You chose: 2");
  delay(2000);
  lcd.clear();

}
```

Appendix E – Design Verification Plan & Report (DVPR)

Project:	Whale Sounds		Sponsor:		Maddie Schroth-Glanz					Edit Date:	6/9/2023
TEST PLAN										**TEST RESULTS**	
Test #	Specification	Test Description	Measurements	Acceptance Criteria	Required Facilities/Equipment	Parts Needed	Responsibility	TIMING		Numerical Results	Notes on Testing
								Start date	Finish date		
t	Redeployment Time	From fully unspooled length, measure amount of time required to fully spool the system and re-engage the pin.	Time	Within 15 minutes	Stopwatch	Prototype and hand crank	Evan	5/4/2023	5/15/2023	15 min +/- 3 min	Some tests were done by spoiling through the open acrylic panel side (which is faster), but that is not practical when redeploying as the rope goes through the hole in the bottom panel. 5 tests were run respooling through the bottom frame hole. Uncertainty is dependent on the endurance of the person spooling.
2	Shock Loading	With fully spooled rope, the weights are dropped from rest so a shock is applied to the PVC and spooled rope.	Permanent damage	No cracks	Two tables, chair	Frame and spooled rope, weights	Chloe	5/24/2023	5/24/2023	40lbs, no damage; 80lb, no damage	Rope gets pulled taut after shock. Most likely will not affect unspooling, just something to note.
3	Impact Strength	Dropping system in floor to see If frame suffers from any deflection at angular joints	Permanent deflection: angular or linear	deflections less than 5deg	Protractor	Frame of prototype	Evan	3/2/2023	3/2/2023	1st drop: 0 deg, 2nd: 0 deg, 3rd: 1 deg, 4th: 3 deg, 5th: 10 deg	Repeated testing indicated that as it is dropped more and more times caused the angle brackets to loosen. It is recommended to check and tighten those connections if it is dropped more than 3 times.
4	Resistance to recovery of weight in water	Place a force gauge on a rope between the weight, and point where rope is being spooled back in. Measure amount of force required to move weight out of water.	Force	Less than 75 lbf	Force gauge, CP Pier	weights and rope	German	5/18/2023	5/18/2023	Drag product: 4.3 lbf s^2/ft^2 Recovery time at 80m: 2-5 minutes	Data showed good agreement with the model (within calculated uncertainty), but y-intercept does not match up. The model works when using a static weight from another test. Data and graphs appended.
5	Linear Actuator Test	Connect the linear actuator to a microcontroller. Use the MCU to power the motor. Verify the actuator is able to pull the pin in a dry environment.	Time	Within 2 minutes	Stopwatch, microcontroller	Shaft assembly, frame assembly, release mechanism assembly, microcontroller	Jathun	5/13/2023	5/14/2023	About 2 seconds for full range of motion, no disparities among all tests	Linear actuator was far stronger than expected. Had no issues pulling weights up to 80 lbs, and could probably pull more.
6	Submerged Linear Actuator Test	Repeat dry linear actuator test underwater at low pressure to verify release mechanism performance.	Time	Within 2 minutes	Stopwatch, microcontroller	Shaft assembly, frame assembly, release mechanism assembly, microcontroller	Jathun	5/18/2023	5/18/2023	About 2 seconds to release	Based on video of buoy resurfacing from the time at which the release is triggered, there were no noticeable delays in the release itself. The capsules did leak, so they are something that needs to be checked every time the device is deployed.
7	Ocean/Hyperbaric Linear Actuator Test	Repeat pool linear actuator test at 80m depth or in a pressure chamber to verify release mechanism performance.	Time	Within 2 minutes	Stopwatch, microcontroller, hyperbaric chamber	Shaft assembly, frame assembly, release mechanism assembly, microcontroller	German	N/A	N/A	N/A	No testing complete due to failure of pressure capsules in submerged test and lack of testing facilities.

Appendix F – Test Procedures

Test Procedure for Redeployment Time

Test Name:
Redeployment Time
Purpose:
The purpose of this test is to determine About how long it would take for the device to be ready from collection to redeployment.
Scope:
The attribute this test is for is to be reusable. The device must be able to be prepared in a timely manner for redeployment. This is important due to costs of boat usage time, and reducing the deployment time of this device will help reduce costs for the sponsor.
Equipment:
Timer (on mobile device), crank system, 100m of line
Hazards:

- Spool spinning at high speeds
- Rope moving quickly

PPE Requirements:
Safety goggles, long pants, closed toe shoes, gloves
Facility:
Outdoors preferably (for space)
Procedure:

1) Unspool the line from the spool and bundle it so that it will not tangle while being pulled.
2) Attach crank to spool shaft and mount/hold down system so that it cannot move.
3) Start timer and start rotating the crank at a comfortable pace. While spool is spinning, move the rope along the shaft to wrap the shaft evenly.
4) When spool fully spooled, stop timer and record time.
5) ~~Repeat steps 1-4 until times vary by less than 5 seconds.~~

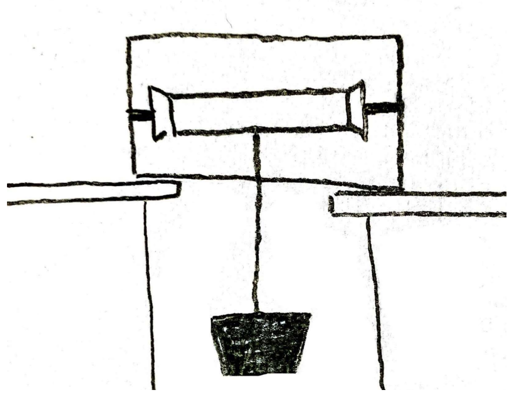
Results:
Take the average of the times recorded and use that as the estimated time of redeployment.
Test Date(s): May 15th
Test Results:

Test #	Time (seconds)
1	865
2	1126
3	732
4	997
5	696
AVG	883
StDev	161

Performed By: Chloe Schofield, Jathun Somasundaram, German Jack Ellsworth, Evan Brown

Test Procedure for Shock Loading on Shaft

Test Name:
Shock Loading
Purpose:
The purpose of this test is to determine the strength of the shaft under the maximum shock loading that is possible.
Scope:
The function the test is for is the deployment of the system and the storage. If the weights are tossed into the water and pull the frame with it, or the weights tug at the frame when placed or retrieved in storage, we want to make sure the shaft does not break.
Equipment:
Full prototype with 80lb of weights, two tables, one chair



Hazards:

- Object breaking and shards flying into eye
- Pinching
- Crushing
- Cutting

PPE Requirements:
Safety goggles, long pants, closed toe shoes
Facility:
ME Department Mustang ’60 outdoors
Procedure:

1) Set up two tables so that the frame of the prototype can rest on both with the weights fitting between the two tables.
2) Place the frame onto the tables in between the gap and put the chair in the gap, but not fully under the frame. Set up the length of the rope so that the weights will not touch the ground when they are hanging, but when they rest on the chair, the line is loose.
3) Attach one 10lb weight to the end of the rope while it is resting on the chair. Push the weight off so that a shock load is applied to the spooled shaft.
4) Continue increasing the number of 10lb weights and repeating step 3 for each interval. Test the full 80lb shock loading three times.

Results:
Passes if shaft does not crack/break.
Test Date(s):
May 24th
Test Results:
Pass or Fail: Pass
Performed By: Chloe Schofield, Jathun Somasundaram, German Jack Ellsworth, Evan Brown

Test Procedure Template for Impact Strength

Test Name:
Impact Strength

Purpose:
The purpose of this test is to determine whether or not the frame can withstand accidental drops onto the floor.

Scope:
The function we are testing falls under "Connect & Mount Parts". It falls under all "Mounting" functions, as the frame needs to be rigid enough when transporting to stay assembled. If it falls apart from simple drops, it cannot provide mounting for all the necessary components.

Equipment:
- Frame
- Unobstructed hard floor
- Protractor
- Ruler

Hazards: (list hazards associated with the test)
- Dropping frame on foot
- Plastic frame shards breaking off and flying at people

PPE Requirements:
- Safety goggles
- Closed toe shoes
- Long pants

Facility:
- In front of Engineering 13 on hard floor

Procedure: (List numbered steps of how to run the test, including steps for calibration, zero/tare, baseline tests, repeat tests. Can include sketches and/or pictures):
1) Measure internal angles and write them down.
2) Drop on any corner from 5 ft.
3) Measure internal angles again and write them down.
4) Drop flat on plate side.
5) Measure internal angles again and write them down.
6) Drop flat on open side.
7) Measure internal angles again and write them down.

Results:
- Passes if less than 5 degrees of angular deflection in total since chances are the device will not be dropped more than once or twice during operation

Test Date:
March 2nd
Test Results:
Angular deflection: Pass
Performed By: Chloe Schofield and Jathun Somasundaram

<u>Test Procedure for Uncertainty Analysis on Weight Recovery Resistance</u>

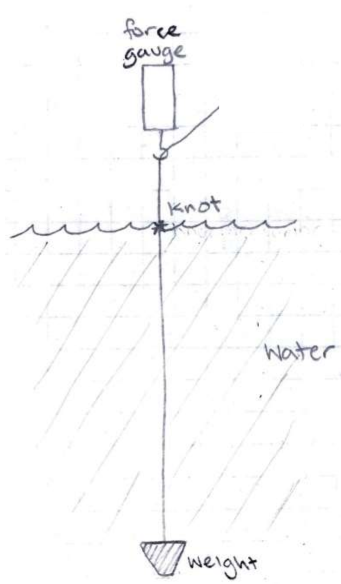
Test Name:
Resistance to Recovery of Weight in Water

Purpose:
The purpose of this test is to find the drag coefficient for when retrieving the weight from the ocean. This is so that we can find if a winch is required to pull the weights up and what the winch needs to be rated to or if a person can lift it themselves.

Scope:
This test is to validate the function of retrieval.

Equipment:

- Tape Measure
- Force Gauge
- Pool/Ocean
- Stopwatch
- Rope
- Weights



Hazards:

- Physical strain from pulling weight
- Dropping weight on self
- Getting caught in rope or tripping
- Drowning

PPE Requirements:
Closed toe shoes, long pants

Facility:
Cal Poly Pier

Procedure:

1) Turn on force gauge and zero it. Attach the rope holding the weights to the end of it so that the weights can hang off the ground. Take the weight measurement and record it.
2) Using the tape measure and tape, mark a distance 10ft from the edge of the dock and 40ft from the edge of the dock.
3) Attach a pulley to the edge of the dock. Thread the rope attached to the weights through the pulley. Attach the end of the 60ft rope to the force gauge.
4) Lower weights into water.
5) Have someone pull the weights up with as constant force as possible and walking with a constant speed until they pass the 40ft mark.
6) Start the stopwatch as the person crosses the 5ft mark (removing the initial acceleration from the measurement). Stop the timer after the person reaches the 40ft mark. Record the time.
7) Repeat this test 10 times, rotating the person pulling the weights up each time to ease muscular stress on testers. Vary the force applied each time.

Results:
Testing total of 10 times.

Starting with the steady state force balance, neglecting buoyancy, $F = \frac{1}{2}\rho\left(\frac{x}{t}\right)^2 A_s C_d + mg$, where rho is the water density, the velocity is taken as an average over the test duration. Solving for the drag characteristics gives the following target value, $A_\perp C_d$, as shown in the following equation (taking the velocity to be the test distance divided by the elapsed time).

Equation: $A_\perp C_d = \frac{2t^2}{\rho x^2}(F - mg)$

Propagation Equation:

$$U_{A_\perp C_d} = \pm\left[\left(\frac{\mathrm{d}(A_\perp C_d)}{\mathrm{d(mg)}}U_{mg}\right)^2 + \left(\frac{\mathrm{d}(A_\perp C_d)}{\mathrm{d(F)}}U_F\right)^2 + \left(\frac{\mathrm{d}(A_\perp C_d)}{\mathrm{d(x)}}U_x\right)^2 + \left(\frac{\mathrm{d}(A_\perp C_d)}{\mathrm{d(t)}}U_t\right)^2\right]^{1/2}$$

Statistical Uncertainty Calculation: $U_{stat} = \pm\frac{ts}{\sqrt{n}}$

	Weight	Force to pull up weight	Distance	Time
Uncertainty	U_w	U_F	U_d	U_t
Propagated	$-\frac{2t^2}{\rho d^2}$	$\frac{2t^2}{\rho d^2}$	$\frac{-4t^2(F-W)}{\rho d^3}$	$\frac{4t(F-W)}{\rho d^2}$
Reading	Force Gauge	Force Gauge	Measuring Tape	Stopwatch
Calibration (from manufacturer)	Force Gauge	Force Gauge	Measuring Tape	Stopwatch

Test Date(s): May 18th
Test Results:
Weight: 80lb
Distance: 30

Test Number	Time [s]	Approximate Force [lb]	Force Variance, U_F
0	*Resting weight in water*	66	1
1	12.5	88	4
2	10.9	100	4
3	9.4	110	4
4	16.3	82	4
5	25.0	72	4
6	12.3	92	4
7	11.5	100	4
8	15.2	85	4
9	17.1	80	4

Findings for 80m Depth Retrieval				
Drag P.	F (lbf)	V (ft/s)	t (s)	t (min)
4.35	70	1.0	274.3	4.6
	80	1.8	144.3	2.4
	90	2.4	110.2	1.8
	100	2.8	92.6	1.5
	110	3.2	81.4	1.4
	120	3.6	73.5	1.2
	130	3.9	67.5	1.1
	140	4.2	62.8	1.0
	150	4.5	58.9	1.0
	160	4.7	55.7	0.9
	170	5.0	53.0	0.9
	180	5.2	50.6	0.8
	190	5.4	48.5	0.8
	200	5.6	46.6	0.8

Performed By: Chloe Schofield, Jathun Somasundaram, German Jack Ellsworth, Evan Brown

Test Procedure for Release Mechanism Dry Test

Test Name:
Release Mechanism Dry Test

Purpose:
Verify release mechanism actuation in a dry environment.

Scope:
Release Mechanism

Equipment:
Assembled release mechanism

Hazards:

- Pinching

PPE Requirements:
N/A

Facility:
No specific facility required.

Procedure:

1) Verify correct installation of release mechanism.
2) Set up release mechanism in the hold position.
3) Actuate the release via microcontroller.

Results:
Pass if shaft is unable to turn while inactive and shaft is able to rotate freely when actuated. Fail if release mechanism does not prevent rotation or if rotation is blocked after actuation. Run 5 tests to verify performance. No uncertainty analysis required.

Test Date(s):
May 14th

Test Results:

Test 1	Test 2	Test 3	Test 4	Test 5
PASS / FAIL	PASS / FAIL	PASS / FAIL	PASS / FAIL	PASS / FAIL

Performed By: Jack Ellsworth

<u>**Test Procedure for Release Mechanism Pool Test**</u>

Test Name:
Release Mechanism Pool Test

Purpose:
Verify release mechanism actuation in a submerged environment.

Scope:
Release Mechanism

Equipment:
Assembled verification prototype.

Hazards:
- Pinching
- Slipping
- Drowning

PPE Requirements:
N/A

Facility:
Pool or similar low-depth water environment.

Procedure:
1) Verify correct installation of release mechanism and sealing of canisters.
2) Set up release mechanism in the hold position.
3) Submerge prototype.
4) Actuate the release via microcontroller.

Results:
Pass if shaft is unable to turn while inactive and shaft is able to rotate freely when actuated. Fail if release mechanism does not prevent rotation or if rotation is blocked after actuation. Run 5 tests to verify performance. No uncertainty analysis required.

Test Date(s):
May 18th

Test Results:

Test 1	~~Test 2~~	~~Test 3~~	~~Test 4~~	~~Test 5~~
PASS / FAIL	~~PASS / FAIL~~	~~PASS / FAIL~~	~~PASS / FAIL~~	~~PASS / FAIL~~

Capsules failed at first test. However, no electronics were harmed so system reacted as expected.
Performed By: Jack Ellsworth

Test Procedure for Release Mechanism Pressure Test

Test Name:
Release Mechanism Pressure Test

Purpose:
Verify release mechanism actuation in a pressurized environment.

Scope:
Release Mechanism

Equipment:
Assembled release mechanism. Pressure chamber OR pier.

Hazards:

- Pinching
- Explosion (if in pressure chamber)
- Drowning (if testing at ocean)

PPE Requirements:
Life jackets if testing in ocean.

Facility:
Pressure chamber OR pier.

Procedure:

1) Verify correct installation of release mechanism and sealing of canisters.
2) Set up release mechanism in the hold position.
3) Connect cable as backup.
4) Set off release mechanism countdown on microcontroller.
5) Place prototype at depth in the ocean.
6) Actuate the release via microcontroller.

Results: Pass if shaft is unable to turn while inactive and shaft is able to rotate freely when actuated. Fail if release mechanism does not prevent rotation or if rotation is blocked after actuation. Run 5 tests to verify performance. No uncertainty analysis required.

Test Date(s):
~~May 22nd?~~
Capsules failed at low depth test and the deployment at higher depth could not be scheduled due to pier construction.

Test Results:

Test 1	Test 2	Test 3	Test 4	Test 5
PASS / FAIL	PASS / FAIL	PASS / FAIL	PASS / FAIL	PASS / FAIL

Performed By: Jack Ellsworth