INTERDISCIPLINARY SENIOR PROJECT

Deep Ocean Vehicle (DOV) Scientific Payload

Final Report

For Dr. Crow White, Associate Professor of Marine Biology at Cal Poly

*By the **Barrel Eye Explorers***

Nikki Arm	(narm@calpoly.edu)	Mechanical Engineering
Mason Gariepy	(mgariepy@calpoly.edu)	Materials Engineering
Brianna Roberts	(brober23@calpoly.edu)	Ocean Engineering
Kyle Walsh	(kywalsh@calpoly.edu)	Industrial Engineering

Overseen by Karla Carichner, Professor of Industrial Engineering at Cal Poly

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CAL POLY
College of Engineering

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LIST OF NOMENCLATURE

Anodized: Coated with a protective oxide layer by an electrolytic process in which the metal forms the anode.

Atmosphere: Unit of measurement equal to the average air pressure at sea level. One atmosphere is equivalent to 14.7 psi.

Autonomously: With the freedom to act independently, without outside control.

AUV: Autonomous Underwater Vehicle

Ballast: Heavy material, such as gravel, sand, iron, or lead, placed low in a vessel to improve its stability.

Bathymetry: The measurement of depth of water in oceans, seas, or lakes.

Bathyscape: A free-diving self-propelled deep-sea submersible.

Benthic: Anything associated with or occurring on the bottom of a body of water.

Biodiversity: The variety of life in the world or in a particular habitat or ecosystem.

Bioluminescence: The production and emission of light by living organisms.

BRUV: Baited Remote Underwater Video

Buoyancy: The ability or tendency to float in water.

Buoyancy Sphere: Specific to DOV Seastang, used to house electrical components and/or increase the vehicles buoyancy.

Burn Wires: Specific to DOV Seastang, wires designed to corrode and break when electricity is sent through them.

CAD: Computer Aided Design

CamDo: Camera accessory that connects with the GoPro Hero 4. Used for programming when camera should start and stop.

Customer Requirements: Design requirements requested by the customer. Can be more general like “Not too Heavy”.

Datum: A fixed starting point or reference value.

DEEPSEA CHALLENGE: A deep underwater submersible designed to reach bottom of the Challenger deep in the Mariana’s Trench.

Deployment: The act of sending a vehicle on its mission – in this case, sending the lander into the ocean to conduct research at a given place or a specified length of time.

Dielectric: A substance that does not conduct electricity.

Diffusion: The net movement of something (usually a substance) from a region of higher concentration to a region of lower concentration.

Dissolved Nitrogen: The amount of gaseous nitrogen dissolved in water.

DOV: Deep Ocean Vehicle

Engineering Requirements: Design requirements specified in quantifiable measurements with reasonable tolerances. Must be more specific like “Maximum Weight of 75 pounds”.

Environmental DNA: Organismal DNA that can be detected in the water.

Fauna: The animals of a particular region, habitat, or geological period.

Framerate: Frequency at which consecutive images are captured or displayed in a video.

FST: Full System Test

Hadal Zone: Relating to the areas of the ocean which are greater than approximately 20,000 feet (6,000 m) in depth.

HADEEP: Hadal Environment and Educational Program

Heat Shrink: Thermoplastic tube that shrinks when exposed to heat. Used to protect exposed wire from surroundings and prevent electrical shorts.

House of Qualities: Conceptual map which provides organization for planning and communication of design requirements.

High-Definition: A high degree of detail in an image or screen.

Instrument: A device that measures physical variables.

LifeSavers: Candy rings made of sugar which dissolve in water. In this document, they are utilized as a candy-melt release system in ocean environments.

LiPo: Lithium Polymer Battery

Lumens: The total quantity of visible light emitted by a source per unit of time.

Marine Snow: A shower of organic material falling from upper waters to the deep ocean.

Microprocessor: A computer processor where the data processing logic and control is included on a single integrated circuit.

Modular: Composed of different modules.

NOAA: National Oceanic and Atmospheric Administration

ROV: Remote Operated Vehicle

Pelagic: Relating to the open ocean.

pH: Quantitative measure of the acidity or basicity of aqueous or other liquid solutions.

Photoreceptors: Specialized neurons found in the retina of an organism's eye that convert light into electrical signals which are received by the brain.

Picolander: Small portable lander capable of being deployed without any special equipment. The smallest kind of lander built by Global Ocean Design.

Pugh Matrix: Criteria-based decision matrix used in engineering design.

PVC: Poly-Vinyl Chloride, a kind of plastic.

Salinity: The dissolved salt content of a body of water.

SolidWorks: CAD program used to develop mechatronic systems from beginning to end.

Subsystems: Isolated systems that contribute to form the total product.

Tensile Force: A resultant force that puts a material in tension. The force acts on the material in a manner like it is being pulled apart.

Tolerance: Allowable amount of variation of specified quantity.

Torsion: The twisting of an object due to an applied torque.

Turbidity: The measure of relative visual clarity of a liquid.

Vacuum: A space devoid of matter.

Voltage: The measurement of the electric potential in a circuit component.

Water Column: A vertical expanse of water stretching between the surface and the floor of a body of water.

Waterjet: A method of manufacturing used for cutting objects using high-speed, high-pressure water. Usually also contains a cutting particulate such as garnet.

WHOI: Woods Hole Oceanographic Institution

Wind Turbine: Large turbine used to generate power for wind.

WiSens: Temperature and Pressure gage rated to varying depths.

EXECUTIVE SUMMARY

This report aims to provide technical insight into the Deep Ocean Vehicle project performed by the Barrel Eye Explorers. The project was a part of the 2021-2022 Interdisciplinary Senior Project class at California Polytechnic State University, San Luis Obispo. The team consisted of Nikki Arm, Mason Gariepy, Brianna Roberts, and Kyle Walsh who were engineering students in the Mechanical, Materials, General, and Industrial engineering departments, respectively. This project was sponsored by Dr. Crow White and overseen by Karla Carichner.

The project was a continuation of Nikki Arm's internship with Global Ocean Design during the Summer of 2021. The lander, Deep Ocean Vehicle (DOV) Seastang, was donated to Nikki by Kevin Hardy at Global Oceans Designs. Dr. White identified the potential need for an affordable vehicle that could observe the effects of the development of an offshore wind farm. Dr. White helped the team define basic requirements for the project: the lander had to be pressure rated for a minimum of 4,200 feet and capable of attracting and observing the biodiversity of the drop area.

A lander is an autonomous subsea vehicle that descends to the sea floor, and autonomously carries out tasks before ascending to the surface for recovery. Landers are often cheaper than other research payload options like remote operated vehicles (ROV) or autonomous underwater vehicles (AUV). Since landers can only move vertically in the water column, they are typically used to survey the biodiversity in specific areas using bait release systems and cameras.

Initially, the team decided the lander needed four new subsystems. These subsystems included a camera, lighting, bait release, and sensors subsystem. Ideas were generated for each subsystem using rapid prototyping techniques learned in class. The concepts for each subsystem were placed into a Pugh matrix and weighted for how well they met the criteria. A single aluminum arm with an attached plate was chosen for the bait release. Custom housings were donated by Global Ocean Design to the project for the camera and lighting systems. After researching the price of sensors, the subsystem was deemed unnecessary. Part sourcing and manufacturing began after the final concept design review. Few changes were made to the design of the lander from this point. After the integration of the new systems, the team added a small support beam to the bottom of the lander to counteract any torsion caused by the bait arm.

With the completion of these subsystems, the team began testing the performance of the entire vehicle. Individual tests were executed on the timed weight release, the release mechanism for the bait arm, the compatibility of the lights and camera, the buoyancy of the lander, and the lander as a whole (Full System Test). The lander and its subsystems successfully passed each test it was put through and acquired research footage in a 200ft deployment. In the future, the team believes the lander is ready for a deployment to part of the ocean at a depth of 4,000 feet.

Chapter 1: INTRODUCTION

Sponsor Background and Needs

This project was completed to help further the research of Dr. Crow White, Associate Professor of Marine Biology at Cal Poly. His research is set to take place 20 miles off the coast of Morro Bay in an area proposed to be used for future floating wind farm development. The goal of this project was to build a vehicle to survey the area with depth ranging from 2,000 - 4,200 feet while collecting video of species living at that depth and collecting qualitative data about the vehicle's surroundings. This was challenging for many reasons including the high pressure (60.6 to 121.2 atmospheres [1]) and low light nature (minimal light penetrates 656-3,280 feet with no light able to reach further depths [2]) of the ocean at that depth.

Problem Definition

This project's mission was to create an operational camera housing and testing module for a preexisting deep ocean vehicle (DOV Seastang) to enable deep sea research of Dr. White as discussed above.

The results of this research could impact potential developers who wish to build a wind farm, as this development could prove to be harmful to the ecosystem below it. Information gathered could specifically benefit Castle Wind Offshore who has already submitted a proposal for their project. The San Luis Obispo community and county residents may also be impacted by the analysis of our research, whether a wind farm is ultimately built or not. Additionally, our advisor, Karla Carichner, was aiming to use this project as an educational instrument for the students involved (the Barrel Eye Explorers team members) to learn the engineering design process and receive experience similar to industry.

Objective

The goal of our group was to build a vehicle to survey the biodiversity of the deep ocean at a maximum depth of 4,200 feet. Companies such as Castle Wind could then use these results to influence their decision for the location of wind turbine anchors.

Engineering Specifications

After discussing parameters and goals with our sponsor, and researching what similar projects have accomplished and measured, our group generated a series of customer requirements for the underwater vehicle (see *Appendix A* for full list). Some crucial customer requirements were agreed upon from the start: The vehicle being able to survive depths of up to 4,200 feet and its ability to take video and lure species were the foundation of the customer requirements. Without these requirements being met, the goal of the project could not be accomplished. These customer needs were then translated into engineering requirements that could be tested for determining the success of the project. The requirements that were needed to accomplish the goal were given high risk factors (H) (see *Table 1* on the next page). The vehicle itself and the electronics housings needed to be pressure tested for 4,200 feet of water and the electronics also had to function properly in the slight vacuum of the housings. Additionally, in order to test the camera quality, we had to test the resolution and framerate of the camera within the housing and conclude that these parameters meet high definition standards. Lastly, a bait release system needed to function properly at depth and the attached bait needed to last the entire mission. The bait also needed to be successful in luring species that were expected to dwell at the survey locations. The mission times may vary depending on the area and sea life native to the area, but a maximum mission time of 120 hours can meet the standards for all mission types of our vehicle may face.

Other customer “wants” consisted of the ability to measure depth, temperature, and salinity. These customer requirements were not crucial to the project goal but were accomplished if possible. These were rated with medium or low risk depending on how important they are for helping the goal of the lander. The engineering requirements generated from these wants were to develop or install sensors that can measure salinity, temperature, and depth within the expected ranges of the vehicle. Other customer requirements involve human interaction with the vehicle. It is necessary for the vehicle to fit on a testing boat and for a small crew to be able to manipulate and carry it. We generated engineering requirements of size and weight tolerances based on the deck size of the boat and the crew members planning to carry the lander. Upon surfacing after the mission, the vehicle needs to be retrieved from the water. So, an additional engineering requirement was added to ensure the vehicle floats above the surface of the water. See the final engineering requirements and values in *Table 1* below. Our team also created a house of qualities to determine the relative importance of the customer requirements and how the engineering requirements relate to the customer’s requests (see *Appendix F* for House of Qualities Table).

Table 1: Deep Ocean Vehicle Engineering Requirements

Spec #	Parameter Design	Requirement of Target	Tolerance	Risk	Compliance
1	Vehicle Pressure Rating	130 ATM	Min	H	A, T, S
2	Electronics Pressure Rating	0.1 ATM	Min	H	A, T
3	Video Clarity	1080p 30fps	Min	M	A, T
4	Size	40 in	±5	M	A, I
5	Weight	90 Lbs.	Max	L	T, I
6	Cost	$5000	Max	M	A
7	Salinity Sensing	0-50ppt	±10	L	A, S
8	Depth Sensing	0-4200 ft	±10	L	A, S
9	Temperature Sensing	0-65°F	±1	L	A, S
10	Time Bait Lasts	120	Max	M	A, T, S
11	Time of Weight Release	120 hours	Max	H	A, T, S
12	Float Height	12in	±2	M	T, S
13	Reuses	100	Min	H	A, S
14	Weight Material	Does not harm ocean life	Min	M	A, I

Chapter 2: BACKGROUND

What is a Lander?

Lander is the name given to an autonomous subsea vehicle that descends to the sea floor, and autonomously carries out a series of tasks for a period of time (ranging from a few hours to several years) while storing data on board before ascending to the surface for recovery by a surface ship [3]. Landers are composed of two primary components: (1) the basic delivery system, and (2) the scientific payload [4]. Typically, landers are designed to be modular such that different scientific payloads may be attached or removed from the delivery system [4]. As explained by I. G. Priede et al., the basic delivery system is comprised of "the frame-work, buoyancy, ballast release and recovery beacon" while the scientific payload includes "cameras, current profilers, metabolism chambers, sediment probes, sonars, traps, etc". Having a modular lander allows easy reuse of the delivery system while providing scientists with more options when doing research. Having separate systems is also beneficial to the vehicles reliability in case of equipment failure of the scientific payload because this separate system would ensure the lander and its components are still able to return to the surface since the delivery system equipment would remain intact [4].

Free vehicles were first used in a deep-sea scientific study by Maurice Ewing (Lamont) and Allyn Vine (WHOI) [5]. They were inspired by Professor Auguste Piccard’s proposal for the bathyscaphe (a deep-sea submarine which used gasoline in its floats) [5]. K. Hardy et al. explains that “Ewing and Vine used rubberized float bags filled with kerosene for flotation to lift their geophysical instruments. With that fundamental design innovation, instruments and samplers began arriving on the floor of the deep sea. Later the bags were replaced with plastic jugs, and the technique has persisted into the 21st century…”. There are many innovations in materials that have allowed for further innovation in lander technologies to become more accessible to a wider variety of researchers [5].

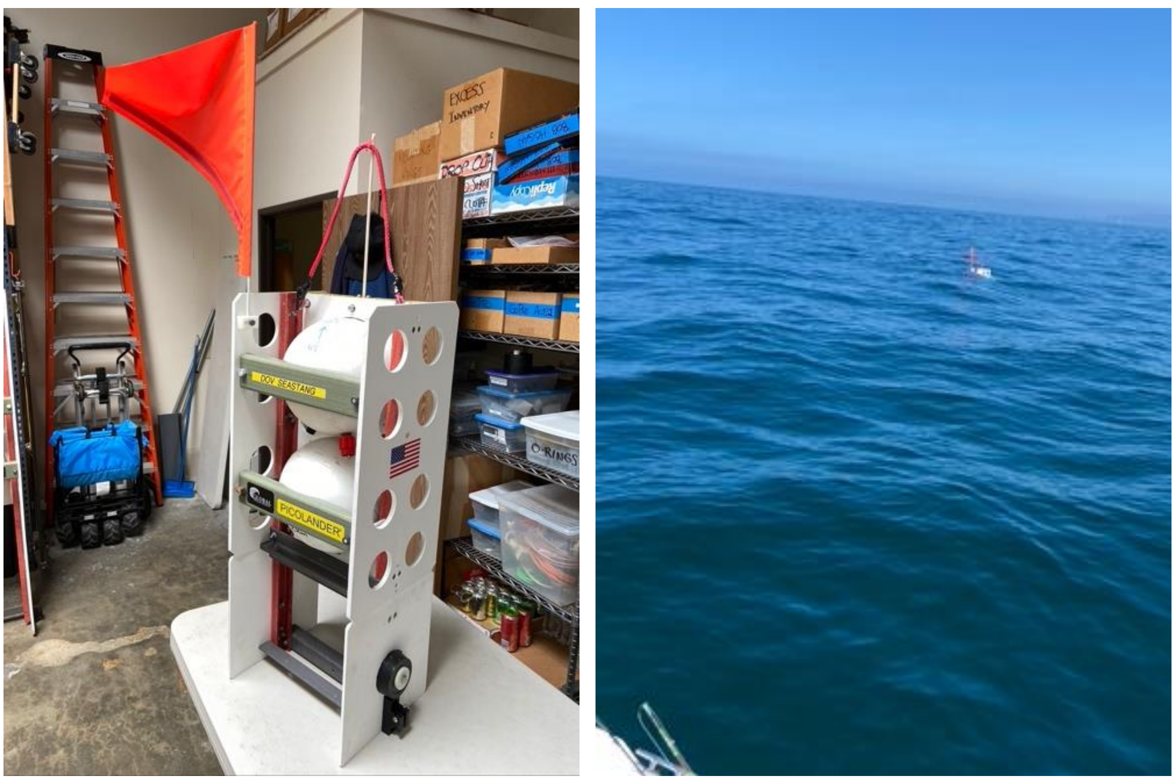


Figure 1: DOV Seastang in the workshop (left) and floating on the surface after deployment (right).

Other Available Ocean Research Vehicles

In addition to Landers, there are other modes of research vehicles typically used for deep-sea exploration. One of these is ROV’s, Remotely Operated Vehicles, is pictured in *Figure 2.*

Figure 2: ROV Deep Discover owned and operated by NOAA [7].

There are many benefits of using an ROV. One being the ability to control it while it's deployed [6]. This allows for another useful feature, taking live samples in-situ as stated by B. H. Robinson et al., "The ability to collect living animals in pristine condition and quickly return them to the lab… has led to unprecedented opportunities for experimental work." Although this is an incredibly useful tool for research, our purpose is not to sample the organisms but to simply observe them. ROV's are also capable of maintaining buoyancy and therefore can "hover" about the water column instead of sinking directly to the bottom. In the water column, they can then observe and sample the pelagic environment as opposed to only benthic [6]. However, our purpose is to directly observe the bottom of the ocean floor, rendering this feature unnecessary. It is notable that deploying a lander can cause more environmental disruption than an ROV, considering it will land with a terminal velocity, possibly disrupting the organisms we aim to observe. However, ROV's are much more expensive and complicated to develop, especially when going as deep as we plan to. They also will need human interaction to remain functional, which then limits the time at depth to humans controlling them.

Another type of vehicle typically used for ocean research are AUV's, Autonomous Underwater Vehicles [7] which can be seen in *Figure 3*.

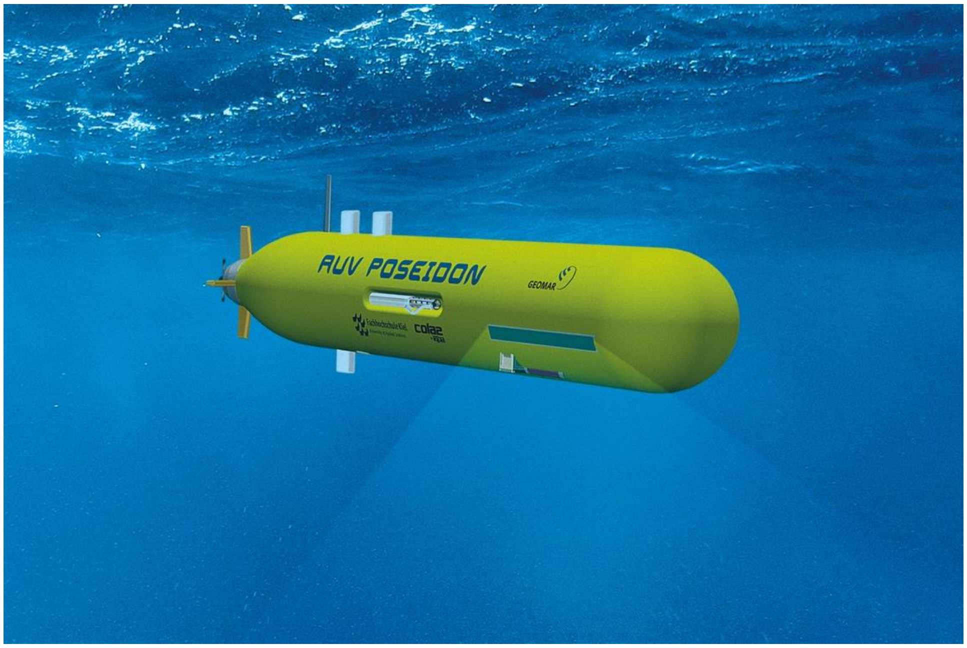


Figure 3: AUV Poseidon projected prototype for GEOMAR [8].

This is more comparable to a Lander, as these do not actively have communication during deployment. As stated by NOAA, “AUVs can be used for underwater survey missions such as detecting and mapping submerged wrecks, rocks, and obstructions…” [7]. This ultimately would be incredibly useful as our purpose is also to survey and map the seafloor, but it does lack the additional capability of observing organisms as closely and accurately as a lander does. We will also be advancing our odds of observing organisms by baiting the lander, which isn’t a feature on AUV’s. Additionally, AUV’s are generally much more expensive, and heavier, requiring a crane or specialized boat to deploy. For our purposes and resources, an AUV is not feasible.

Benefits of Using Landers

While landers do not have as much mobility or response to their surrounding environment as other kinds of vehicles used for deep sea research, they have numerous offsetting benefits for oceanographic exploration [5]. First, they are flexible in configuration which allows landers to be sized and configured to fit any ship at the team’s disposal (also known as ships-of-opportunity) [5]. Additionally, landers are often built to be modular with interchangeable payloads for different experiments that can be delivered anywhere in the ocean and safely recovered with the same vessel [4], [5]. Landers can also function as test beds to verify the operation of components for different vehicles in development by attaching a piece and operating it at depth. To add to their versatility, landers can be used at any depth for any length of time if the proper batteries and pressure spheres are used [5]. Landers may also be used as scouts to precede operations of other manned or unmanned vehicles to locate specific areas of interest [5]. Landers can function as samplers: collecting any number of water, sediment, or animal samples in addition to numerous chemical, biological, physical, geophysical, acoustic, and imaging data through sensors [5]. Landers also contain no hazardous materials making them easy to travel through customs and retrieve parts on location [5]. The anchors of landers are also cheap and expendable, only needing scrap iron, so ballast weights can be cheaply and easily purchased for each dive [5]. Lastly, landers are a disruptive technology because they are simple, cost effective, and accessible to any size institution [5].

Cameras and Other Instrumentation

Deep ocean landers are often compared to space vehicles because of the extreme conditions they endure. Landers equipped with HD cameras have given scientists and researchers an eye into some of the most unexplored places on Earth. These deep-water trenches are known as the hadal zone and reach nearly 11 kilometers under the surface [9]. These cameras are deployed using landers, manned submarines, ROVs (remote-operated vehicles), or winches. Landers are best at capturing sea life on the ocean floor and are often used in hadal dives. Cameras on these vehicles typically have wide lenses to capture as much of the ocean floor as possible. These devices must also adapt to the lack of light on the ocean floor. In the DEEPSEA CHALLENGE missions, a “Canon 5D Mark II DSLR was selected by Larry Herbst, a seasoned underwater imaging expert, for its high-resolution sensor and low-light capabilities” [5]. With the requirements and resources given to us as a group, we believe a lander is the most effective way to complete our mission.

As unmanned vehicles, landers use pre-programmed software to complete tasks on the ocean floor. Some of these tasks include taking videos and photos, gathering sediment samples, measuring depth, etc. When taking photos and/or videos, the HADEEP landers used “a relay board, with built in microprocessor, as the interface between the camera, lights, and recorder and enabled the recorder to power off and on to maximize battery life” [9]. These landers were equipped with 12,000 meter rated 50-watt lamps and a Hitachi HV-D30, 3CCD color video camera [9]. Every unit was powered by a 12-volt lead acid battery manufactured by Deep Sea Power & Light. Hadal creatures have adapted to the low-light environment in various ways and the use of bright white lights can lead to retinal damage for these animals. Other researchers have found that equipping a lander with “low-light cameras using red LEDs can image animal behavior without detection by most animals of the deep sea” [5]. The shortfall of red LEDs is they do not attract animals as much as white lights.

When diving to the hadal zone, custom hardware is often used to protect expensive sensors and cameras from the pressure of the ocean. Glass and acrylic are the most common materials used as camera viewports. However, during the creation of the HADEEP landers, engineers noticed a 2-millimeter creep of their dome-shaped, acrylic viewports which resulted in distorted video recordings. The engineers decided glass, plane disc windows would reduce visual distortion and minimize material deformation [9]. Learning from the studies done by other researchers helped us create an affordable and effective camera system to deploy with our lander.

Local Fauna

There is a broad range of species in the North Pacific, even in the deep sea. Corals and sponges can be abundant at depths but cannot be lured by bait from a deep ocean vehicle. However, many carnivorous and mobile species also live in the deep ocean and can be attracted to bait. Squid species as seen in *Figure 4*, deep sea sharks, anglerfish, orange roughy, cookiecutter sharks, and some jellyfish are just a small number of mobile carnivores and scavengers that can be lured and photographed by a deep ocean vehicle [10].

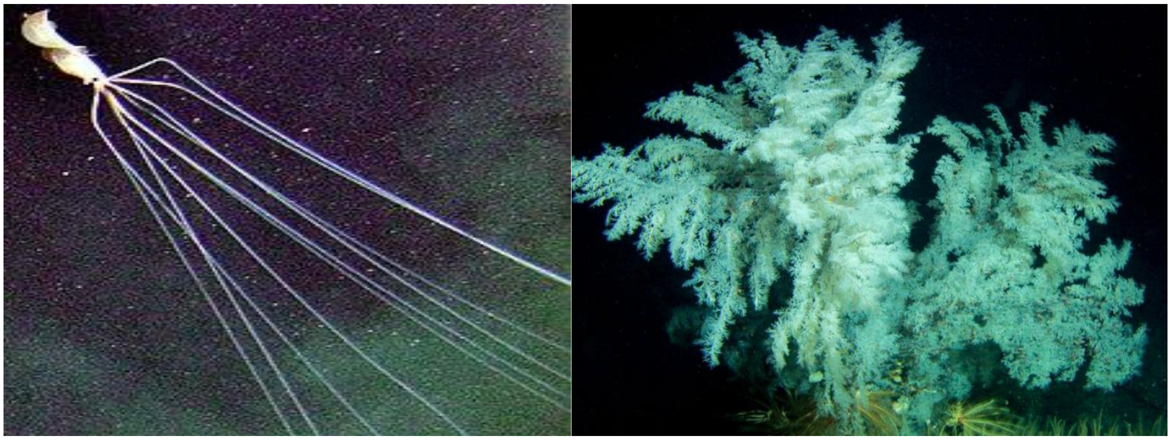


Figure 4: Bigfin squid & deep-sea coral both found at depths greater than 4,000ft. [Photos from https://ocean.si.edu/ecosystems/coral-reefs/deep-sea-corals].

Baiting Techniques and Effects

For baited vehicles, different types of bait have different effects on the species they lure and how effectively they are lured. Two main types of bait are commonly used: animal and plant-based bait. Animal based bait, such as tuna or beef liver, shows a much higher rate of species lured when compared to plant-based bait, like turmeric dough. The success of animal-based bait is especially prominent in deep sea scenarios. Past the lighted zone of 3,000 feet almost no plant matter is found, so many of the species have never experienced the smell or hunger for plant-based food. Additionally, animal-based bait tends to have a larger detection area for species due to the diffusion of animal matter and the sensitive detection tools that many carnivorous species have in the deep ocean [11].

It is important to understand the effects underwater research has on species in the area. In deep ocean conditions, there is little to no light penetrating the water, so species have evolved with sensitive photoreceptors or no eyes at all [12]. Studies have shown that light sources emitting less than 4.9 W/m^2 do not tend to permanently harm deep ocean creatures for a normal period that a species may be in contact with an underwater vehicle. Some species could experience photoreceptor damage that quickly recovers in darkness like glancing at the sun for a human [13].

Permits

Permits are required in situations where materials are either dumped or left at the bottom of the ocean. The use of a lander, although very efficient, requires leaving material on the ocean floor. According to the EPA (Environmental Protection Agency), "Any United States department, agency or instrumentality transporting material from any location for the purpose of dumping it into ocean waters" is required to get an ocean dumping permit [14]. Since we got to the point of testing the lander where ropes were unable to retrieve the weights, we contacted the EPA to determine if we needed an ocean dumping permit. We learned that a since our weights were classified as 'ballast weights' being used on a research vessel it did not require us to get a Dumping Permit in order to operate our vessel. If we had reached our stretch goal of doing some sediment sampling, we would have needed a scientific collecting permit administered by the California Department of Fish and Wildlife [15]. After being put in contact with Dr. Anastasia Telesetsky, another Marine Science professor at Cal Poly who has extensive experience with research permitting, she advised us to also reach out the US Coast Guard to determine any safety markings needed by our vehicle and NOAA to determine if we need an 'accidental take permit'. The Coast Guard informed us that our current flag system is fine as long as our ship remains nearby, and testing/recover happens during the day. If we want to do a night recovery, we would need to install additional lights which would flash on the lander when floating on the surface to warn other vessels of its presence. NOAA informed us that an accidental take permit would cover us incase an endangered species accidentally got caught on our vessel during deployment, however we were told it is a necessary permit for our study since it is only relevant in rivers and near coastal waters. Lastly, while it was not relevant to this specific mission, if we were to deploy the lander in a sanctuary, Dr. Telesetsky informed us we would need to investigate getting a sanctuary permit from NOAA as well.

Chapter 3: DESIGN DEVELOPMENT

General Approach

Throughout our project, our group maintained a “team-first mentality”. In order to develop solutions, team members discussed problems and determined the needs and constraints involved. As a group, we started by brainstorming potential solutions that were within the requirements of the project. Team members then had the opportunity to individually research solutions to similar problems. At the end of this phase, all potential solutions were presented to the whole group. One solution was unanimously chosen for each subsystem. We worked together to create and analyze these solutions. After the ideation was completed, we implemented the prototype into our final product or redesigned the prototype as necessary. This process is displayed in *Figure 5* below.

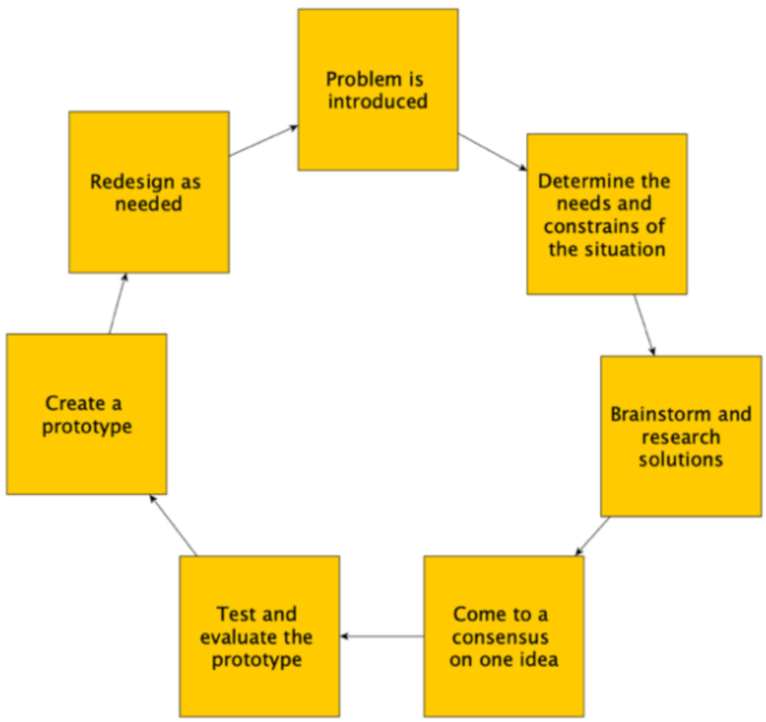


Figure 5: Engineering Design Process

Class Flowchart/Modifications

A more specific flowchart for how the engineering design process was implemented in this senior project class was given to the students (see *Figure 6* below). We used this flowchart as a base skeleton for the process we followed for our project but have needed to make additions/modifications. For example, we needed to file various paperwork throughout the year for everything from applying for grants, requesting permits to operate our lander in federal waters, and requesting/reserving use of the Cal Poly pier and boat.

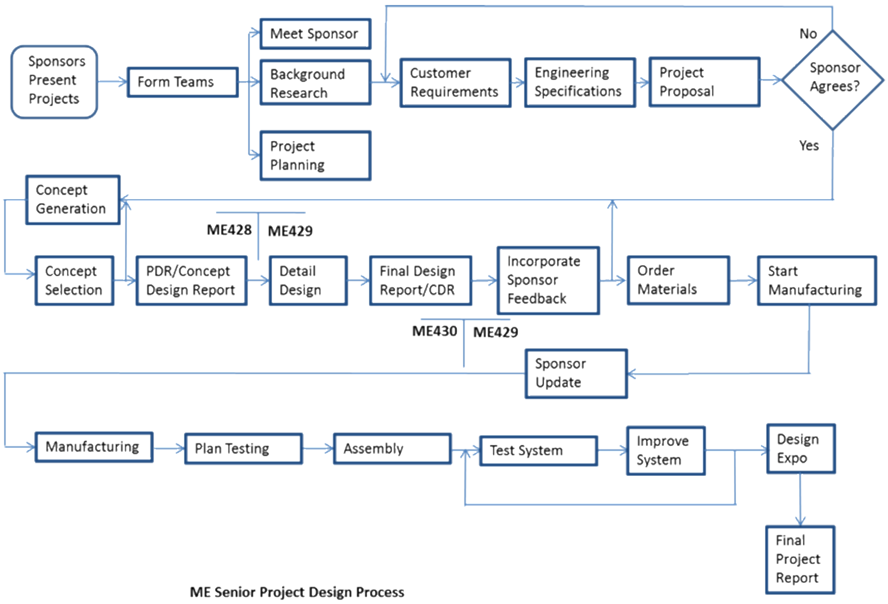


Figure 6: Senior Project Engineering Design Process

Bait Release Subsystem

Concept Generation

We began work on the bait release system with a thorough round of brainstorming. This involved each member suggesting ideas for complete or partial bait release systems for both our existing lander and entirely new lander models. These ideas were inspired from a combination of the team's creativity and use of elements we found on existing bait systems from our background research. Next, we did a brainstorming prototyping session in class which allowed us to develop additional ideas and further develop our existing ones (see *Figures 7-9*).

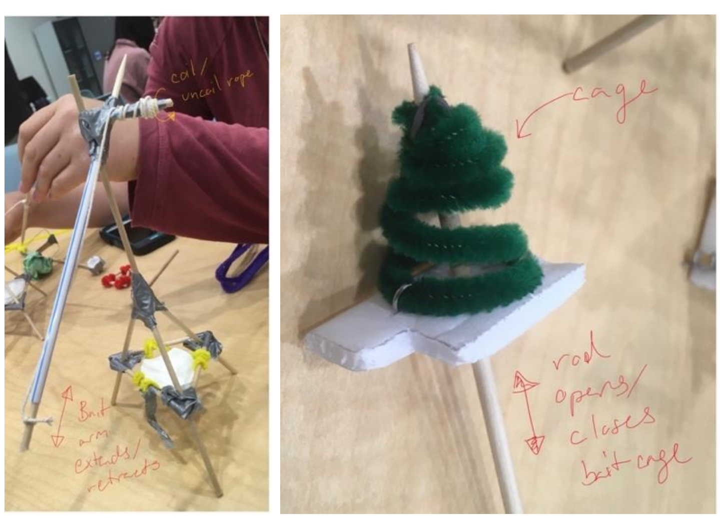


Figure 7: Prototypes of Extendable Bait Arm and Spring Bait Cage

Figure 8: Prototype of Bait Drop Below Lander

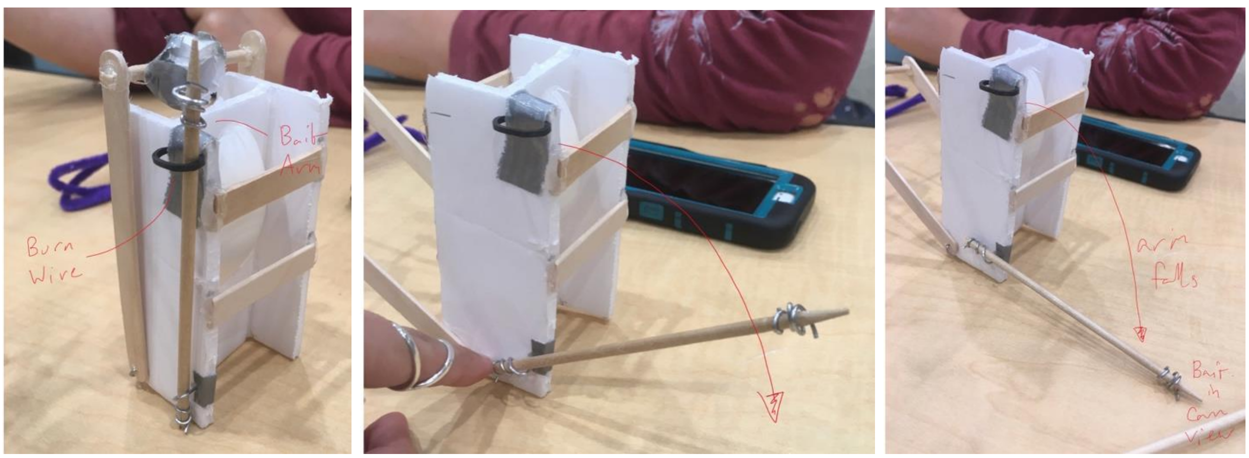


Figure 9: Prototypes of Single and Double Drop Bait Arms

After this small-scale prototyping session, we looked at which prototypes were most feasible to build and implement. This included looking at a design's simplicity (number of parts and complexity of making them), the cost (wanting to keep it as low as possible), durability (ability to function at depth and not break in any part of deployment), and function (properly positioning the bait in view of the camera). We picked the idea we thought had the most potential and made some sketches of how it would operate in deployment as seen in *Figures 10-12*.

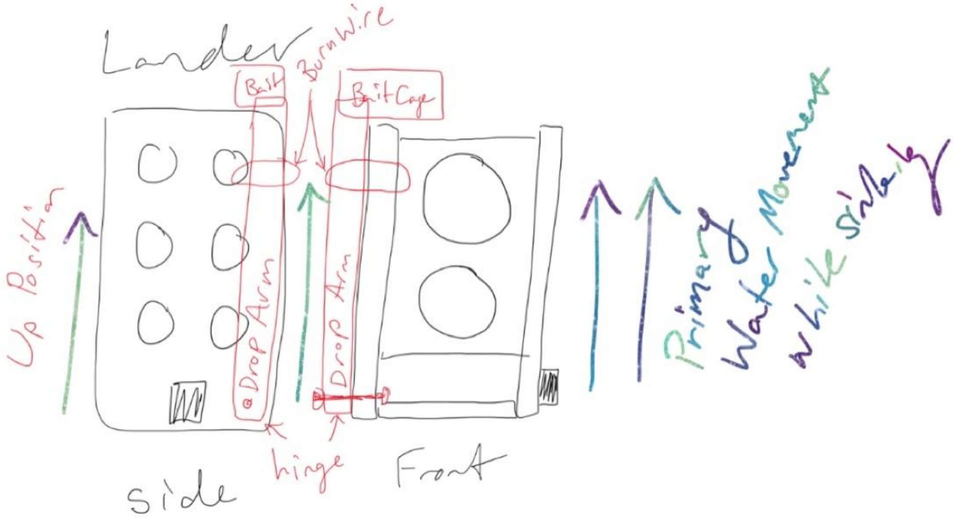


Figure 10: Sketch of Lander with Single Drop Arm Bait System in Descent
(Left: Side View, Right: Front View)

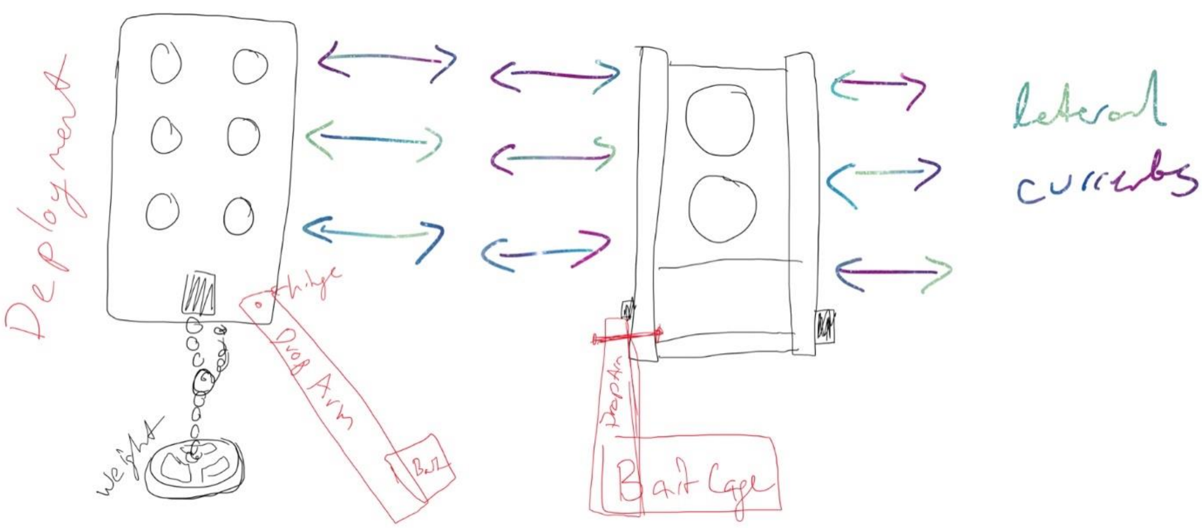


Figure 11: Sketch of Lander with Single Drop Arm Bait System at Depth
(Left: Side View, Right: Front View)

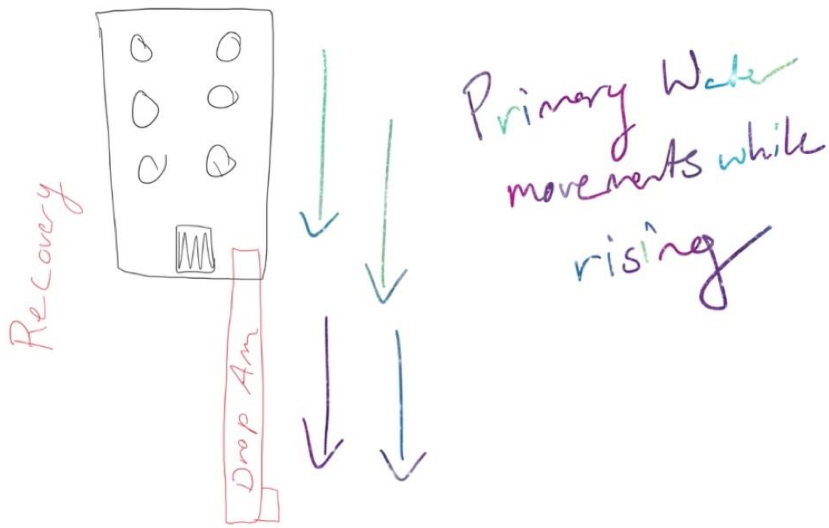


Figure 12: Sketch of Lander with Single Drop Arm Bait System in Ascent (Side View)

Once we sketched out what the full-scale model would look like, we went to work building a model which would work on DOV Seastang as it currently existed. We used only scrap material, a few bolts and zip ties in the Mustang ’60 machine shop, but successfully built a full-scale model of the single drop arm bait release system. As seen in *Figure 13*, the bait arm is compact when in its stored position but easily falls forward placing the bait in view of the camera once it reaches the sea floor.

Figure 13: Full Scale Prototype of Single Drop Arm with Bait Cage

Once we were able to see that our small-scale prototypes worked just as well at full scale, we knew it was time to begin the selection process.

Idea Selection

We started this process by generating a Pugh Matrix to weigh the concepts against each other. The matrix, seen in *Table 2* on the next page, was made to assess prototypes/concepts generated by the team for the bait release subsystem in order to determine how to narrow down our concept list before doing more testing. The design we used for the full-scale prototype (the Single Drop Arm with Bait Cage) – this design became our datum in this matrix *(Concept #2)*. This was then compared to our current bait system *(Concept #1)* and all other design ideas *(Concepts #3-7).* One thing that becomes very clear with this matrix is that concepts *#3* and *#6* should be eliminated from consideration immediately because both have zero criteria listed which are better than the datum and several criteria listed as worse. Additionally, concept *#5* must be eliminated because it violates criteria *A* which is a Go-No Go Criteria, meaning it is a critical design requirement that must be met. This leaves concepts *#1, 2, 4, & 7* up for consideration. From this matrix alone it appears that concepts *#4* and *#7* are not optimal concepts because their number of negatives are higher than their number of positives compared to the datum, but further testing and research needed to be done on all four concepts before making a more detailed decision matrix.

Table 2: Bait Release Subsystem Initial Pugh Matrix

Criteria \ Concept		1	2	3	4	5	6	7
		Zip-tying Bait to the Weight *(Current)*	Single Drop Arm with Bait Cage on End *(Prototype)*	Two-Sided Drop Arm with Bait Cage in Middle	Spring Cage on Plate	Bait Drop Below Lander	Extendable Arm (Rod in Pipe)	Timed Release System (Releases Pieces Periodically)
A	Fits on Current Lander	S		S	S	-	S	S
B	Positions Bait in Front/Away from Lander	-	**D**	S	-	-	S	-
C	Bait in View of New Camera	-	**A**	S	-	S	S	-
D	Bait Lasts for Dive Length	-	**T**	S	S	-	S	+
E	Uses Minimal Components/ Controls	+	**U**	-	-	+	-	-
F	Durability in Deployment	+	**M**	-	+	+	-	+
G	Low Cost	+		S	S	S	-	-
SUM of +		3		0	1	2	0	2
SUM of -		3		2	3	3	3	4
SUM of S		1		5	3	2	4	1

For looking at this narrowed selection of concepts, we decided a weighted decision matrix was the best next step to show not only which concepts perform better, but of what importance these improvements rank. As can be seen in *Table 3*, we rated each concept on its percent satisfaction of the given criteria. This percentage is then multiplied by the assigned weight of the criteria (the larger the weight the more important it is to our project). Lastly, these values are added up and the concept with the highest score represents the best design. *Table 4* shows that using this system concept #2, the single drop arm with bait cage on end, is the best design and should be used as the final design concept for this project.

Table 3: Meaning of Weights for Decision Matrix

Rating (%)	Description
100	*Complete Satisfaction:* Objective satisfied in every respect.
90	*Extensive Satisfaction:* Objective satisfied in all important aspects.
75	*Considerable Satisfaction:* Objective satisfied in the majority of aspects.
50	*Moderate Satisfaction:* A middle point between complete satisfaction and no satisfaction.
25	*Minor Satisfaction:* Objective satisfied in some, but less than half of the aspects.
10	*Minimal Satisfaction:* Objective satisfied to a very small extent.
0	*No Satisfaction:* Objective not satisfied in any aspect.

Table 4: Bait Release Subsystem Weighted Decision Matrix

Criteria \ Concept		Weight	1	2	4	7
			Zip-tying Bait to the Weight *(Current)*	Single Drop Arm with Bait Cage on End *(Prototype)*	Spring Cage on Plate	Timed Release System (Releases Pieces Periodically)
B	Positions Bait in Front/Away from Lander	0.025	10% / 0.25	100% / 2.5	10% / 0.25	50% / 1.25
C	Bait in View of New Camera	0.150	5% / 0.75	100% / 15	25% / 3.75	25% / 3.75
D	Bait Lasts for Dive Length	0.200	25% / 5	90% / 18	90% / 18	100% / 20
E	Uses Minimal Components/ Controls	0.075	100% / 7.5	90% / 6.75	70% / 5.25	40% / 3
F	Durability in Deployment	0.300	10% / 3	90% / 27	90% / 27	80% / 24
G	Low Cost	0.250	100% / 25	80% / 20	50% / 12.5	10% / 2.5
Total		1.000	41.50	89.25	66.75	54.5

This design was selected due to its cost-effective achievement of being able to repeatably place bait in view of the lander's camera system for the full time at depth. Exact dimensions and materials had not yet been determined, but the general shape and relative size compared to the existing lander can be seen in *Figure 14*. The plan was to make the bait arm out of low cost and pressure safe materials (like a hollow PVC pipe allowed to be filled with water at depth, so it is equal pressures inside and out) for the arm, metal mesh for the bait cage, and a steel bolt for its hinge attachment on the lower corner of the lander. It was also planned to have a release system near the top of the arm when in its stored position which is used to keep the arm in place during descent. The exact form of release system had not yet been decided but was thought to likely be either an electric burn-wire (like used in the weight release system) or an ice or candy melt release system. For this concept, the attachment of the bolt-hinge and release systems can be simply done with drilling appropriately sized holes in the lander frame. The cage was expected to be attached to the arm through some combination of bolts and zip ties depending on how the final geometries lined up best. This design was planned to be very similar, but much higher quality as the prototype shown in *Figure 13* in the Design Development section.

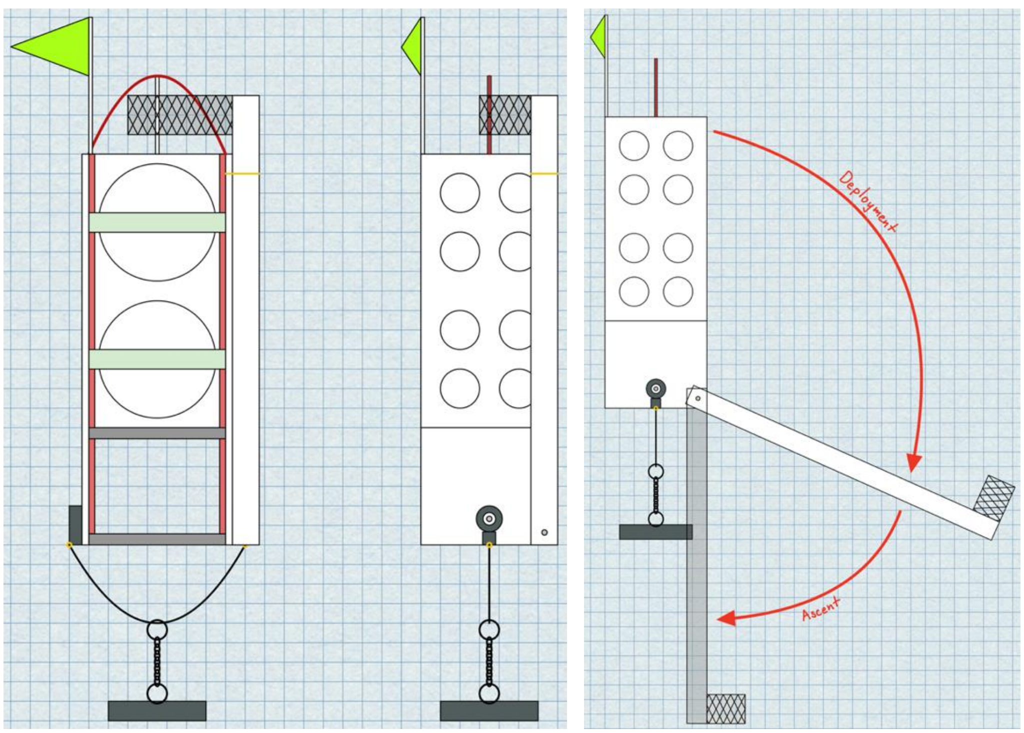


Figure 14: Preliminary Final Concept Sketch of Bait Release System
(Left: Stored Position, Right: Deployment and Ascent Positions)

Camera/Housing Subsystem

Concept Generation

Concept generation began during the background research segment of our project. We wanted to look into other cameras and camera systems used in other deep-sea missions. We found that many cameras are custom-made to the mission parameters. Standard retail cameras are unable to withstand the pressure of the hadal zone without a special underwater housing. We also researched companies who specialize in deep sea cameras and found their cameras to be equally expensive. To build off these concepts, we began to brainstorm solutions to the camera issue.

At the beginning of our concept generation phase, the lander was equipped with a GoPro action camera. This camera is only capable of withstanding depths of 50 meters. We needed a camera that can reach depths of at least 1,200 meters. During the brainstorming period, the first step was to determine the requirements that the camera subsystem needed to fulfill. The requirements we chose were lander compatibility, HD video capability, proper depth rating, long battery life, cost effective, and footage that is not warped. We came up with seven new ideas that would satisfy our selected requirements. The ideas were a mix of building a new housing for the current camera, creating a housing out of a pressure sphere, and purchasing a new camera/housing subsystem entirely.

As stated in the background section of this report, there are lots of proven camera housings on the market. So as not to “reinvent the wheel”, we decided to immediately rule out some of the ideas. The ideas included a camera attached to a fishing rod, a camera mounted on a whale, and dropping the empire state building in the water and using the stairs to reach the bottom. Some of these ideas are quite absurd but were important in the progression of our brainstorming process.

Prototyping took place immediately after the brainstorming session. We focused on ways to attach a new housing to the lander so that it is properly aligned to view the bait arm. One of the prototypes, shown in *Figure 15* (left) below, uses a single camera mounted to the bottom of the lander frame. The prototype shown in *Figure 15 (right)* depicts a camera with a pressure sphere. Another prototype utilizes a two-camera layout with the two cameras pointed towards the bait arm as well. The benefit of using two cameras is the ability to measure the size of objects and animals that pass within the frame.

Figure 15: Single camera setup to view deep sea animals attracted to the bait.

Idea Selection

To narrow down our concepts and select a final design, we created a Pugh matrix which is shown below in *Table 5*.

Table 5: Pugh Matrix for the Camera/Housing Subsystem

Criteria \ Concept		1	2	3	5	6	7	8
		GoPro Action Camera *(Current)*	Buy a Pressure Rated Camera	Build a Pressure Sphere Housing for GoPro	Design and Build a Housing for New Camera	Buy a New Housing and a New Camera	Design and Build Housing for GoPro	Buy a Pressure Rated Housing for GoPro
A	Fits on Current Lander		S	-	S	S	S	S
B	HD Video/Pictures	**D**	+	+	+	+	-	S
C	Able to handle pressure at max depth	**A**	+	+	+	+	+	+
D	Battery lasts the duration of the trip	**T**	+	+	+	+	S	S
E	Fits within budget	**U**	-	+	-	-	+	-
F	Timed with lights so that the area is visible	**M**	S	S	S	S	S	S
G	Footage is not warped		+	S	-	+	-	S
SUM of +			4	4	3	4	2	1
SUM of -			1	1	2	1	2	1
SUM of S			2	2	2	2	3	5

After developing the Pugh matrix, we determined that there were three concepts with similar scores. To complete our selection process, we created a weighted matrix. This can be seen on the next page in *Table 6*.

The most promising concept for this problem involves repurposing a pressure sphere into a housing for the GoPro. Near the end of our preliminary design process, Global Ocean Design offered to donate a prebuilt camera housing made from a pressure sphere. With this concept, we asses that we would meet all of our design criteria. While at the time we had not received money from our grant requests, we believed the material costs for this concept should remain within our budget due to minimal additional purchases needing to be made on our front to make this system functional.

The other two concepts scored much lower than the pressure sphere housing. The major difference between these designs was the cost. Buying a specialty camera would most likely exceed our budget. Using the weighted matrix proved that our best option is to move forward with the pressure sphere housing.

Table 6: Camera and Housing Weighted Decision Matrix

Criteria \ Concept		Weight	1	2	3
			Buy a Pressure Rated Camera	Build a Pressure Sphere Housing for the GoPro	Buy a New Housing and New Camera
A	Fits on Current Lander	0.17	70% / 11.9	100% / 17	75% / 12.75
B	HD Video/Pictures	0.103	100% / 10.3	75% / 7.73	100% / 10.3
C	Able to Withstand Pressure at Max Depth	0.17	100% / 17	100% / 17	100% / 17
D	Battery Lasts the Duration of the Trip	0.103	85% / 8.76	100% / 10.3	85% / 8.76
E	Fits within the Budget	0.25	15% / 3.75	100% / 25	5% / 1.25
F	Timed with Lights so Area is Visible	0.103	50% / 5.15	100% / 10.3	50% / 5.15
G	Footage is not Warped	0.103	100% / 10.3	90% / 9.27	100% / 10.3
Total		1.000	67.16	96.6	65.51

Lighting Subsystem

Concept Generation

Lighting is a simple concept for this project, and we decided not to reinvent the lightbulb. Our biggest decision that needed to be made here was how many lights should we use, what kind, and how bright should they be. To brainstorm different setups, we sketched a few different layouts that would achieve different criteria as depicted in the *Figure 16*.

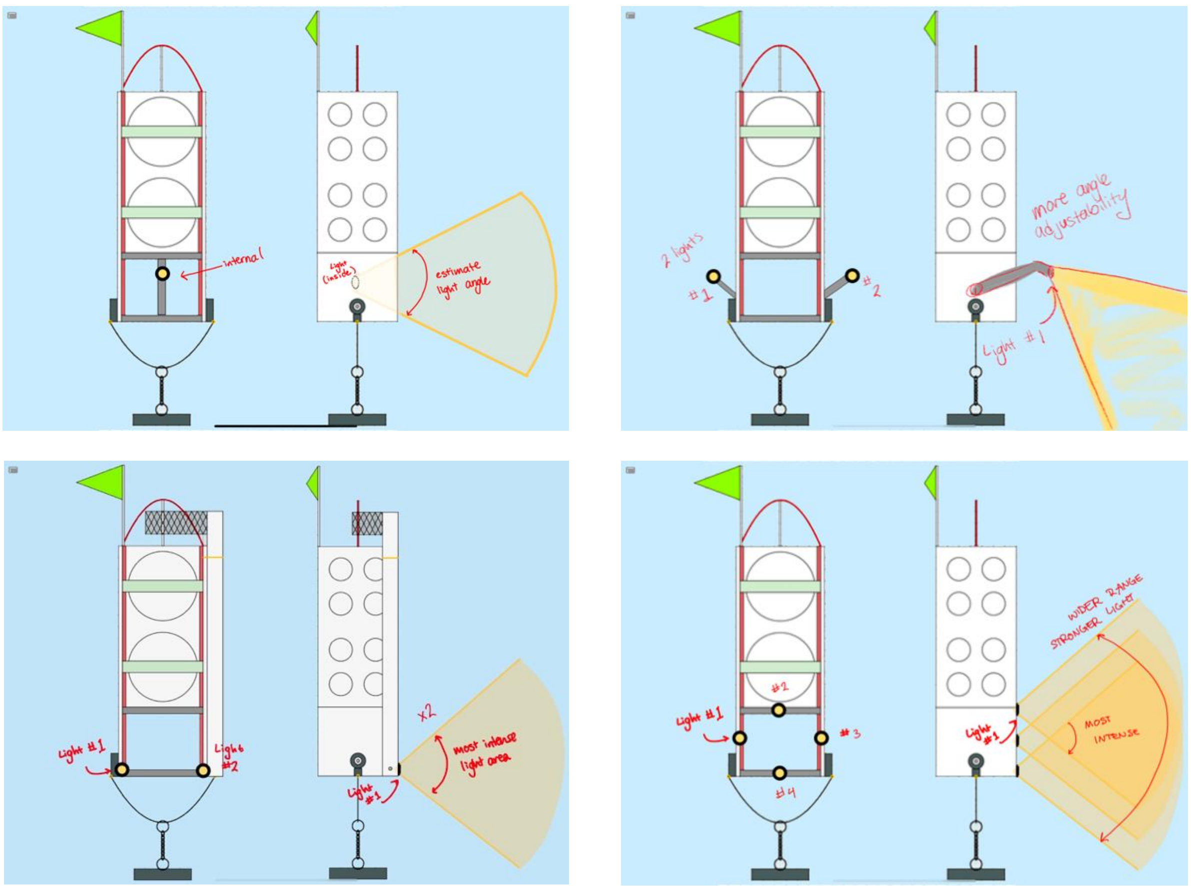


Figure 16: Sketches of Lander with various lighting configurations.

To refine the criteria for lighting systems, we searched through different existing ocean technology catalogs such as Ocean News Buyers guide [16], Sea Technology [17], and OceanographyforEveryone[18]. One guide led us to the DeepSea LED SeaLite [19] which presented us with a high-end goal of desirables to look for in our lighting setup as shown in *Figure 17*.

Figure 17: LED SeaLite with Key Features Listed [19]

Idea Selection

After we had come up with possible configurations and base criteria to look for in a deep-sea lighting system, we put together a Pugh decision matrix (*Table 7*) considering the different possibilities. We decided to use concept configuration *#3*, "Two lights inside lander", as the DATUM because it was the average of the number of lights ideated. It is notable that these configurations and the criteria grading scale were created before the concept for the bait apparatus and camera setup was decided and therefore were influenced with that in consideration. Concept *#1*, "no lights", scores equally with concept *#7*, "Lights on front and back." If a front and back camera and a front and back bait arm are used, concept *#7* makes the most sense, albeit will be the most expensive. Alternatively, if our sponsor decided bioluminescence is what they wanted to observe at the bottom of the ocean, and if grants hadn't been acquired, concept *#1* (no lights) would have made the most sense. Concept *#2*, "One light inside the lander", and concept *#6*, "4 lights positioned in front", scored similarly in that there is a greater sum of negatives than positives. It makes sense to say that regardless of bait arm decision and grant money, these are the first concepts to forfeit. One light won't be enough and 4 is excessive. The most similar in scores are concept *#3*, "Two lights inside lander", the DATUM, and concept *#5*, "Two lights outside lander." Both get the job done amiably and aren't overpowered by negative scores. Concept *#4* and concept *#5* will be more useful if the camera takes up the entire bottom storage component of the lander.

Still, this left concepts *#3*, *#4*, *#5*, and *#7* as plausible configurations for the lander. These concepts were then placed in a weighted decision matrix (*Table 8* on the next page) for further comparison.

Table 7: Pugh Matrix for Possible Lighting Configurations

Criteria \ Concept		1	2	3	4	5	6	7
		Nothing (Current)	One Light Inside Lander	Two Lights Inside Lander	One Light Outside Lander	Two Lights Outside Lander	4 Lights Positioned on Front	4 Lights on Front and Back
A	Fits on Current Lander	+	+		S	S	-	-
B	Lights-Up where Camera is Pointed	-	S	**D**	S	-	-	+
C	Wide Beam Angle	-	-	**A**	+	+	+	+
D	High Lumens	-	-	**T**	-	+	+	+
E	Durability in Deployment	+	S	**U**	-	-	-	-
F	Low Cost	+	+	**M**	+	S	-	-
SUM of +		3	1		2	2	2	3
SUM of -		3	2		2	2	4	3
SUM of S		0	3		2	2	0	0

Table 8: Weighted Decision Matrix for Final Four Concepts

Criteria \ Concept		Weight	3 Two Lights Inside Lander	4 One Light Outside Lander	5 Two Lights Outside Lander	7 4 Lights On Front And Back
A	Fits on Current Lander	0.154	100% / 15.4	100% / 15.4	100% / 15.4	85% / 13.1
B	Lights-Up where Camera is Pointed	0.231	60% / 13.9	60% / 13.9	75% / 17.3	80% / 18.5
C	Wide Beam Angle	0.077	60% / 4.6	60% / 13.9	90% / 6.9	100% / 7.7
D	High Lumens	0.231	85% / 19.6	50% / 11.5	85% / 19.6	100% / 23.1
E	Durability in Deployment	0.154	100% / 15.4	90% / 13.9	60% / 9.2	50% / 7.7
F	Low Cost	0.154	50% / 7.7	60% / 9.2	50% / 7.7	10% / 1.5
Total		1.000	76.6	68.5	76.1	71.54

Based on these results, it is apparent that the most criteria conforming configuration for the lights are two lights outside the lander.

Similar to the camera housing, two LED lights were donated by Global Ocean Design. This not only matched our concept from the decision matrix, but also increased its cost effectiveness. The LEDs are pictured below in *Figures 18* and *19*.

Figure 18: LED Light With and Without Diffuser

Figure 19: LED Lights along with battery

The cavity surrounding the LED is filled with oil before deployment to be pressure compliant. The final configuration is depicted in the following *Figure 20*.

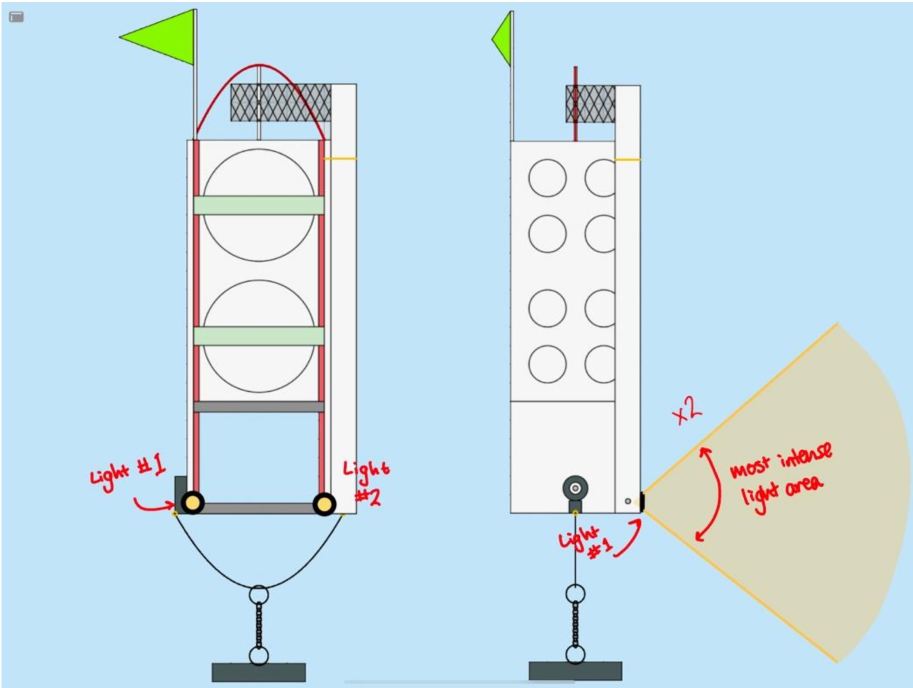


Figure 20: Schematic of final concept lights attached to the Lander

The way we attach the lighting system was still in consideration at the time of preliminary idea selection but was determined once we got the materials and grant results in hand. The battery packs for both the LEDs will be stored in the camera housing but may also be kept in the middle buoyancy ball.

Buoyancy/Weight Subsystem

Concept Generation

The lander has important requirements to sink down to the bottom of and area, stay there for a specific time and return to the surface all on its own. To do this, the system has to manage and change its buoyancy throughout the mission. The first step for concept generation was absorbing knowledge that is already out there for landers similar to the one we are producing.

From past projects, and research, our team had already made a system that is able to release a chain that is looped through weights. This set up was tested at the Cal Poly Pier and was successful. After the successful test of the existing design, the brainstorming was not over. Using the experience of the test and further research, new ideas were generated to compare with the tested design and see if there could be improvements. One major concept that could be a factor for the weight system is the ability to drop and leave iron weights with permitting regulations. New ideas were formulated with that in mind.

Idea Selection

Once we had some ideas, they were put into a Pugh matrix (*Table 9* on next page) to see how they compare and produce new ideas.

The main focus for creating new ideas was to allow the system to not rely on lead or specific weights in order to make it as versatile as possible for permitting and regulations. The concept with a hinged tray connected to a burn wire showed the most promise with only 1 negative result when compared to the datum. A line connecting the DOV also fits many criteria but would not work if the DOV had to stay under for a long period of time or if it was especially deep. Having other mechanisms other than burn wires like air tanks or motors would be too complicated to create and test especially within our budget. A similar idea to the promising tray would be the chained net idea, which would have a similar mechanism to the tray. However, it may be slightly less reliable if the net gets tangled during descent or release. Overall, the datum works well, but the hinged tray shows better versatility if it is reliable. The hinged tray would need to be tested more for reliability.

The existing and tested system of weight release shows promise and reliability. After speaking with permitting officials, we confirmed that the existing system complies with permitting regulations and is there for the most cost effective and overall best choice for the project requirements.

Table 9: Buoyancy/Weighing Subsystem Pugh Matrix

Criteria \ Concept		1	2	3	4	5	6
		Chain Passing Though Weights *(Current)*	Chain Passes Through Net w/ Weights Inside	Tray Connected on Hinge with Burn Wire on One Side	DOV Connected to Line	Air Tank with Ballast	Motorized Method to Drive Up
A	Fits on Current Lander		S	S	S	S	S
B	Can Work with Different Weights	**D**	+	+	+	+	+
C	Easy to Source Parts	**A**	-	S	-	-	-
D	Repeatable	**T**	+	-	+	S	-
E	Not Time Constrained	**U**	S	S	-	S	S
F	Reliable	**M**	-	S	+	S	-
G	Low Cost		S	+	-	-	-
SUM of +			2	2	3	1	1
SUM of -			2	1	3	2	4
SUM of S			3	4	1	4	2

Sensors Subsystem

Concept Generation

We began by researching the similar databases as we did for the lighting system and discovered that most of the sensors available are generally similarly shaped and sized, as can be seen in *Figure 21*.

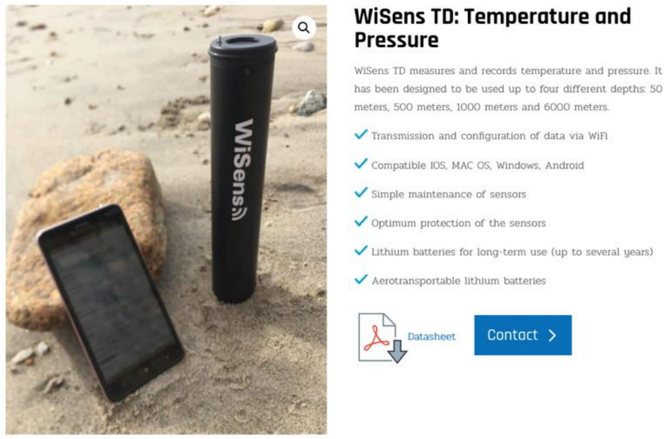


Figure 21: WiSens Cylindrical Temperature and Pressure Sensor [22]

Based on this it was simple on where we wanted to put them. We decided that attaching them to the corners of the bottom compartment of the existing lander made the most sense as pictured in *Figure 22*.

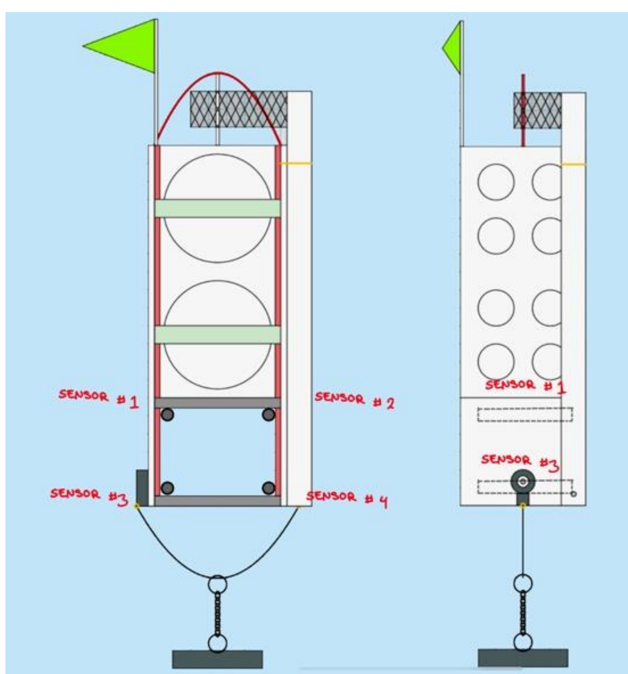


Figure 22: Lander depicted with 4 possible sensors positioned in all 4 corners

In order to get a better understanding of different possible sensors that would be useful on the lander, we researched all the different types of sensors and compiled a list of the most useful and feasible ones.

The sensors we chose to compare are pH, turbidity, dissolved nitrogen, dissolved oxygen, environmental DNA, parallel Lasers, and salinity sensors. The pH, dissolved nitrogen, dissolved oxygen, and salinity sensors all detect the levels of their namesakes in the water. The turbidity is a measurement of the clarity of the water [20], while the environmental DNA is the DNA that is found in the environment via shed organic material and excrement [21]. Alternatively, parallel lasers could be mounted next to the camera and pointed towards the field of view. The purpose of this is that when an organism moves in front of them, we can measure the distance and size between the two markers to get the relative size and distance of the organism on camera.

Idea Selection

The list of sensors was then placed in a Pugh matrix as seen in *Table 10*. The temperature and pressure sensors are consistent throughout the concepts because these are the minimum sensors we plan to have. It is notable that all the sensor options were compared with the temperature and pressure to simplify the selection process instead of comparing possible combinations of 4 different sensors, which would give us a longer list with more indistinguishable criteria to consider. We chose to use temperature, pressure, and pH level as our datum, because pH is a commonly used sensor for ocean research and is becoming more relevant in the passing years because of ocean acidification. Initially, it is apparent that Concepts 3, turbidity, and 6, environmental DNA, can easily be ruled out due to lack of meeting criteria. Similarly, concepts 4 and 5, dissolved nitrogen and dissolved oxygen respectively, scored similarly against the datum and were ruled out due to concepts 8 and 9 meeting the wants more closely. That left concept 1, 7, 8, and 9, temperature and pressure alone, parallel lasers, salinity, and sediment respectively left for closer analysis as seen in *Table 11*. Sediment sampling was included in the sensor selection because of its similarity in criteria.

Looking at the results from *Table 11* on the next page, it is apparent that there is not a significant difference between choosing two concepts (#*1* and #*7*). It is also notable that we have room for at least four total sensors, and there are cases where the temperature and pressure sensors can be combined into one compartment as seen in the NKE WiSens [22]. Therefore, it was determined that, if the necessary funding is procured, we may be able to incorporate all of these sensors into our final design.

Table 10: Pugh Matrix for Different Sensors

Criteria \ Concept		1	2	3	4	5	6	7	8	9
		Temp & Pressure	Temp & Pressure & pH	Temp & Pressure & Turbidity	Temp & Pressure & DN	Temp & Pressure & DO	Temp & Pressure & eDNA	Temp & Pressure & II Lasers	Temp & Pressure & Salinity	Temp & Pressure & Sediment
A	Fits on Current Lander	+		-	S	S	-	S	S	S
B	Meets Wants	S	D	-	-	-	-	-	+	+
C	Observes Organism Survivability	-	A	-	+	+	-	S	S	S
D	Observes Organisms	-	T	-	-	+	+	+	S	+
E	6 Hr Bottom Time	+	U	S	+	+	-	+	+	+
F	Minimal Space	+	M	-	S	S	-	-	S	-
G	Low Cost	+		S	S	S	-	S	S	-
SUM of +		4	0	0	2	3	1	2	2	3
SUM of -		2	0	5	2	1	6	2	0	2
SUM of S		1	0	2	3	3	0	3	5	2

Table 11: Weighted Decision Matrix for Different Sensor and Sampling Concepts

Criteria \ Concept		Weight	1	7	8	9
			Temp & Pressure	Temp & Pressure & II Lasers	Temp & Pressure & Salinity	Temp & Pressure & Sediment
A	Fits on Current Lander	0.154	100% / 15.4	70% / 10.8	80% / 12.3	80% / 12.3
B	Meets Wants	0.231	50% / 11.5	60% / 13.9	80% / 18.5	80% / 18.5
C	Observes Organism survivability	0.154	50% / 7.7	30% / 4.6	50% / 7.7	30% / 4.6
D	Observes Organism	0.231	10% / 2.3	95% / 21.9	40% / 9.2	80% / 18.5
E	6 Hr Bottom Time	0.154	90% / 13.9	70% / 10.8	60% / 9.2	100% / 15.4
F	Minimal Space	0.077	80% / 6.15	30% / 2.31	40% / 3.1	30% / 2.3
G	Low Cost	0.231	80% / 18.5	45% / 10.4	40% / 9.2	50% / 11.5
Total		1.000	75.38	74.62	69.23	83.08

Our initial design for the sensor system is depicted in *Figure 23*. We chose to include only the temperature and pressure sensors as the primary sensors we ideally wanted to use (pending funding) and left the final two sensors decision up to how much money we got from the grants. With this, our base criteria were met of having a temperature and pressure sensors, and depending on monetary resources, our other criteria of also having a salinity and sediments sampler had the possibility of being met.

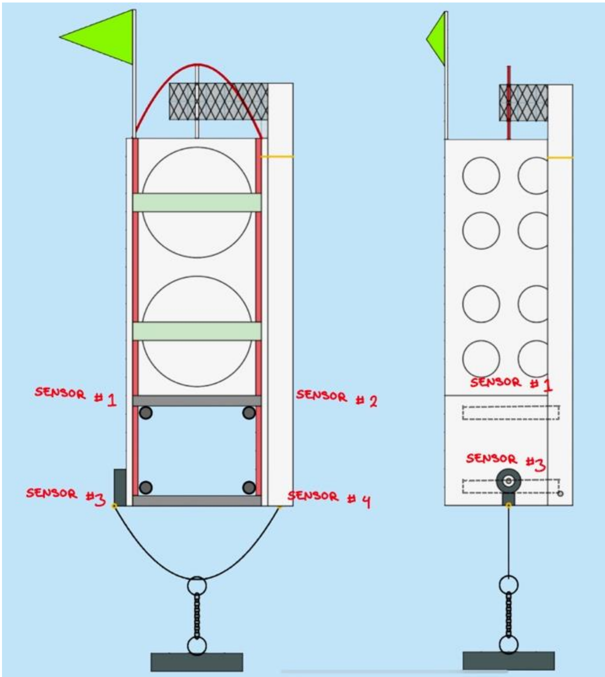


Figure 23: Final Sensor Concept

Depending on the types of sensors we would have gotten and how each stored data would have determined where each one was connected and if it needed an additional external battery pack that needed to be housed in the pressure secured sphere systems.

Preliminary Design

After looking at our budgeting requirements, our team decided to use as much of the existing lander as possible instead of looking at building a new lander from scratch since the largest constraint on our project was keeping it low cost. Because of this, we decided every new subsystem should fit the existing lander with as few modifications as possible. This works well because the lander was built with an open payload bay at the bottom used for storage of cameras, lights, and sensors, in addition to being made from easy to machine composite for exterior attachments. Below in *Figure 24* is a final concept sketch of the base lander without modifications.

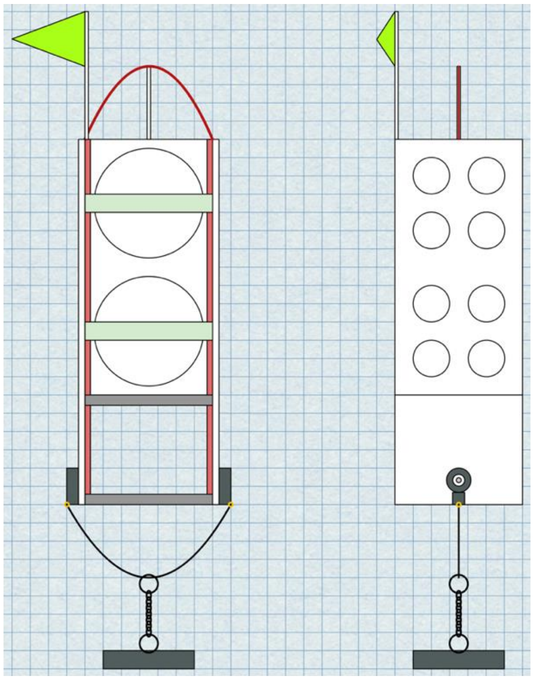


Figure 24: Final Concept Sketch of Base Lander

In addition to this sketch, SolidWorks part and assembly models of a similar lander model (Global Ocean Design's Picolander) were provided courtesy of Kevin Hardy of Global Ocean Design (*Figure 25*). These models were modified in order to create the base model of DOV Seastang which all modifications and additions were designed on prior to fabrication. You can also reference images of DOV Seastang in its original form in *Figure 1*.

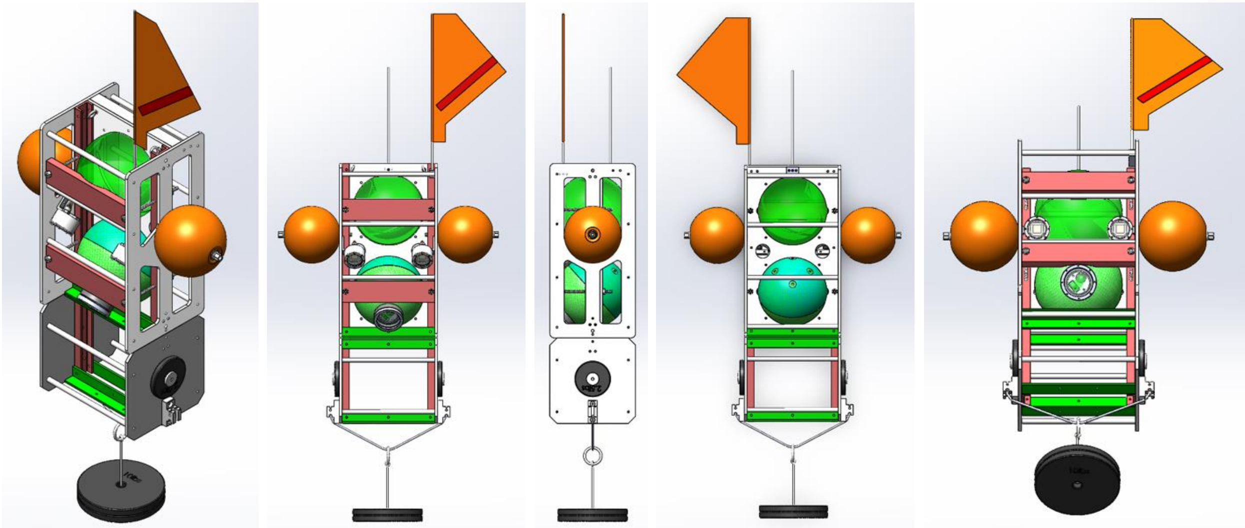


Figure 25: SolidWorks Assembly of Picolander from Global Ocean Design

Combining all of our subsystems, we have our initial design concept for our lander. As shown in *Figure 26* below, the plan was for our lander to contain a single drop arm with a bait cage at its end, a repurposed pressure sphere with a GoPro Hero 4 action camera placed inside and two LED lights donated by Global Ocean Design, at least two bathymetry sensors (temperature and pressure), and a burn wire weight release system.

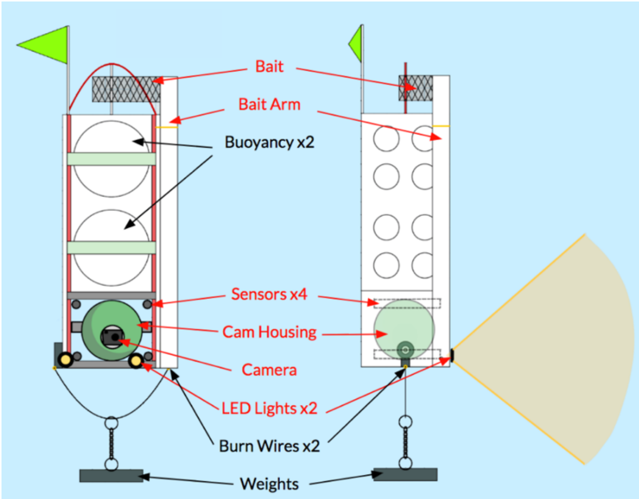


Figure 26: Complete Lander Final Concept Sketch

Since the design in *Figure 26*, we altered a few components of the design, which can be seen in *Figure 27.* Specifically, the camera moved from the bottom compartment to the middle because it fit better with the current design due to pre-existing sphere attachment set-ups. The lights remained relatively in the same place, just now at an angle. The sensors for the lander were also removed, for reasons which will be discussed in the Final Design section.

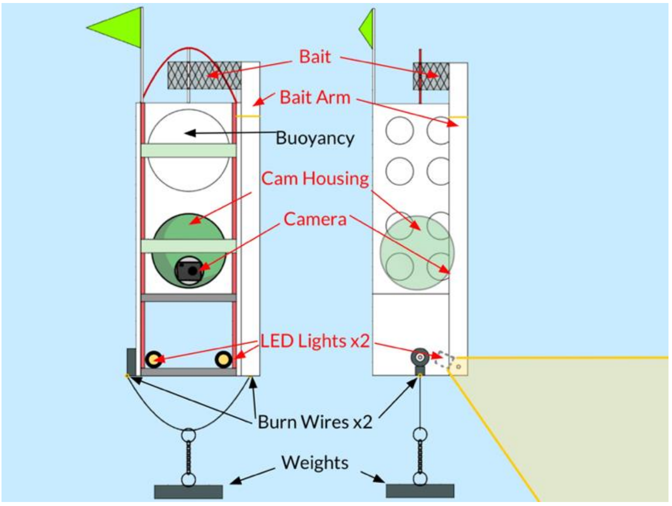


Figure 27: Final Simple Design for Lander

Chapter 4: FINAL DESIGN

Baker-Koob and CP-Connect Grants

As mentioned previously, our team applied for a grant of $5,000 from both Baker-Koob and CP Connect. On January 5th 2022, we were informed that we received the Baker-Koob grant for $5000! The receival of this grant allowed us to make more finalized decisions from our idea selection performed above. These decisions are discussed below.

Overall Lander

Our final design consists of the pre-existing lander base, the buoyancy/weight release system, and the burn wires. Added on to that is the bait arm subsystem, the camera and camera housing, and the lights. Each of these components is thoroughly analyzed below.

Figure 28: Finished Lander with and without Buoyancy Spheres

An overall SolidWorks assembly can be seen on the following page in *Figures 28* and *29*. Full SolidWorks drawings of assemblies and parts can be found in *Appendix C*.

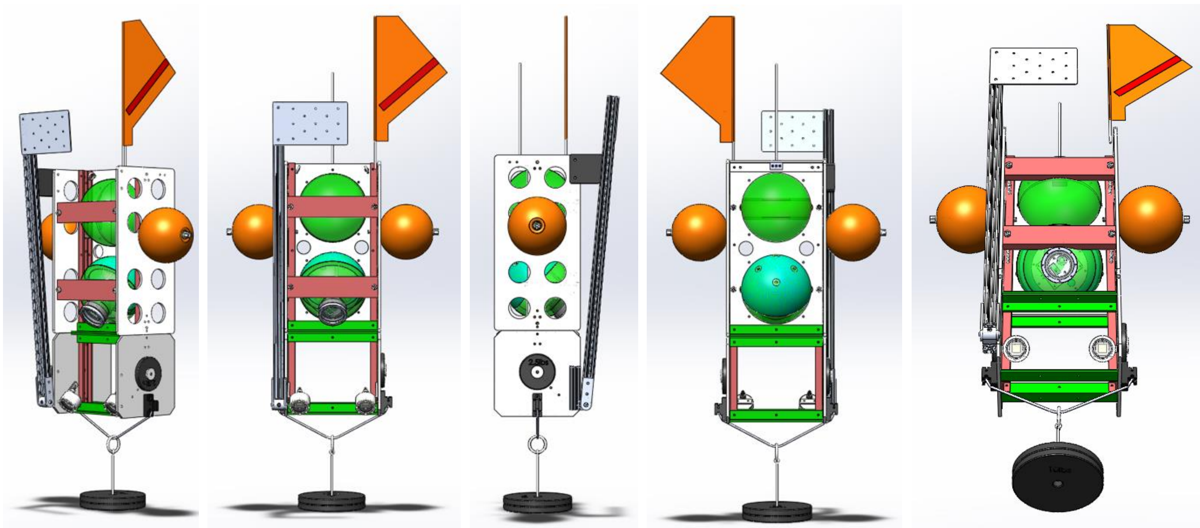


Figure 29: SolidWorks Assembly of DOV Seastang

Figure 30: Photo360 Render of DOV Seastang

Bait Release Subsystem

The final design selected for the bait release subsystem was nearly identical to the design discussed in the *Preliminary Design* section with a few minor changes. Primarily instead of the single drop arm with a bait cage at its end, we decided to change from a cage to a plate with holes. The purpose of these holes is to allow us to use string or zip ties to attach bait directly to the arm. This change was made after concerns were raised of large predators possibly getting frustrated by a cage blocking access to their food. We decided that we would rather risk the bait not lasting the entire dive time rather than have a large predator attempt to take the entire bait arm with it. We also added a rubber standoff plate at the top of the lander where the bait arm will rest in its descent position in order to hold the arm out at a slight angle. This is done to ensure the arm will fall forward after released at the sea floor.

The only other changes were to the materials selected for the arm itself and the release system. It was decided to make the bait arm out of low cost and pressure safe materials: an extruded aluminum T-slotted bar for the arm, 1/8" stainless-steel sheet for the bait plate, and aluminum T-slot hinge from McMaster-Carr used on the lower corner of the lander. For the release system, we did many tests and analysis as seen in the *Testing* section in *Chapter 6*. After these tests, we decided to use a candy melt release system due to its cost-effective nature and ease of procurement and travel. Specifically, we chose LifeSaver Mint Hard Candy Rings for our melt of choice since they passed our strength and dissolve tests while being made in a shape that is easy to attach to. The release system is attached with two pieces of rope. One connects the ring to the body of the lander and the other connects the arm to the ring. Once the ring dissolves, the arm falls forward to place the bait in view of the camera as seen in *Figure 30* below. For this design, both the stand-off plate and the T-slotted bar mount are attached to the lander frame with bolts through holes drilled in the side plates of the lander's frame. Additionally, the hinge and bait plate are designed to bold directly into these T-slot bars for flexibility of placement and ease of assembly. This design was selected due to its cost-effective achievement of being able to repeatably place bait in view of the lander's camera system for the full time at depth.

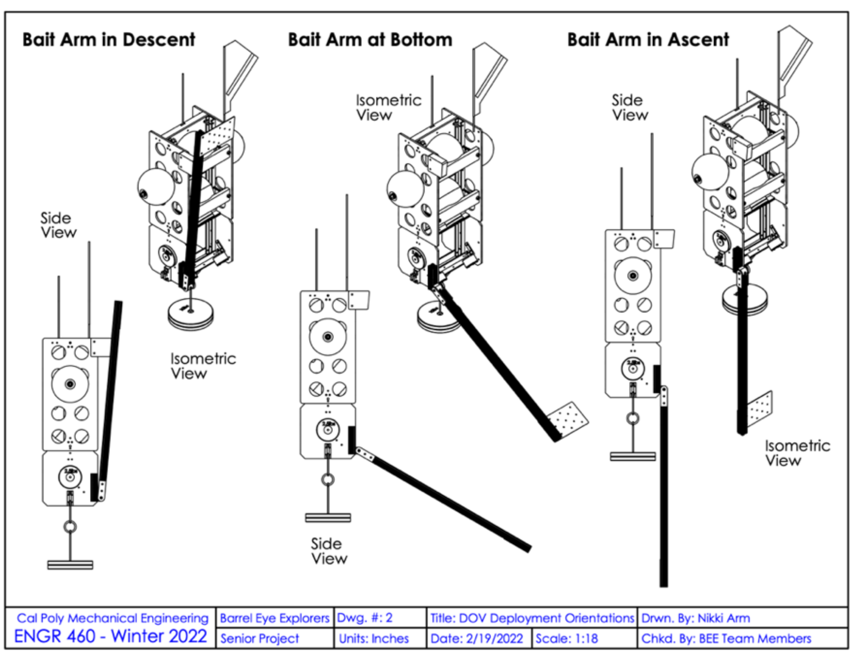


Figure 31: SolidWorks Drawing of Final Bait Release Arm Orientations

Camera/Housing Subsystem

The final design for the camera and housing subsystem is a modified pressure sphere with a GoPro Hero 4 action camera placed inside. This can be seen below in *Figures 31* and *32*. This housing has been donated to our team by Global Ocean Design. A vacuum is pulled on the sphere to seal the housing. Inside, the camera is pressure rated up to 2 kilometers, which meets our pressure rating requirement. The housing and acrylic viewport can be seen in *Figure 31* below. Detailed engineering drawings can be seen in *Appendix B*.

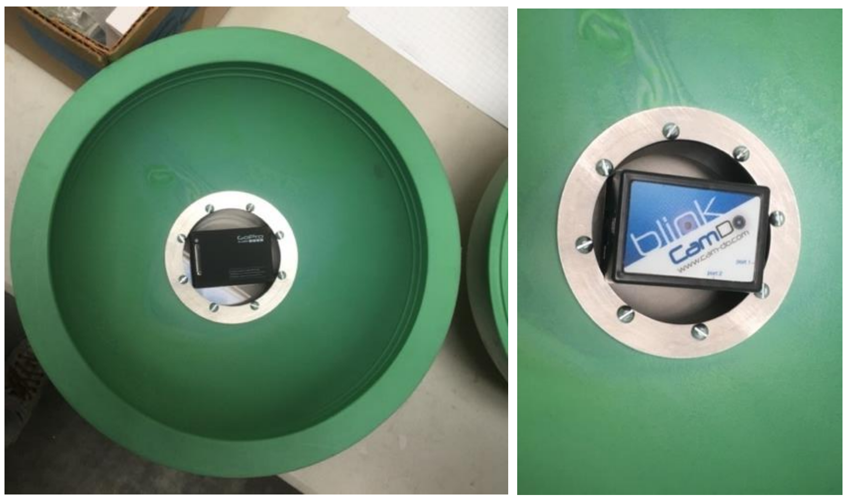


Figure 32: Camera and Camera Controller inside pressure sphere

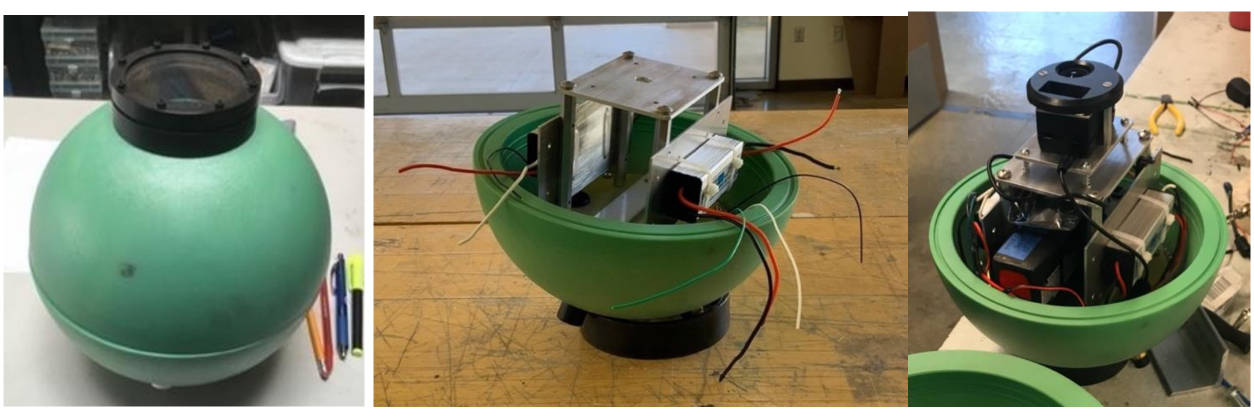


Figure 33: Pressure Sphere Housing with Viewport

The GoPro Hero 4 meets the filming requirements as it has the ability to record video in 4K at 60 FPS or 1080p at 120 FPS. It has a 60-minute battery which gives us a maximum depth time of 6 hours (if the CamDo is set to 10-minute intervals activated every hour). The battery is augmented by an external battery pack which allows us to have a total battery life of 6 hours. The camera and camera controller can be seen in *Figure 31* above. The pressure sphere also contains a housing for a 14.8 volt LiPo battery. This battery is used to power the lander's lights.

One of the most important aspects of this design is its compatibility with the current lander. As shown in *Figure 33*, the new housing is placed in between the bottom support beams. The camera has an unobstructed view of the bait arm and any wildlife attracted to it. The support beams are designed to be removed so that a pressure sphere can be placed between them. Once in place, the support beams are reattached to the lander.

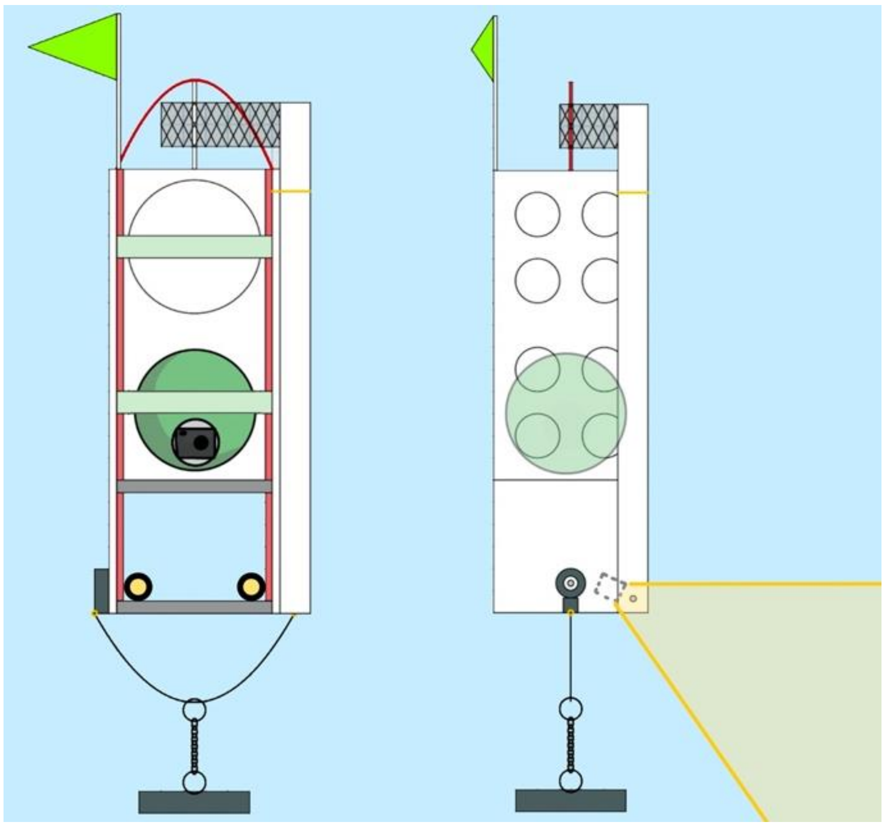


Figure 34: Sketch of Camera Housing Concept Implemented on Lander

Software

The only software used in this project will be a CamDo GoPro controller. This controller can be programed using a smart phone or computer to define recording intervals. This device can turn on the camera, recording a period of time, and turning the camera off when recording is finished. The controller can also be connected to the light subsystem for simultaneous activation. The schematic in *Figure 34* shows the connection between the camera, controller, and lights.

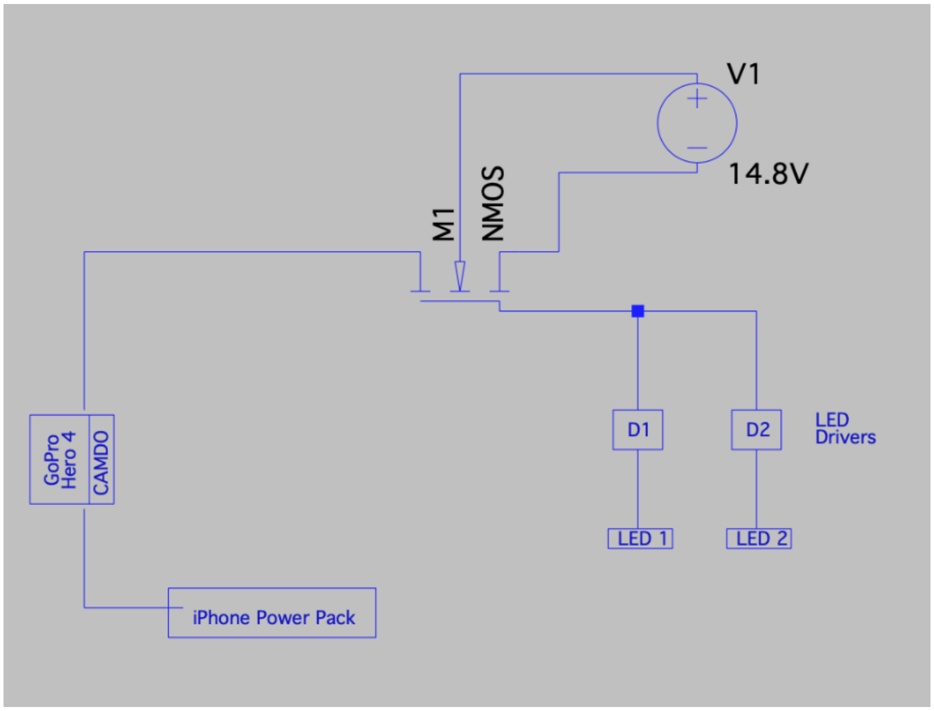


Figure 35: Schematic Detail Connection between Camera, Controller, and Lights

Lighting Subsystem

Our final design for the lighting subsystem is the two LED's donated by Global Ocean design and attached to the bottom of the lander as seen in *Figure 35*. The circuit for the LED's attached to the BMS and the batteries can be found in *Figure 36*.

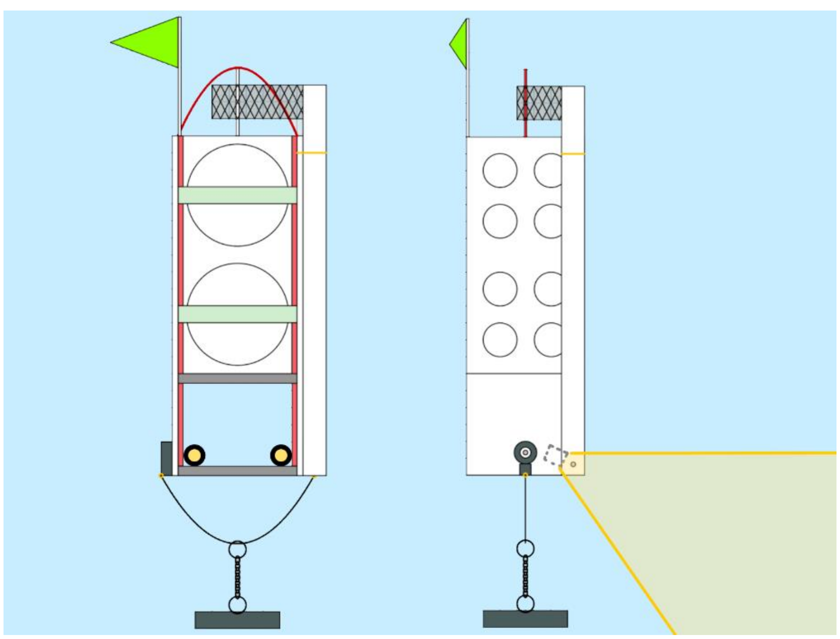


Figure 36: Final Design of Light Diagrams

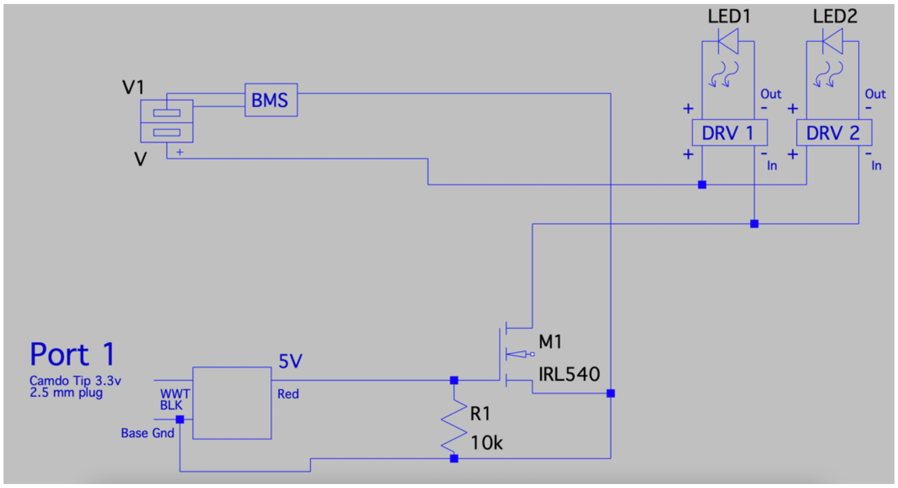


Figure 37: Lighting Subsystem Circuit Schematic

The lights are housed inside the lander as decided in our decision matrix. They are also attached to the lander at an angle to maximize the light pointing towards the camera's field of view. This also minimizes the illumination of marine snow or suspended particulates in the water column which can possibly reflect into the camera and blind us from seeing what's on the bottom. The lights are also connected to the CamDo as mentioned in the camera housing subsystem. This causes the lights to turn on and off with the camera in order to minimize battery usage and maximize bottom time possible. We used L-brackets to attach the lights to the lander at an angle such that the front face of the lights was close to parallel with the camera viewport. Due to the wide area which the lights illuminate, we found that the specific angle of light placement was not critical in sufficiently lighting our view field. Testing completed for the lights can be found in *Chapter 6*. The components for the lights that were donated can be seen getting assembled in *Figure 37* below.

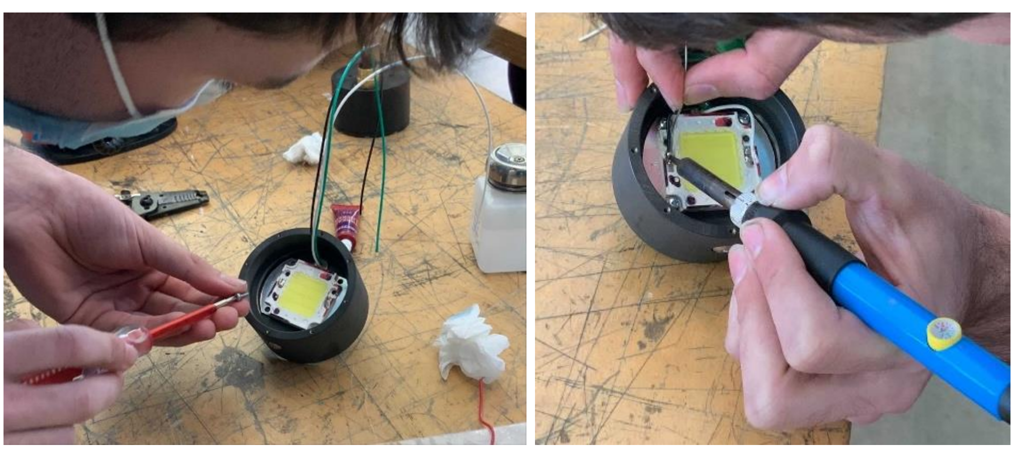


Figure 38: Light Assembly Process - Attaching the diode to the light housing (Left), Connecting the wires that will connect to the battery with soldering (Right)

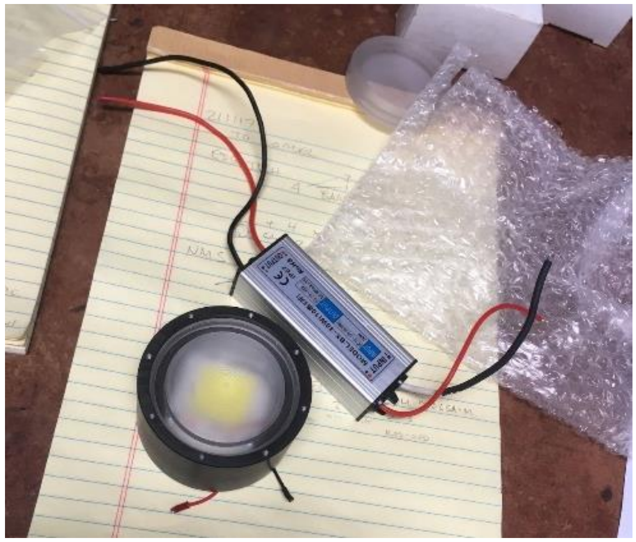


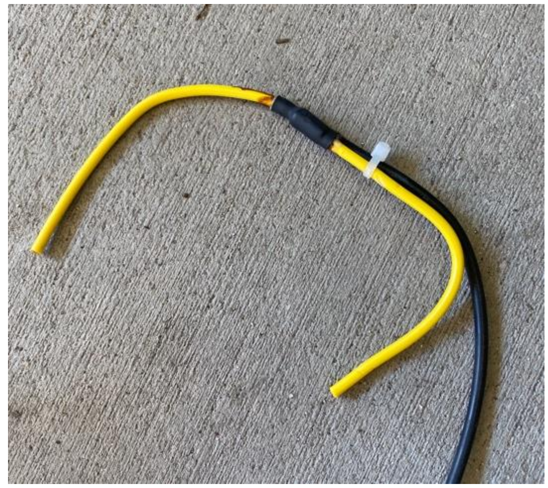
Figure 39: Light Assembly - LED components and battery back.

As seen in *Figure 38*, the completed light is filled with mineral oil in order for it to be pressure compliant. Mineral oil is used because it is non-conductive and won't interfere with the electronics.

This design meets all our design requirements. The lights can fully integrate with the existing lander, and as mentioned before, the materials have been donated by Global Ocean Design which is cost effective. They also have a minimum of 2,000 Lumens which meets our design specifications as well.

Buoyancy/Weight Subsystem

The lander must be able to travel on its own to the bottom of a specified area of ocean and then return after observing the environment. This means that the lander must sink at a reliable speed in order to accurately go to a landing area. At launch, the lander has additional weights (approximately 20lbs underwater) to make it considerably heavier than the water it displaces. The weights are made of iron to be dense enough to weigh the lander down but not pollute the ocean. However, if iron is not allowed by permitting services in a desired deployment zone, the weight material can be changed to sand or rocks in a natural sack. After a set amount of time, the weights need to be released, allowing the buoyant lander to return to the surface. To do this, there are timers which allow a voltage from a lithium battery to travel through an exposed steel cable (approximately 14 gauge). This voltage on the exposed steel will create electrolysis with the sea water, producing oxygen which will corrode the steel cable (see *Figure 39* below). The steel cable is looped around a chain connecting the weights to the lander so that when the cable corrodes away in approximately 15 minutes, it releases the weights and allows the lander to return. There are two of these steel cables or "burn wires" each timed to start corrosion about 25 minutes apart in case one wire fails to corrode.



Burn Wire before Electric Current After Current and Corrosion with Salt Water

Figure 40: Burn-Wires Before and After Use

This set up satisfies multiple project requirements. For one, it allows for the lander to be repeatable, the lander returns to the surface near where it was dropped and will be able to repeat the mission by just recharging the batteries and replacing weights and burn wires. Also, with the lander being naturally buoyant after the weights detach, the system can return to the surface and be safely recoverable. The lander should float with about 8 inches of the lander sticking out of the water to allow for an easy retrieval without having to dive in the water or have any special cranes to lift it. Lastly, the lander will be able to conduct tests for a desired amount of time at the bottom since the timers that trigger the battery can be set for any amount of time up to 4 days.

Sensors Subsystem

As briefly mentioned in the *Preliminary Design*, we decided to no longer include sensors in our final design. Although we did get a grant for $5,000, after consulting and getting quotes for many different sensors, it was apparent that we would not be able to find any within our budget range. Chris Malzone, VP of Sales Marketing at AML Oceanographic, was even willing to meet with us to discuss and demo some sensors in person. After discussion however, it was clear that one sensor would exceed $5,000, which would then leave nothing left over for bait arm materials and boat deployments for testing. After looking locally (within the US, Canada, and Mexico) we tried other companies overseas. The sensor shown in *Figure 21 in Chapter 3: Design Development*, was quoted at $3,118.53, and although we technically can afford this, it too would not leave much room in our budget for other materials and deployments. Before we had received the grant or were donated any of the materials for other subsystems, we discussed this dilemma with our sponsor Crow White and he expressed more of an interest in ensuring the lander functioned as a BRUV. He referred to the addition of sensors as simply “icing on the cake”. Because of this we changed the sensors from a “Want” to a “Would be Nice” and are now no longer in our plans for the lander.

Material Selection

Bait Arm

The bait arm structure uses a 6105 Aluminum Rod due to it high corrosion resistance in saltwater conditions. The aluminum also allows the arm to be slightly lighter than a steel version and supports our goal to make the lander easy to carry with two people. The bolts that hold the arm together are made of 818 stainless-steel because they are stronger than standard zinc bolts and have good corrosion resistance.

Weight/Buoyancy System

The current weights being tested and used are made of iron. Iron is not considered harmful to the ocean, but the requirement may change in certain deployment areas pending that locations’ permits. The goal for the weight material is to be dense and heavy in salt water and to do the least amount of harm when left in the ocean. The weight material may change to a more natural material such as stone or silica sand. The burn wires are another crucial aspect of the weight system and contain a small section of steel cable that is not insulated. The steel wire will corrode quickly when a current is passed through and shorted into the salt water. The resulting material is iron oxide that will flake away ultimately dropping the weights.

Lighting/Camera

The light housings are made of anodized aluminum to protect the electrical components inside from sea water and to prevent corrosion of the body over time. The aluminum housing is not strong enough to withstand pressures experienced by the lander so the hollow spaces inside are filled with mineral oil. The mineral oil is incompressible, so it protects the body from collapsing. Additionally, the oil is a dielectric, so it will not interfere with the electrical components inside.

Safety Considerations

A hazard checklist was used to determine hazards within the design and use of the lander (See *Appendix G* for complete *Safety Hazards Checklist*). Overall, the design does not contain many unsafe moving parts that can cause injury. The main hazard concern would be a pinch point where the bait arm rotates around its mount. Also, the design does undergo high deceleration when it lands on the sea floor. However, it will not create a safety hazard for people as no one would be near the lander when it hits the bottom of the ocean. Similarly, the lander itself is a large moving mass when in use. This is only a hazard when moving or transporting the lander but not during actual deployment as no one will be near it underwater. It is possible that the lander could fall under gravity and create injury so precautions must be taken, and the lander should only be stored on the ground and on level surfaces.

The electrical systems are not high voltage and are properly grounded while above water. Hazards would be present when the system is underwater and actively passing a voltage through exposed wires. However, no one will be near the lander when the voltage is passing through the water because it will be at the bottom of the ocean. Extra care must be taken to ensure that the electrical system is properly sealed and programmed to not have active power when the lander is placed in the water and people are around. During deployment of the lander, the user or users may have to exert force to lift and release the lander into the water. In order to mitigate risk, multiple users should work together to reduce the force exerted by the individuals. The overall material makeup of the lander is mostly non-hazardous, but the lithium batteries could pose a risk if exposed to humans. Proper inspection of the health of the batteries must be done before each use.

The system will be exposed to extreme conditions, the main one being high pressure. However, it is high external pressure which would not cause projectiles or harmful conditions if the system fails. Also, the system is only subjected to high pressures when it is far away from any people. Other potential hazards can be produced during testing and transportation of the system. Deploying the system with ropes for testing introduces more moving parts that can get tangled with a person or cause abrasive burns. Proper equipment like gloves and clear communication with equipment must be used. Lastly, the lander is designed to be deployed in the deep ocean so travel with a boat may be necessary. The ocean environment and travel can pose many risks to people involved so proper briefs and training must be implemented before ocean travel or work around the ocean such as pier tests.

Sustainability and Maintenance

Our design utilizes multiple aspects of sustainability in order to make the lander as beneficial as possible to the consumers and stakeholders. One main goal for the lander is to be reusable and repeatable. This goal is inherently sustainable as products that can be reused more with prolong the use phase and prevent end of life waste. Each part of the lander as well as the whole system was tested for reliability and designed to have a long lifetime. The only system of the lander that contains consumable items is the weight release system.

Currently, the weight system releases iron weights that are left on the ocean floor. Iron is not toxic or harmful to the ocean environment. In fact, many researchers believe that iron is beneficial as a nutrient to the ocean. The team looked into other options to iron as well which could be used as weight alternatives if environmental issues are discovered. Having to replace these weights after each deployment does add up material usage as well. The benefit of the weight release system is that it is versatile for multiple types of weights. Although iron weights are currently being used, the team compiled a list of other more sustainable weight options such as sand or rocks in a burlap sack. The only other consumables in the system are the burn wires which are small, braided steel wires. These wires do not use a lot of steel due to the small gauge and only use a small length for each deployment.

Additionally, much of the lander has parts that are modular. If a part malfunctions or is damaged, the user can replace the single part and not have to acquire a new lander. This will reduce the overall waste during the lifetime stage and increase the lander's lifetime. Many other landers have complex electrical or mechanical systems that are made individually and not designed to be repaired easily. The simplicity of our lander not only provides new opportunities for ocean research, but it creates a more sustainable product over its lifetime. Overall, the lander's long lifetime, reduced consumables, and modular system create a more sustainable system than many more complex landers.

Cost Breakdown

Unlike some interdisciplinary senior projects, this project does not have a monetary sponsor. We applied for two research grants (Baker-Koob Endowment Fund and CP Connect Grant) and were awarded a $5,000 from the Baker-Koob Endowment committee.

The majority of travel funds were planned to be used to travel to marine drop zones. We planned to use the Cal Poly boat, the TL Richards, which gets close to 1 mile per gallon to reach these areas. The cost of gas to get to and from the drop locations 20 miles offshore was estimated to cost close to $200 per trip. Unfortunately, due to scheduling difficulties with the Cal Poly boat, our team was only able to complete one boat deployment during the school year. However, the team still hopes to complete future boat deployments over summer or in later terms since Nikki Arm will be continuing work on the project as a part of her Masters Thesis next year. Other travel expenses we budgeted for include gas for our car to travel to testing sites such as the Cal Poly pier.

Cameras and their housings were specially made for dealing with extreme pressure. Some of the significant parts like a camera, housing, and lighting have been donated to us by Global Ocean Design, which significantly reduces our overall cost. We decided a sensor was not necessary for our mission. This decision saves money and allows the team to put funds towards necessary purchases. Additional parts for the lights subsystem were purchased from Ocean Innovations.

The bait release system plays a crucial role for the research of marine species. Data cannot be accurately gathered without marine life being attracted to the lander. The bait release system must function under extreme pressure for the duration of the mission. These systems had to be custom built for the lander and contained expensive hardware to ensure it functions reliably. Materials for the bait arm subsystem were purchased from

McMaster-Carr. A full breakdown of the project's initial budget is shown below in *Table 12*. A complete Bill of Materials with individual item costs can be found for our project in *Appendix C*.

Table 12: Project Budget Breakdown

	Amount	Notes
Subsystem Expenses		
Camera	$0	Donation
Lighting	$383.95	Ocean Innovations
Camera Housing	$0	Donation
Lander	$0	Donation
Boat	$0	Will use the Cal Poly Boat
Bait	$30	
Bait Arm Materials	$165.24	McMaster-Carr
Counterweights	$273.72	

Initial Total	$5,000
Total Spent	$822.91
Amount Left	$4,177.09

Chapter 5: Product Realization

Manufacturing Process

Manufacturing was only necessary for the bait arm, bait plate, burn wires, lead ballast weights, and the lighting system. The bait arm subsystem was manufactured by our team in Cal Poly's machine shops. The arm itself was made from a t-slotted framing rail. A 4 foot by 1.5" x 1.5" rail was purchased and received from McMaster-Carr. The rail was cut to 42 inches. A hole was cut in the lander's frame and the rail was bolted to another framing rail using a t-slotted framing bolt and inline pivot. The smaller rail used for the mount was cut to 6 inches. These cuts were performed on a horizontal bandsaw. The bait plate is a 10.5" x 6" plate fastened onto the end of the bait arm. This plate has a pattern of 13 holes with 1/4" diameters. Two holes with 0.328" diameters were also cut into the plate. These holes allow the plate to be connected to the arm using framing bolts. This plate was cut on the waterjet with holes cleaned up on drill presses as necessary. The bait release stand-off was a T-slot bolt attached to the bottom hinge slot to push the larger arm and prevent it from standing straight up.

Figure 41: Waterjet Cutting the Stainless-Steel Bait Plate

The lighting subsystem required minimal assembly which was performed by our team. The diodes in the housing were resoldered to ensure there is no fault in the connections. Mount holes for the lights were drilled into the lander plate using a drill press and mounted using ¾ inch stainless steel bolts. These mounts are "L" brackets that are each 3 inches in length. Detail drawings can be seen in *Appendix B*. The lights were then filled with mineral oil to combat the intense pressure changes they will experience. The system was connected to the battery using 1 foot, 20 AWG lead wires purchased from Ocean Innovations. These connections were secured using Micro Locking Sleeves which were placed around the male-to-female bulkhead connectors found on the light housings and in the pressure sphere where the battery is located.

Figure 42: Soldering LED Leads for the Light before Filling the Housing with Oil

Figure 43: Heating the Shrink Tubing for the CamDo and Light System

Prototype Differences from Design

Our final lander was almost identical to our final design plan. There were four primary differences we made to the design through the course of prototyping and testing. The first was that we removed the bait release stand-off from the design. This is because we found that we could place a bolt on the bar near the hinge attachment which would function as a stand-off instead. In addition to this solution being simpler and lower profile, it also allows for greater flexibly since adjusting how far the bolt is from the hinge allows us to fine tune the angle of stand-off for the bait arm. After attaching the bait arm to the lander, we found that the weight of the arm on the thin polypropylene was too much, causing the material to bend. To combat this, we added a support beam between the front corners of the lander made from spare t-slotted rail stock. This bar successfully stabilized the structure and allowed us to not worry about the instability in deployment or the side panels breaking. Next, during our buoyancy test, we found that the lander with the new camera sphere and bait arm was no longer naturally buoyant. To fix this, we attached two additional buoyancy spheres to the sides of the lander. These spheres are rated to a depth of 1200 meters which is a little under 4,000 feet. Lastly, while doing our night test off the Cal Poly Pier, one of our counterweights on the side of the lander broke. Because of this, we had to manufacture new counterweights. The original counterweights were made from 2.5 pounds of lead shot cast in a polyurethane matrix. Since this original design was too soft (causing the break during testing) we decided to make the new weights out of an epoxy/urethane hybrid to increase strength while still allowing for some flexibility due to the high-pressure environment. The manufacturing can be seen in the Figure 44 below.

Figure 44: Making counterweights from lead shot and epoxy/urethane

Additionally, we decided to make the weights only 2 pounds each in order to remove an extra pound of weight since our lander was still less buoyant than was ideal.

Recommendations for Future Manufacturing

Some of the parts for the prototype were manufactured using the tools and machines that were readily available and open in the Cal Poly machine shop. Other tools may be used to get the same finished product. For example, the holes in the bait plate did not need to have a high tolerance and therefore could be machined on a drill press instead of a waterjet. Additionally, the bait arm thickness could be reduced to lower the overall weight of the lander and make it lean less as it floats on the surface. The weights for the lander also just need to be dense and not harmful if left on the ocean floor. Different types of weights could be attached to the lander such as rocks in a burlap sack of concrete blocks with dense stones inside.

Other instruments could be used as well depending on the mission type. For example, specific sensors could be attached to the sides of the lander if certain environmental conditions are to be analyzed. Also, for longer tests where a timer and burn wire release would be difficult, acoustic releases could be implemented in the weight system where the burn wires were attached. A boat could then send a ping down to the lander at any point they want the lander to return to the surface instead of having a set time.

Lastly, if the lander is being used in conditions where there is an abundance of suspended particles in the water column, light hoods could be manufactured to lessen the vertical spread of light in front of the camera. The hoods can be made of plastic or noncorrosive metal that can be mounted to the rear holes of the light and then can bend to overhang the lights. The hoods would need to be strong enough to survive the currents and forces of the descent and landing as well as the return and boarding a boat.

Cost Estimation for Large Scale Production

Table 13: Cost Estimate to Produce a New Lander from Scratch

Description	**Value**
Picolander with payload bay, "DOV SEASTANG", less spheres	$7200*
underwater digital camera system with 2 LED lights and CamDo controller, with housing, rated 1.5 km	$5270*
Command Sphere with dual countdown timer release, with NiMH batteries, rated 2 km	$2200*
Vacuum Purge Unit	$1200*
Desiccant spares	$183*
SPOT Trace satellite beacon and mount (installed)	$185*
NiMH battery charger	$125*
LiPo Battery Charger	$57*
CBA III Pro Computerized Battery Analyzer	$255*
LiPo ESR (Equivalent Series Resistance) Meter, Mark II	$175*
Auxiliary Buoyancy (2 x 5.5-lbs), with mounts	$150*
Burn wires (10 ea @$75 each)	$750*
Burn wire spare parts to make additional burn wires	$150*
GoPro camera in 30m housing with mount for shallow water testing and evaluation imaging	$220*
manual and operations binder	$350*
SubConn 3 Contact, Male Micro Bulkhead Connector, Brass, 1 ft 20 AWG lead wire, 19mm TL	$69.70
SubConn 3 Contact, Female Micro Bulkhead Connector, Brass, 1 ft 20 AWG lead wire, 19mm TL	$79.35
SubConn 3 Contact, Male Micro Inline Connector on 2 ft. std. cable	$40.95
SubConn 3 Contact, Female Micro Inline Connector on 2 ft. std. cable	$44.40
Subconn Micro Locking Sleeve - Female	$13.15
T-Slotted Framing, 4'	$42.64
T-Slotted Framing, End-Feed Nut, Button Head, 4 5/16"-18 Thread, Stainless Steel, Packs of 4	$5.80
T-Slotted Framing, Inline Pivot for 1-1/2" Single 1 Rail	$24.32
18-8 Stainless Steel Button Head Hex Drive 1 Screw, 5/16"-18 Thread Size, 3/4" Long, Pack of 25	$8.26
Total	**$18,798.57**

It is important to note that much of the materials in this project were donated to the team. In *Table 13* above, the items with asterisks are price estimations received from Global Ocean Design. To obtain a real estimate, many other factors would need to be considered. This is due to the large quantity of custom parts used while constructing the lander.

Chapter 6: Design Verification

Testing

We tested each of the individual subsystems separately and then all together. Testing was performed on land as well as in the water. To get a basic understanding of how our final prototypes work together, we conducted a few dry land tests. The official list of tests with descriptions and testing dates can be found in *Appendix H*. For all the procedures and detailed results of completed tests, see *Appendices I*.

Timed Weight Release

<u>Description:</u>

The purpose of this test was to ensure that the burn wires function properly and that the base lander is waterproof. This test was completed towards the start of the Fall Quarter in 2021. The material needed for this test were the base lander and new burn wires. Ropes (2) were also needed. One was attached to the weights, and another was attached to the lander itself for easy retrieval. Also, a conductive fluid (preferably seawater) that the lander can be fully submerged below the surface is required to complete the test. To pass this test, the lander had to be deployed, submerged, and successfully return to the surface with no help from rope.

<u>Results:</u>

This test was successful. Burn wires went off, and the lander successfully resurfaced. It is notable that the wires did not break within the planned time, and so the backup burn wires were also undergoing electrolysis. We hypothesize that this is because the salinity was lower than average that day. This hypothesis is supported by the fact that a marine biology class was at the pier the same day and mentioned getting very low readings for the pier water’s salinity. *Appendix I1* has the procedure and detailed result analysis.

LifeSavers Tensile Test

<u>Description:</u>

The purpose of this was to test the tensile strength of lifesavers. This test was performed in the middle of the Winter Quarter. The materials needed for this test were two thin pieces of wood 1.5in x 5 in x ¼ in with a small hole drilled at the end of each, 10-gauge steel wire, a Instron tensile test machine, and the different LifeSavers that need testing. To pass this test, the LifeSavers need to withstand 10 lbs of tensile force.

Results:

This test was also successful. Different flavors of LifeSavers were tested and all turned out with approximately similar results. In *Figure 43*, we can see the resulting output of the machine for one of the tests.

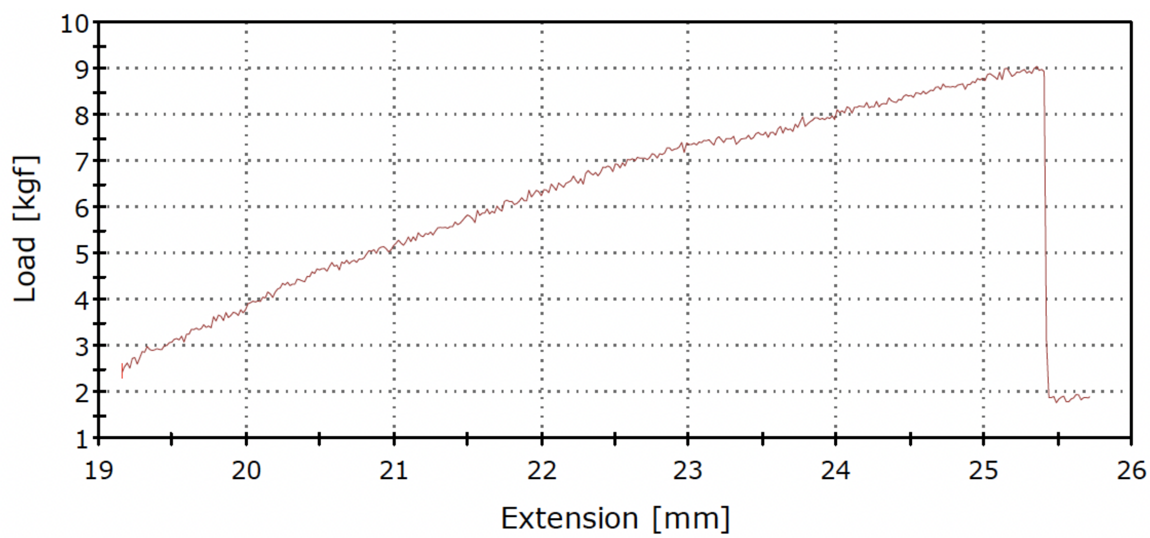


Figure 45: LifeSaver Tensile Strength (Load [kgf] vs. Extension [mm])

From this graph (and the graphs of the other test samples), we concluded that the average tensile strength for LifeSavers was about 14.33 lbs. For procedure and detailed results, see *Appendix I2*.

LifeSavers Dissolution: Stagnant Sea Water

Description:

The purpose of this was to test the time it takes for a lifesaver to dissolve. This test was performed at the middle of the Winter Quarter. The materials needed for this test were a bucket, sea water, 2.5 ft wooden dowel rod, weight varying between 1 and 3 lbs, rope, 10-gauge steel wire, timer/stopwatch, and finally the LifeSavers flavors that need to be tested. For this test to be successful, the lifesaver needed to hold at least 1 lb (or more) and hold for at least 10 minutes.

Results:

All the LifeSavers tested passed this test. Multiple tests were performed, and a graph (*Figure 44*) was made from the results.

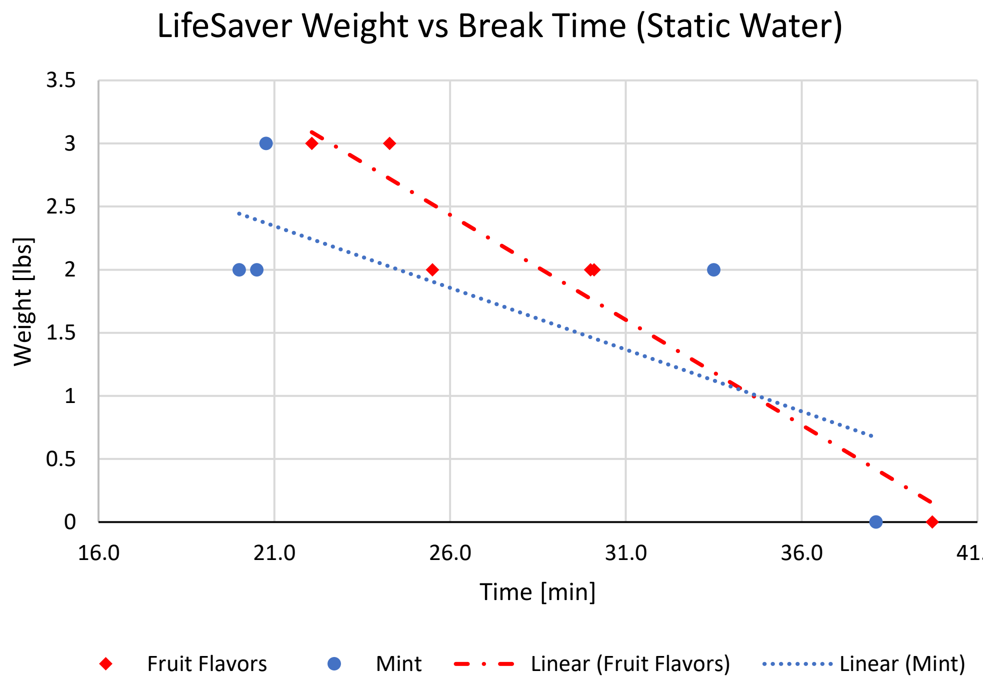


Figure 46: How Long it took for each LifeSaver to Break (x axis) vs How much Weight was being Held (y-axis) of Mint and Fruit LifeSavers in Stagnant Water.

We notice a trend that with increasing amount of weight, the amount of time it takes for each LifeSaver to break is decreased. We then considered the effect of flowing water on these LifeSavers, because during deployment, the lander will have water flowing past it during descent. This concept was then tested in our next verification test. For procedure and detailed results of the stagnant water dissolution test, see *Appendix* I3.

LifeSavers Dissolution: Flowing Sea Water

<u>Description:</u>

The purpose of this was to test the time it takes for a LifeSaver to dissolve in moving water. This test was performed in the middle of the Winter Quarter. The materials needed for this test were a cooler, a cement block, a hose that supplies ocean water, a 2.5 ft wooden dowel rod, weights varying from 1 to 3 lbs, rope, 10-gauge steel wire, timer/stopwatch, and finally the LifeSaver flavors that need to be tested. For this test to be successful, the LifeSaver needs to hold at least 1 lb (or more) and hold for at least 10 minutes.

<u>Results:</u>

The results of these tests can be seen in the following *Figure 45*. Another trend is also observed, similar to the stagnant water: as the amount of weight applied to each LifeSaver increases, the amount of time it takes for each LifeSaver to break decreases.

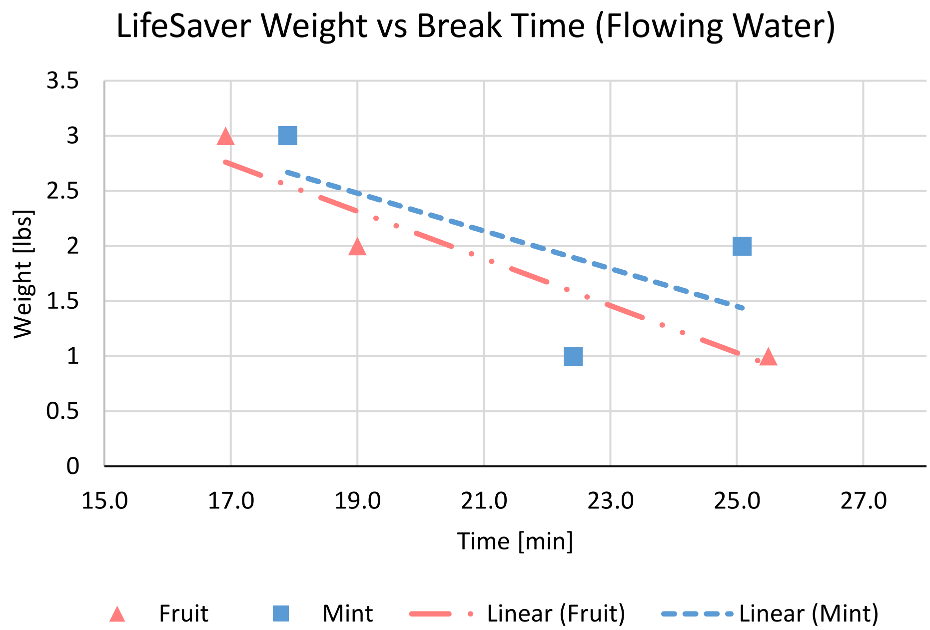


Figure 47: How Long it took for each LifeSaver to Break (x axis) vs How much Weight was being Held (y-axis) of Mint and Fruit LifeSavers in Flowing Water.

It is also notable that the overall amount of time it takes for each LifeSaver to break decreases when changed from flowing to stagnant water. The results for both combined tests can be seen in *Figure 46*.

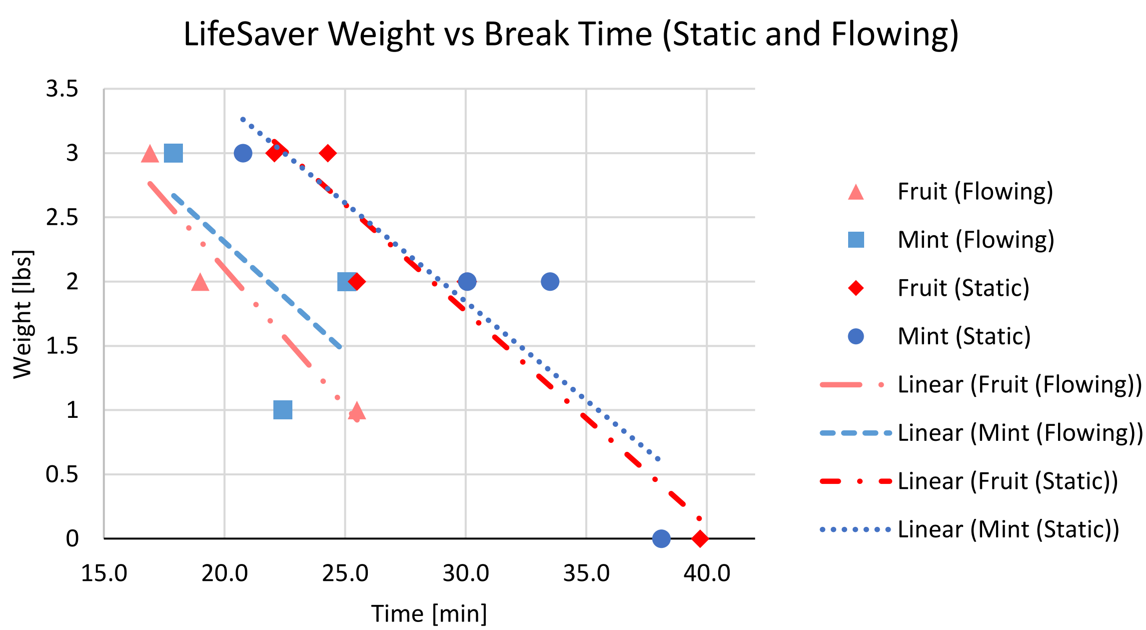


Figure 48: Comparing the Static and Flowing Test Results

All together, we can see that the break time for each LifeSaver type (mint or fruit) is about the same regardless of the conditions they are put in. What does change is the amount of time it takes for each LifeSaver to break. In flowing water, it takes less time than in stagnant water. It is noticeable that the stagnant water was flowing relatively slowly compared to the actual conditions the LifeSaver will be placed in. We are confident that the LifeSaver will still be able to work for our application. For procedure and detailed results, see *Appendix I4*.

Camera and CamDo Compatibility

Description:

This test was to make sure all the software for the CamDo and GoPro camera are properly updated, and work compatibly. At least two tests were done for this: one to make sure the software, camera, and CamDo work together properly, and another to test the longevity of the setup. The materials needed for this test were the Camera, CamDo, and device to connect to the CamDo. In order to pass this test, the camera must operate on the set program. For the first scenario, it must take an image every thirty seconds, over a span of 3 minutes. For the second scenario, it must take a video 5 minutes in length, every 10 minutes for the length of an hour and a half.

Results:

The system passed both the first and second test. During the first test, the camera successfully took pictures every 30 seconds for a span of 3 minutes and a total of 6 images. For the second test, the lights activated, and the camera took a 5-minute video every 10 minutes for a total of 45 minutes of video. A version of this test was repeated before every full system test deployment to ensure the camera system would work properly when the lander was deployed.

Lights, Camera, CamDo!

Description:

This test aimed to check compatibility of the lights with the camera system. The CamDo has a port that allows the lights to be activated at the same time as the camera. To be successful, the lights and camera must turn on and off at the same time.

Results:

On the first attempt, the system failed this test. After doing some investigating, we realized the connector cable for the lights had a faulty internal connection. Once this component was replaced, we conducted this test again. On the second test, the system operated as designed.

Camera Field of View

Description:

This test analyzed whether the GoPro camera was able to capture a clear and full view of the bait from all possible positions the bait arm can end up in. The test was conducted on land and involved some assumptions of the sea floor topography which could affect the way the arm rests on the floor. The camera view in its fixture was adjusted to maintain the best and most versatile view of the bait arm after this test is conducted.

Results:

The GoPro passed this test and provided a sufficient field of view. This test was first conducted manually on land. The test was then additionally verified during our full system test at the pier. The bait arm deployed directly into the camera's field of view. The cross supports for the lander hold the camera housing in position so that the bait arm is always in view during deployment.

Light Angle and Lander Compatibility

Description:

The purpose of this test was to ensure that mounting angle of the lights would maximize the light pointed towards the camera's field of view. This was also to ensure that the amount of "flood" light is minimized in front of the camera's lens to minimize particulate reflection back into the camera. To do this, we placed the lights in a dark room against a flat vertical surface (wall) and measured the angle coming out of the light when they are turned on using a protractor. To pass this test, the angle of the light must be greater than 20 degrees because less would not illuminate enough of the sea floor, and less than or equal to 90 degrees because more would flood too much light into the water column, illuminating marine snow and possibly leaving us blind.

Results:

The system failed this test. Though the angle of light is greater than 20 degrees, it is much more than 90 degrees. At 160 degrees, the light angle is much larger than we had anticipated. This proved to be both good and bad for bottom visibility. We decided that the best way to eliminate the flooding of light in the water column would be to add hoods to the lights instead of finding new lights. This will maximize the amount of light flooding the bottom and should minimize the light in the water column reflecting on the marine snow. We later tested the full system without adding hoods to the lights due to manufacturing delays and found that the wide-angle flood lights had less effect on light reflected by the marine snow than we had anticipated. Therefore, it was decided that we did not need to manufacture the hoods in time for full deployment and instead would be added to the list for future recommendations.

Night Test

Description:

The purpose of this test was to mimic the pitch-black conditions at extreme ocean depths and analyze the ability of the light and camera combination. Our goal during these tests was to ensure the bait arm, burn wire, buoyancy, light, and camera systems work properly. The bait arm needed to drop to the sea floor when the lander reached the bottom. If the weight system is malfunctioning, the lander will not sink to the bottom. The camera/light systems, which operated on a timer system, needed to turn on, record, and turn off properly to pass this testing phase. To return to the surface, the burn wires needed to properly corrode and drop the weights. This test was performed at the Cal Poly pier to closely emulate the conditions of deep-water testing. Conducting this test at night more closely resembled the lack of light at depths of 2,000 feet or more without having to travel to those depths. Data was collected with the camera on the ocean floor at the Cal Poly Pier and analyzed to see if the lights provide enough light and did not distort the colors with no other light source. Passing criteria for this test was if the lights illuminate the full field of view of the camera and each subsystem works as designed.

Results:

This test passed all conditions. The lights perfectly illuminated the bottom of the ocean and in view of the camera. It is notable that there was high turbidity that night. Because of this large amount sediment in the water column, it was difficult to see anything. This was deemed as not going to be problematic for our future application because we were still within the mixed layer of the ocean and knew visibility would be affected by marine snow more significantly at actual deployment depths than suspended sand like we saw on this night test.

Buoyancy Tests

Description:

The purpose of the test was to ensure the lander floats out of the water without extra weights and that it is oriented correctly when floating. The lander must float approximately 8 inches out of the water when the weights are released to be seen and collected from a boat. Also, the lander must float in an upright position for the visibility flag to be out of the water and for ease of collection. The first test with all lander components attached was conducted off the Cal Poly pier. This was done by dropping lander (without weights) into the ocean and observing how it floats. If the test was unsuccessful, extra buoyancy balls or weights were added in specific location to correct the way it floated.

Results:

Initially, the test without the additional buoyancy spheres was unsuccessful - the lander was negatively buoyant and began to sink. Once the buoyancy spheres were added, it floated out of the water enough to pass the test, though just barely. It is notable that this test is essential to perform before every deployment and after any changes are made to the lander.

Full System Test (FST) on Boat with Backup Line

Description:

Final testing took place on the Cal Poly boat. The lander was attached to a line on the boat in a way that allowed it to float back to the surface once the burn wires corroded. The line provided a fail safe for the lander if the burn wires did not corrode correctly and we would be able to haul the lander back up to the surface. This phase of testing was the first real pressure test for the lander's hardware. This deployment took place at a depth of approximately 200ft.

Results:

This deployment was a success! We had minor user error during set up where we forgot, to plug in the battery for the lights. Thankfully, we noticed this on the boat prior to deployment and had prepared, bringing the necessary tools to open the lander, diagnose and fix the problem, and reassemble the device with only a 10-minute delay to our lander launch time. Once in the water the deployment went perfectly: the bait arm deployed immediately after landing on the sea floor, the camera and lights turned on/off in synch and on our desired schedule, the burn wire went off on time and took the expected time to burn, and the lander floated on the surface at a height which was easy to recover. Additionally, our research mission was very successful - seeing numerous creatures at depth (lured by our squid bait). We saw many flounders, a few sea stars, three octopi, a large crab, and even a chimera. Below are videos of our deployment that Kyle put together.

Highlights Reel: https://youtu.be/v46f98DyfGI

Full Length Videos: https://youtube.com/playlist?list=PLuk_hd8AUuSN-A1yM4HbZvQGju5kJxz_-

*Specificati*on Verification

Below Table 14 depicts our projects design requirements, risks, compliance, and testing verification proving it's success.

Table 14: Specification Verification Table

Spec #	Parameter Design	Requirement of Target	Tolerance	Risk	Compliance	Relevant Testing
1	Vehicle Pressure Rating	130 ATM	Min	H	A, T, S	FST (Pier, Boat)
2	Electronics Pressure Rating	0.1 ATM	Min	H	A, T	FST (Pier, Boat)
3	Video Clarity	1080p 30fps	Min	M	A, T	Lights, Camera, Camdo
4	Size	40 in	±5	M	A, I	N/A
5	Weight	90 Lbs.	Max	L	T, I	Buoyancy Test
6	Cost	$5000	Max	M	A	N/A
7	Salinity Sensing	0-50ppt	±10	L	A, S	N/A
8	Depth Sensing	0-4200 ft	±10	L	A, S	N/A
9	Temperature Sensing	0-65°F	±1	L	A, S	N/A
10	Time Bait Lasts	120 hours	Max	M	A, T, S	FST (Pier, Boat)
11	Time of Weight Release	120 hours	Max	H	A, T, S	Timed Weight Release
12	Float Height	12 in	±2	M	T, S	FST (Pier, Boat)
13	Reuses	100	Min	H	A, S	N/A
14	Weight Material	Does not harm ocean life	Min	M	A, I	N/A

Chapter 7: CONCLUSIONS & RECOMMENDATIONS

Ultimately, the lander design and tests showed that most of the design requirements were met and the project was successful overall. The team was able to work effectively over the year, and the sponsor and associated professors and stakeholders were satisfied and enjoyed the work. Currently, the lander is showing successful results and has been successful but there is still opportunity for additional work.

Further testing is needed to ensure the lander can function as design at the conditions necessary. Deeper tests with a winch or backup line are recommended to ensure the lander returns if there is a malfunction. Additionally, a full system deployment without the backup line can be tested if preceding tests are successful. The lander can be lowered in the water and allowed to autonomously lower to the ocean floor at a depth of up to 4,000 feet. After the preset timer goes off, the lander should return to the surface and can be retrieved by a crew.

Additionally, team member Nikki Arm will be continuing to work with Dr. Crow White on DOV Seastang next year as a part of her Master's Thesis. She will be designing and testing composite pressure spheres as possible alternatives to the existing plastic and glass models. She will be comparing cost, depth rating, buoyancy, durability, and other critical criteria to determine whether composites could provide comparable or improved possibilities for deep sea vehicles.

Chapter 8: ACKNOWLEDGEMENTS

The Barrel Eye Explorers would like to give a special thanks to Karla Carichner (Project Advisor), Dr. Crow White (Marine Science Professor + Sponsor), Kevin Hardy of Global Ocean Design (Financial Sponsor), Jason Felton & Tom Moylan (Cal Poly Pier & Boat Management), and Dr. Jim Widmann, Dr. Lily Laiho, & Dr. Vladimir Prodanav (Interdisciplinary Senior Project Advisors)!

This project would not have been possible without your help, guidance, and contributions!

Chapter 9: REFERENCES

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APPENDICES

A. Customer Requirements

List of Needs (Required)

- Depth to 1,000ft
- Ability to take video
- Cost effective
- Bait/Lure
- Return to surface
- Safely recoverable
- Anchor weights don't harm the sea floor
- System is repeatable
- Ability for 1 or 2 people to carry it
- Up to 6hr of Bottom Time

List of Wants (Highly Preferred)

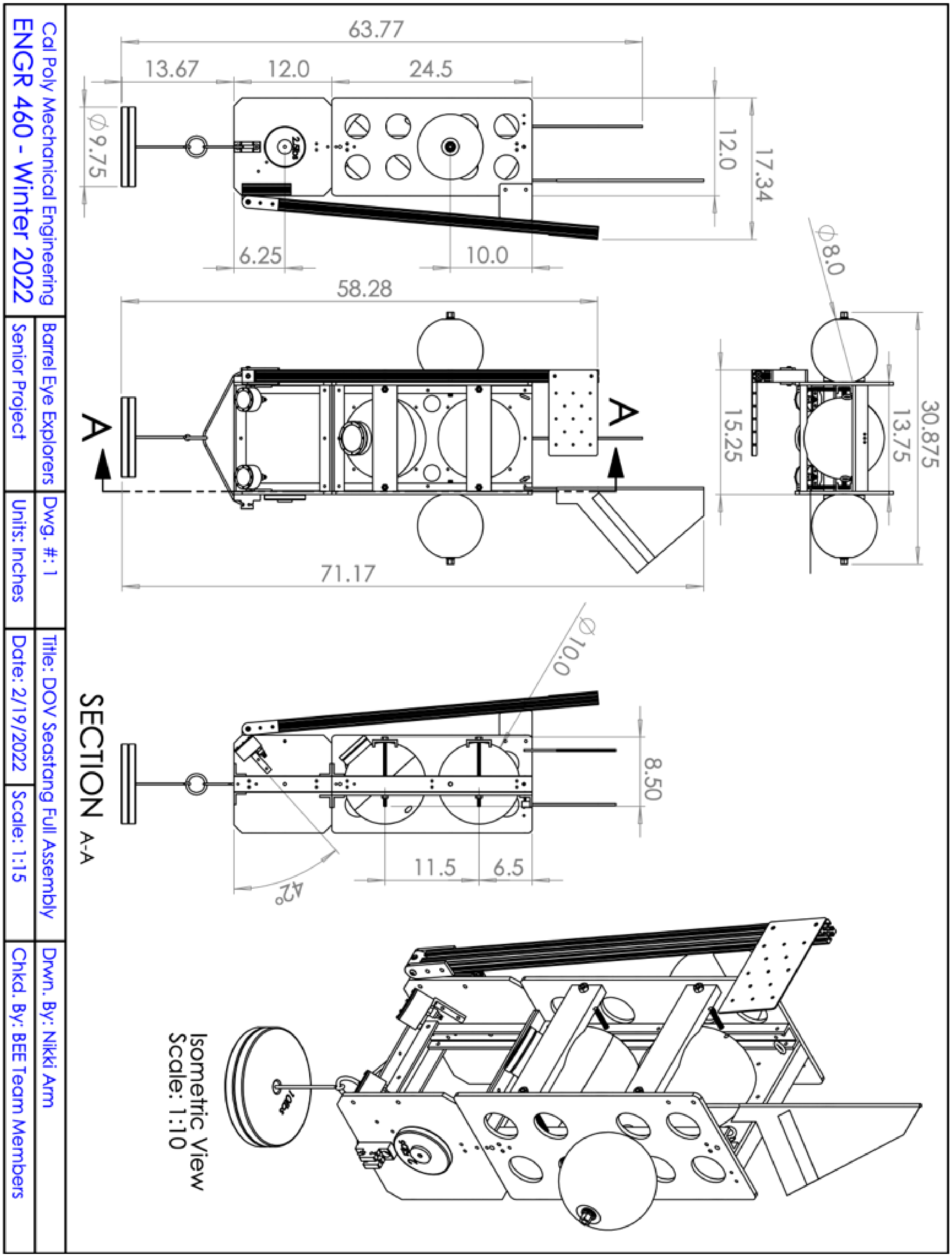
- Depth to 4,200ft
- Pressure/depth sensor
- Temperature sensor
- Salinity sensor

List of Likes (Would be Nice)

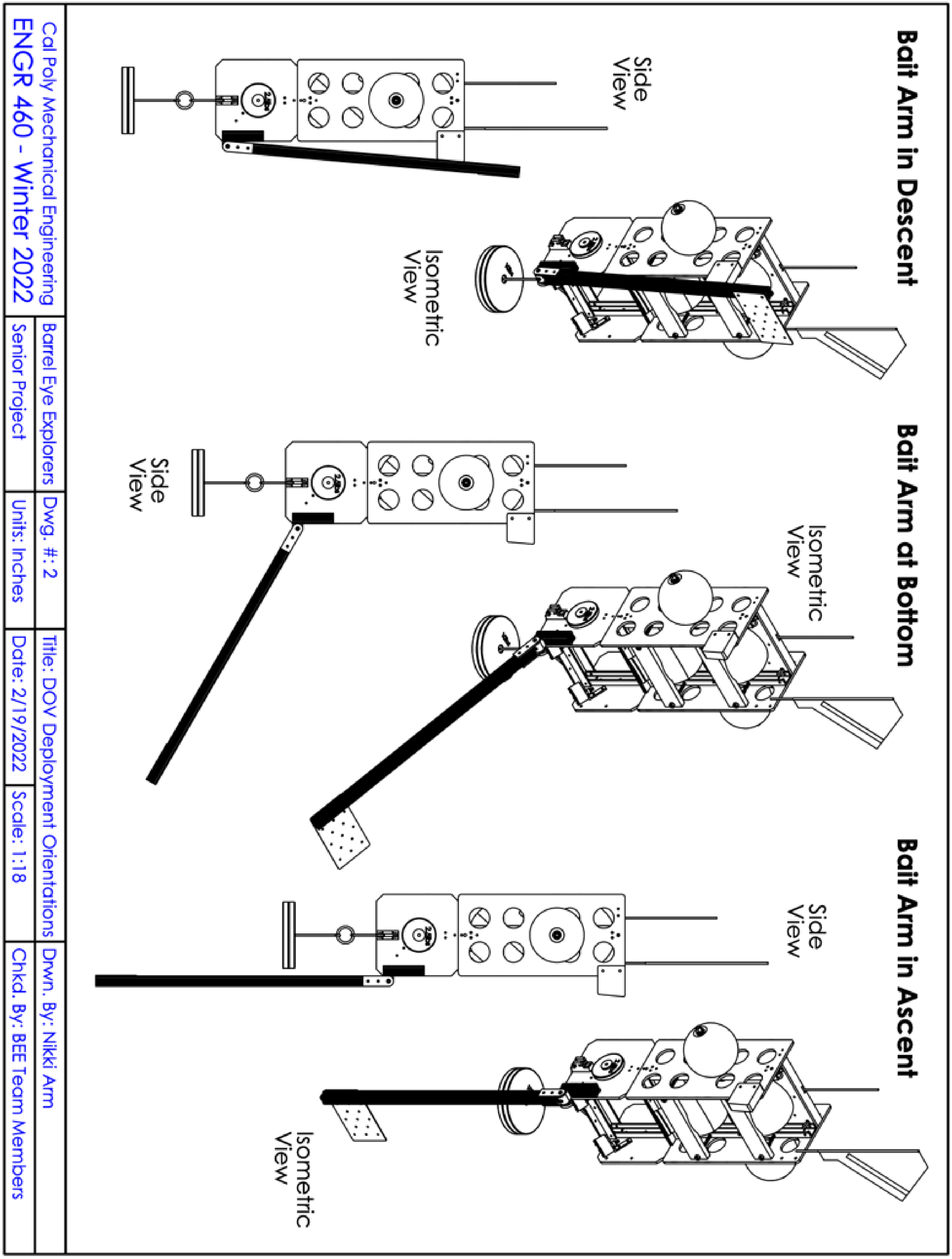
- Sediment samples

B. Final Drawings

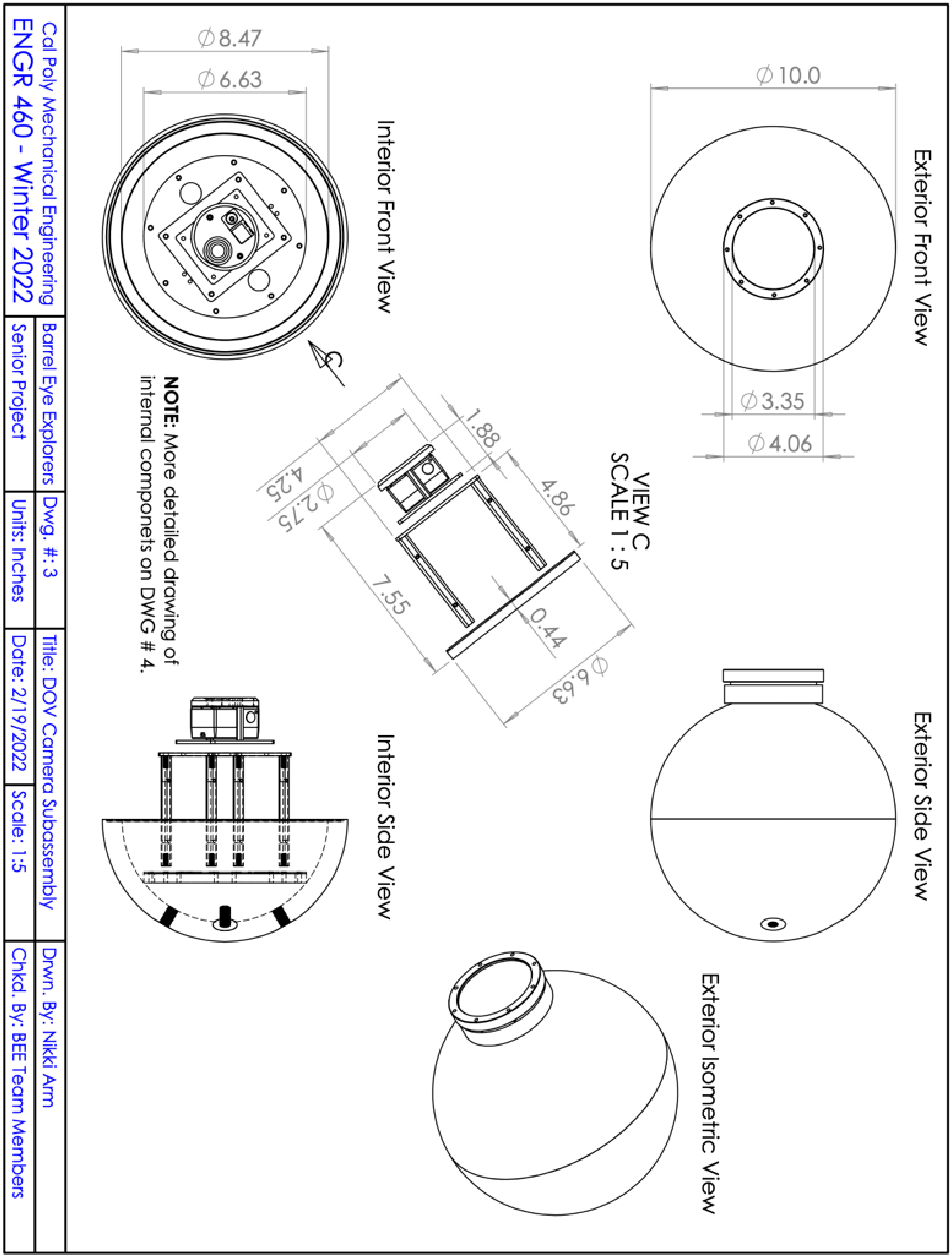
Drawing 1: DOV Seastang Full Assembly



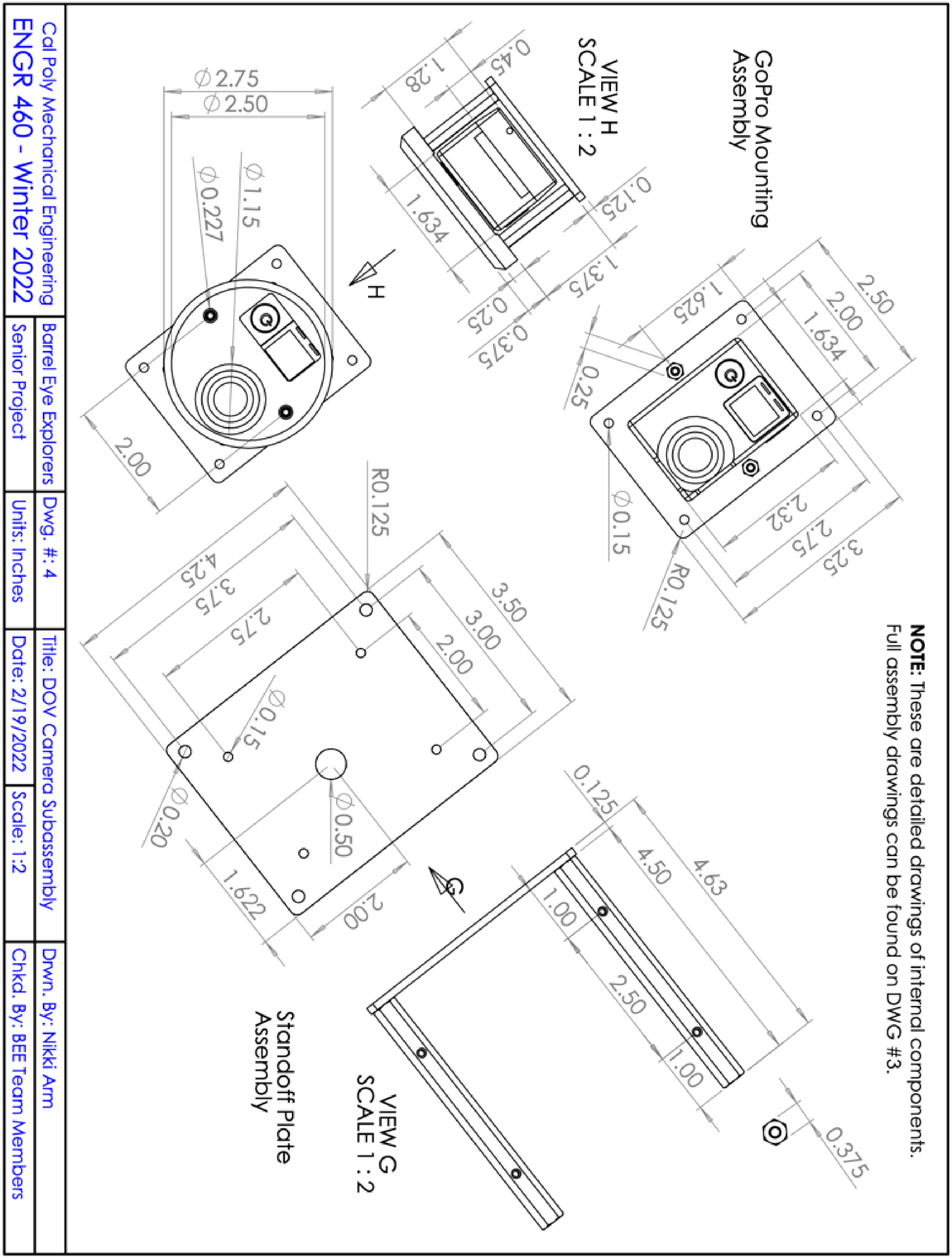
Drawing 2: DOV Deployment Orientations



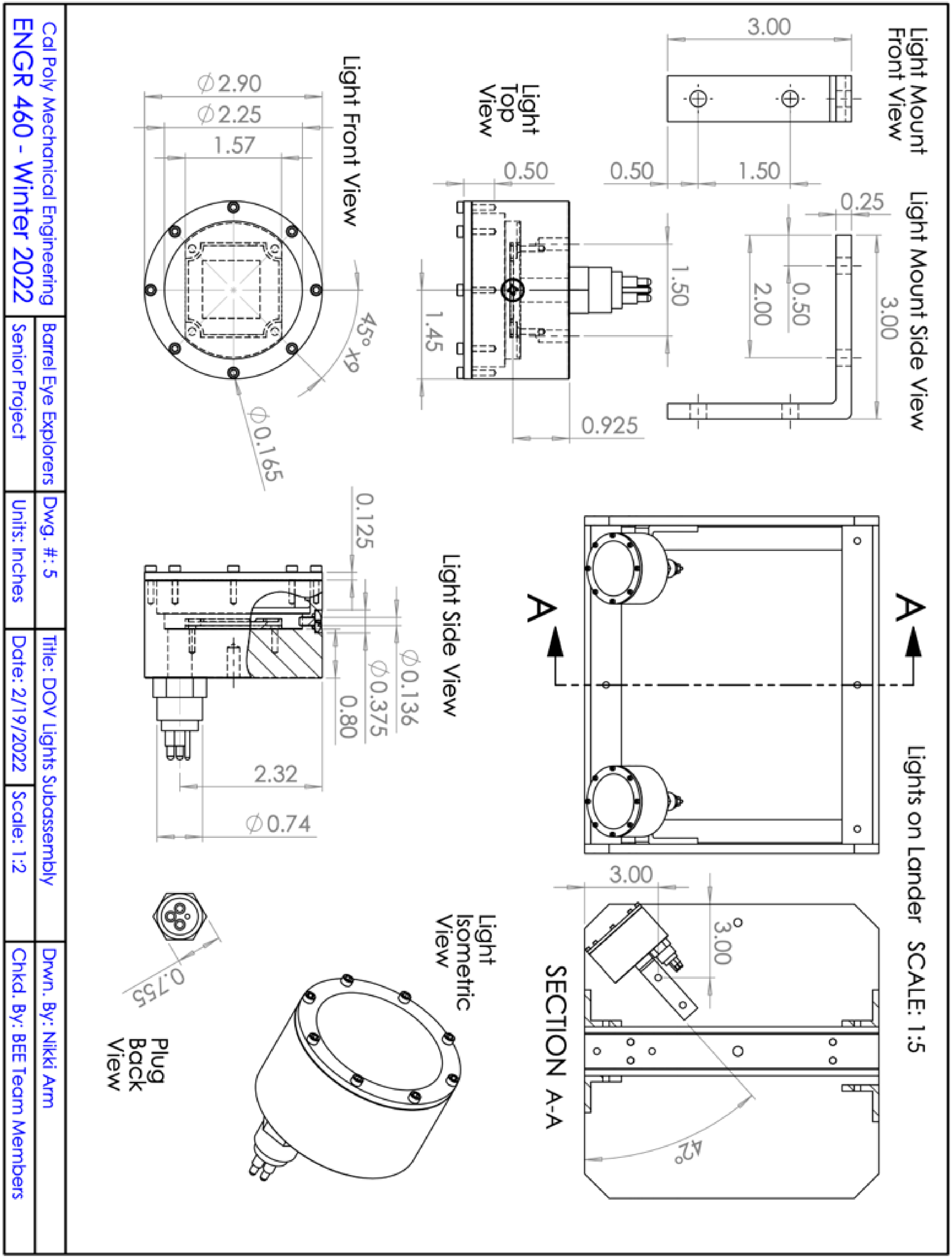
Drawing 3: DOV Camera Subassembly – Full



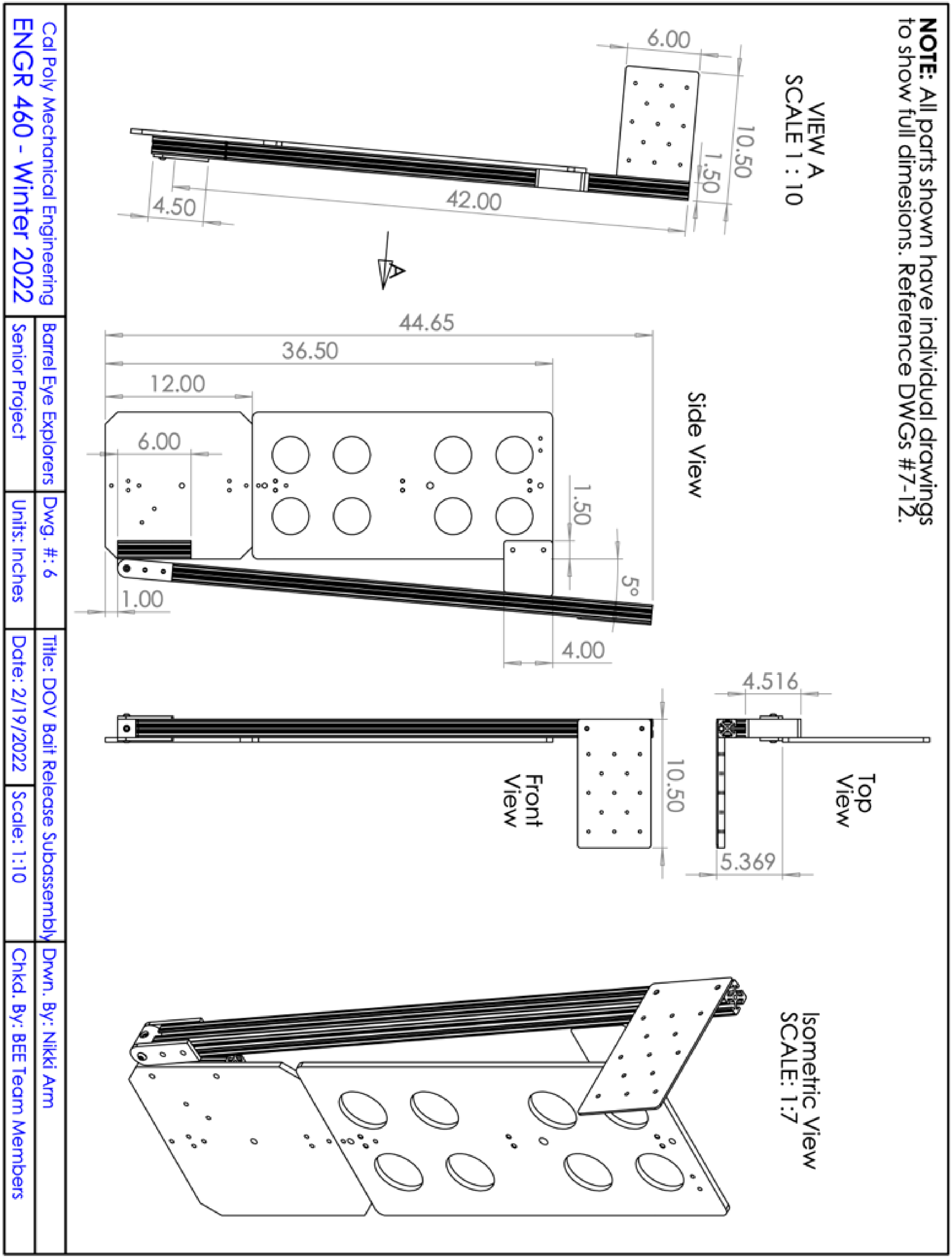
Drawing 4: DOV Camera Subassembly – Detailed



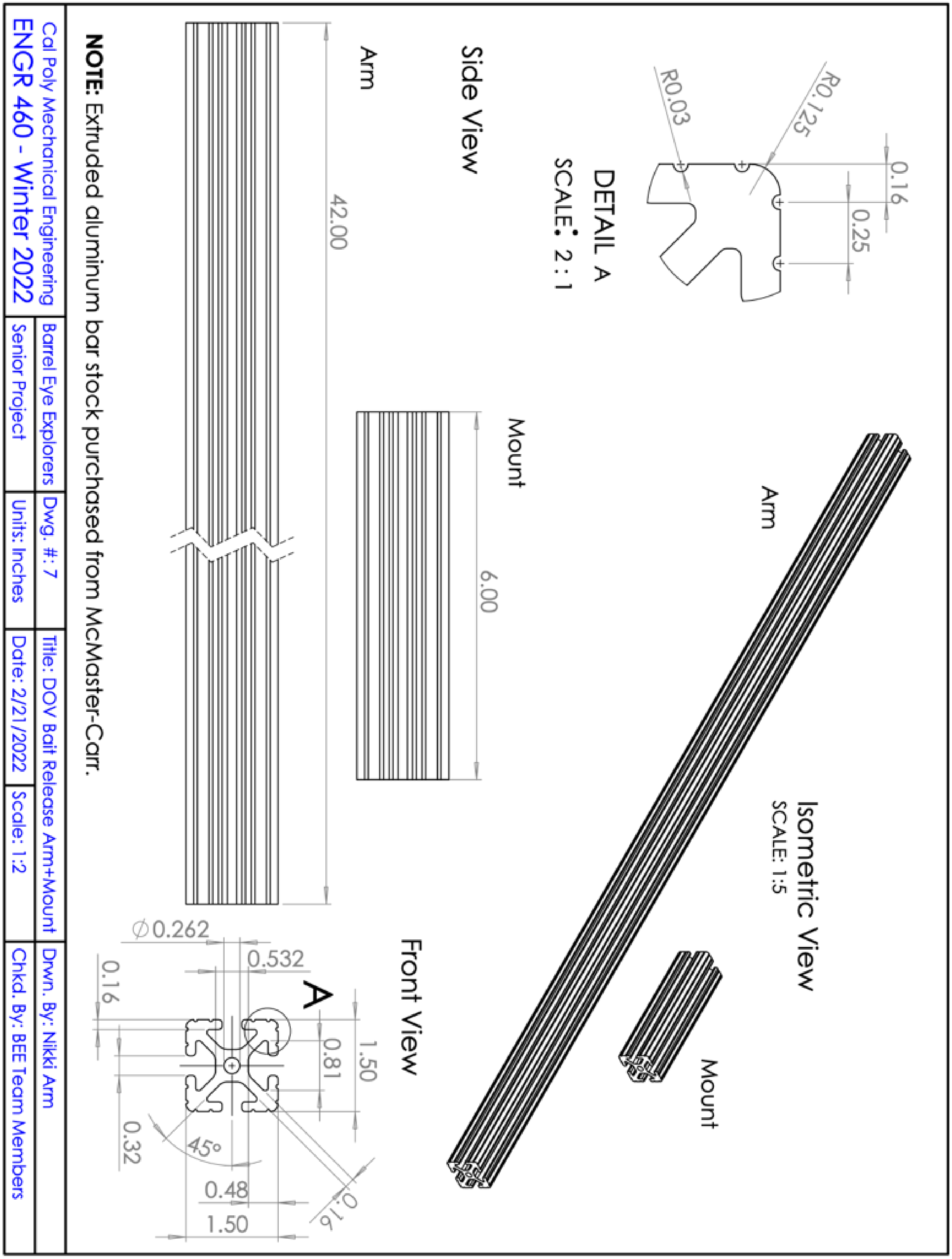
Drawing 5: DOV Lights Subassembly



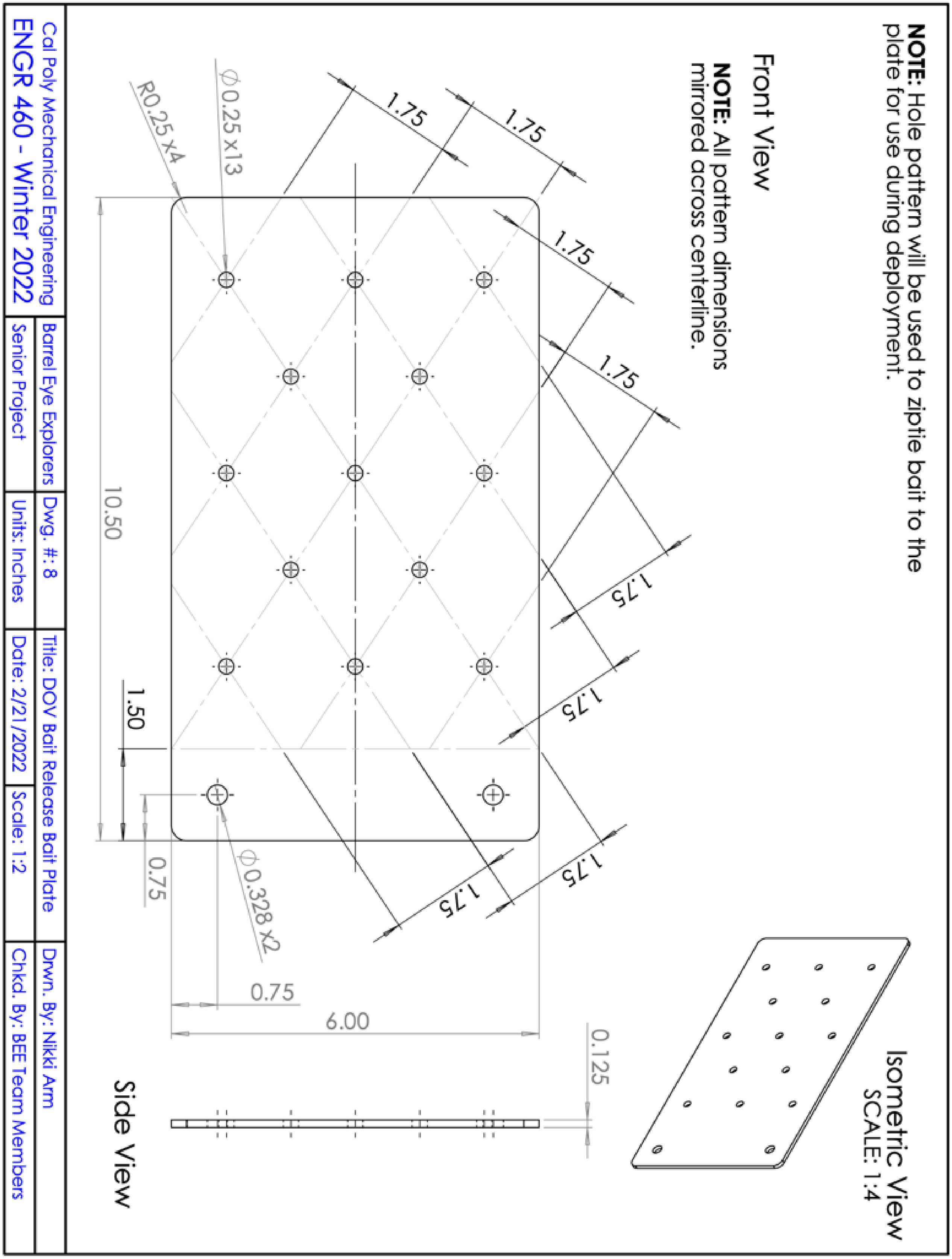
Drawing 6: DOV Bait Release Subassembly



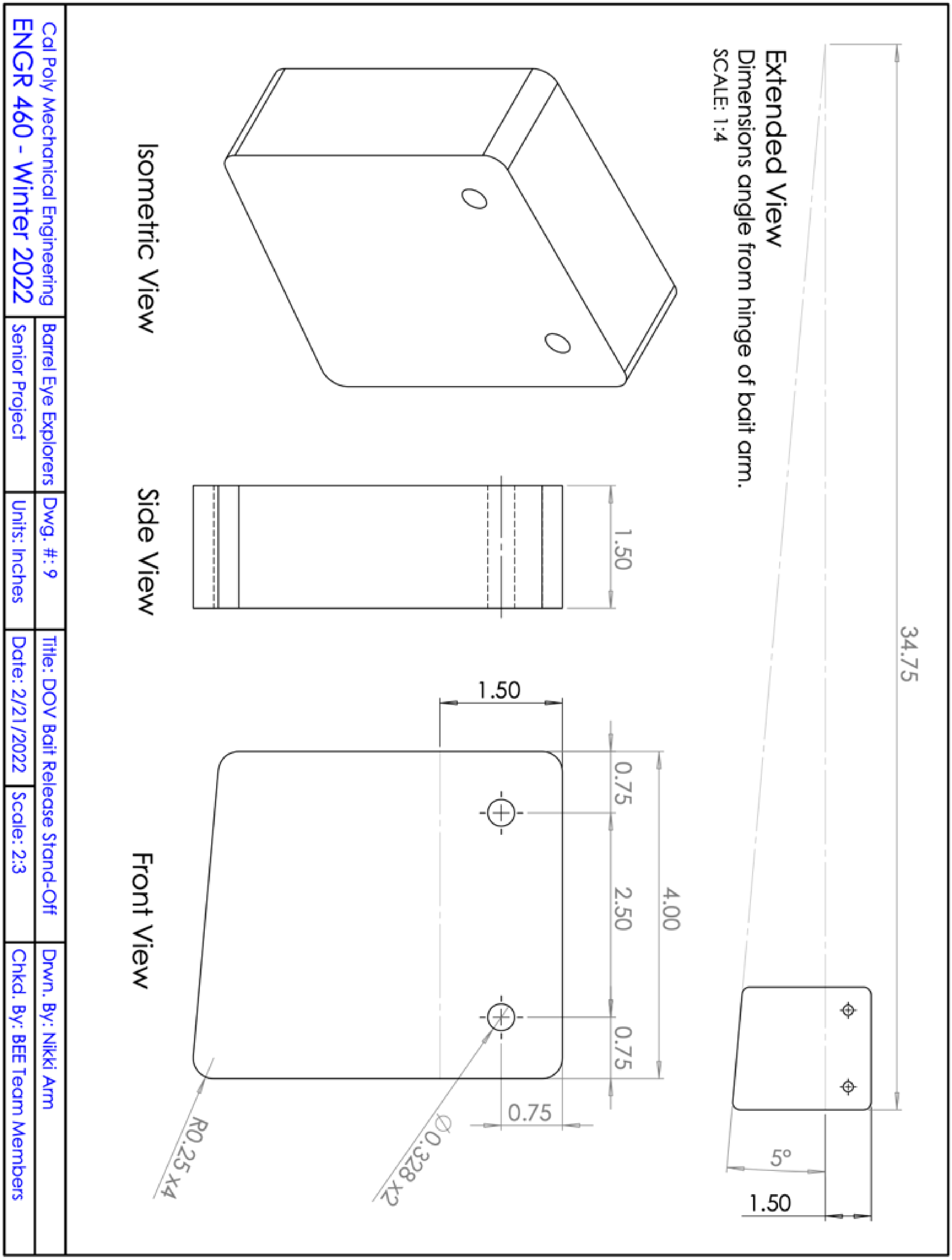
Drawing 7: DOV Bait Release Arm + Mount



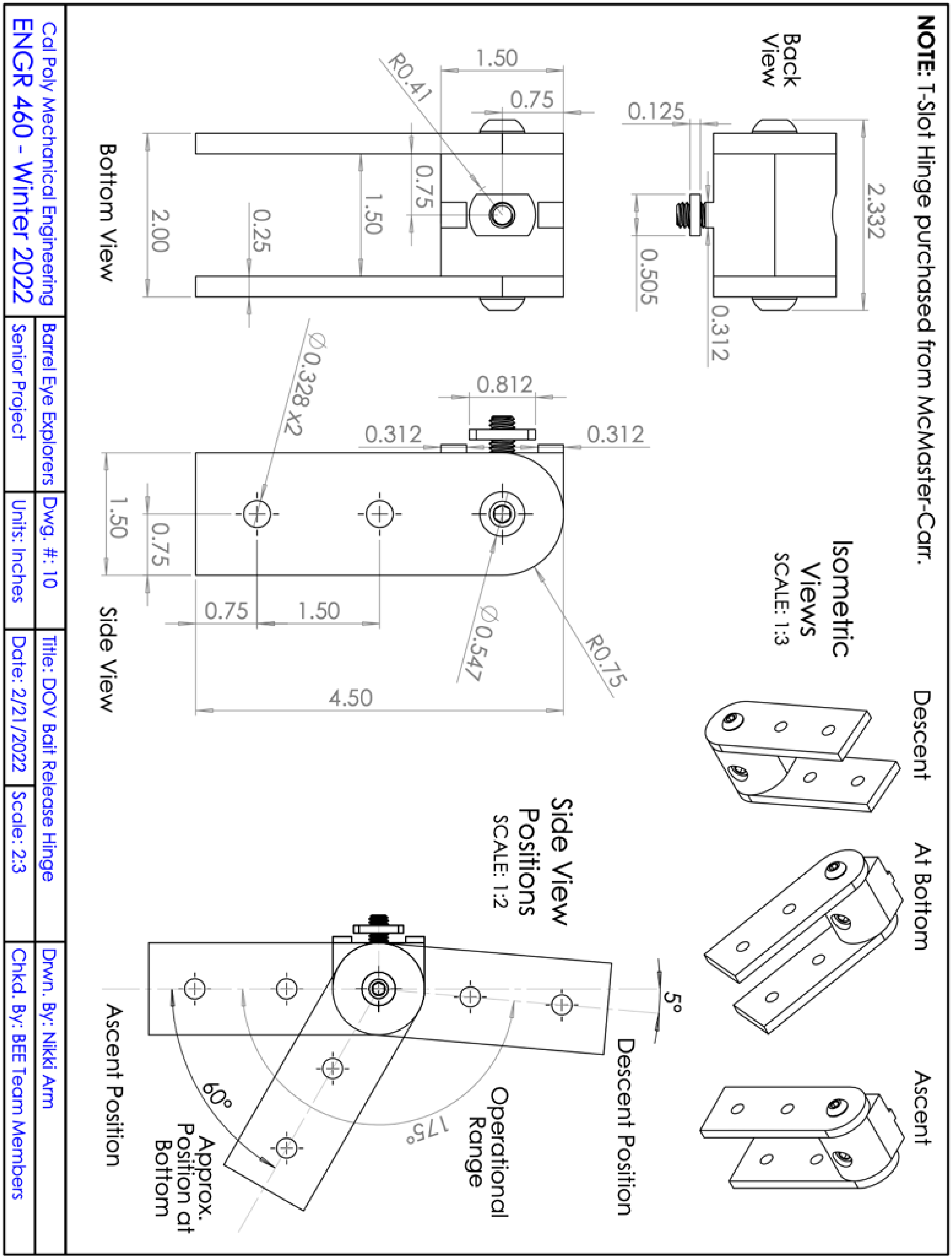
Drawing 8: DOV Bait Release Bait Plate



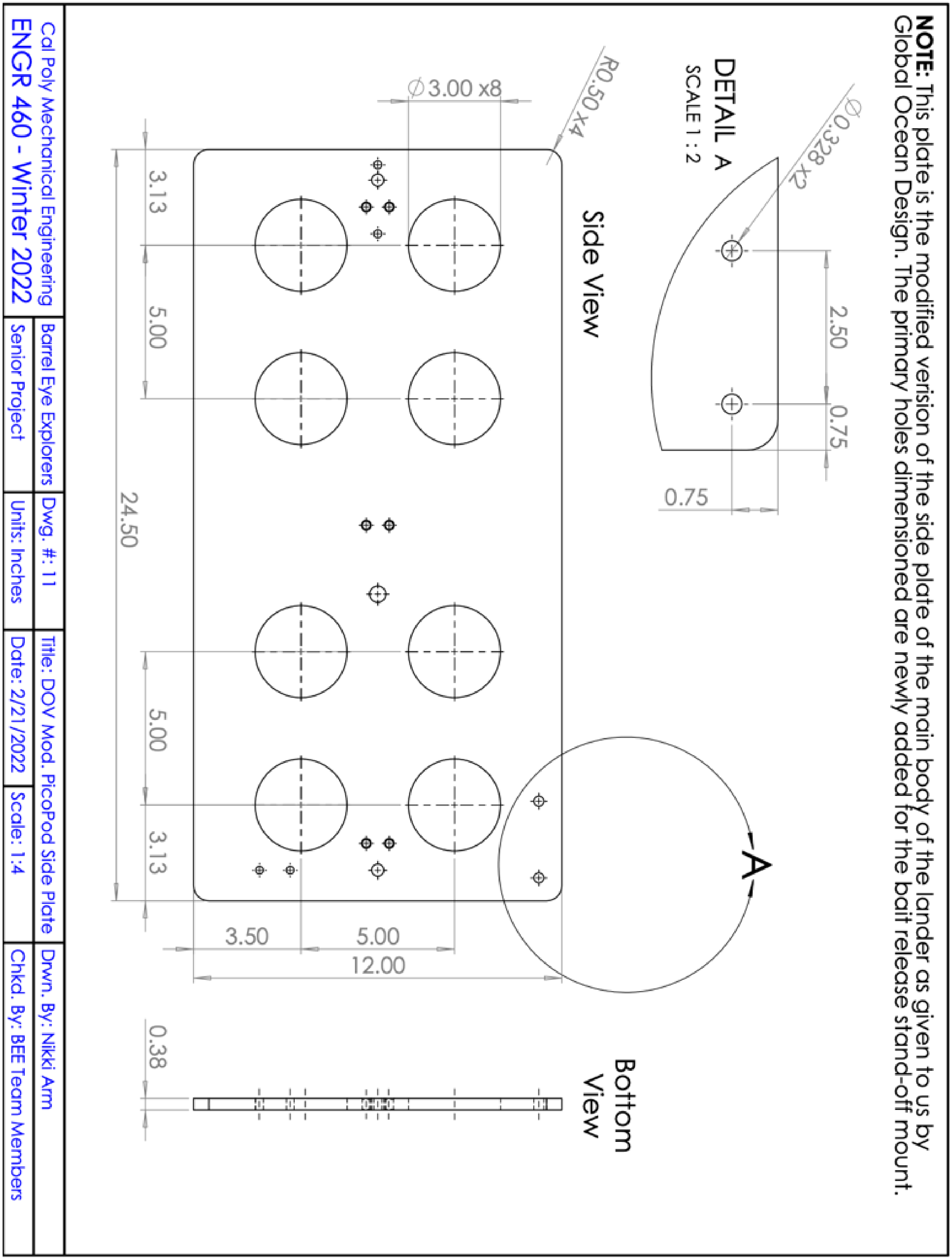
Drawing 9: DOV Bait Release Stand-Off – Removed from Design



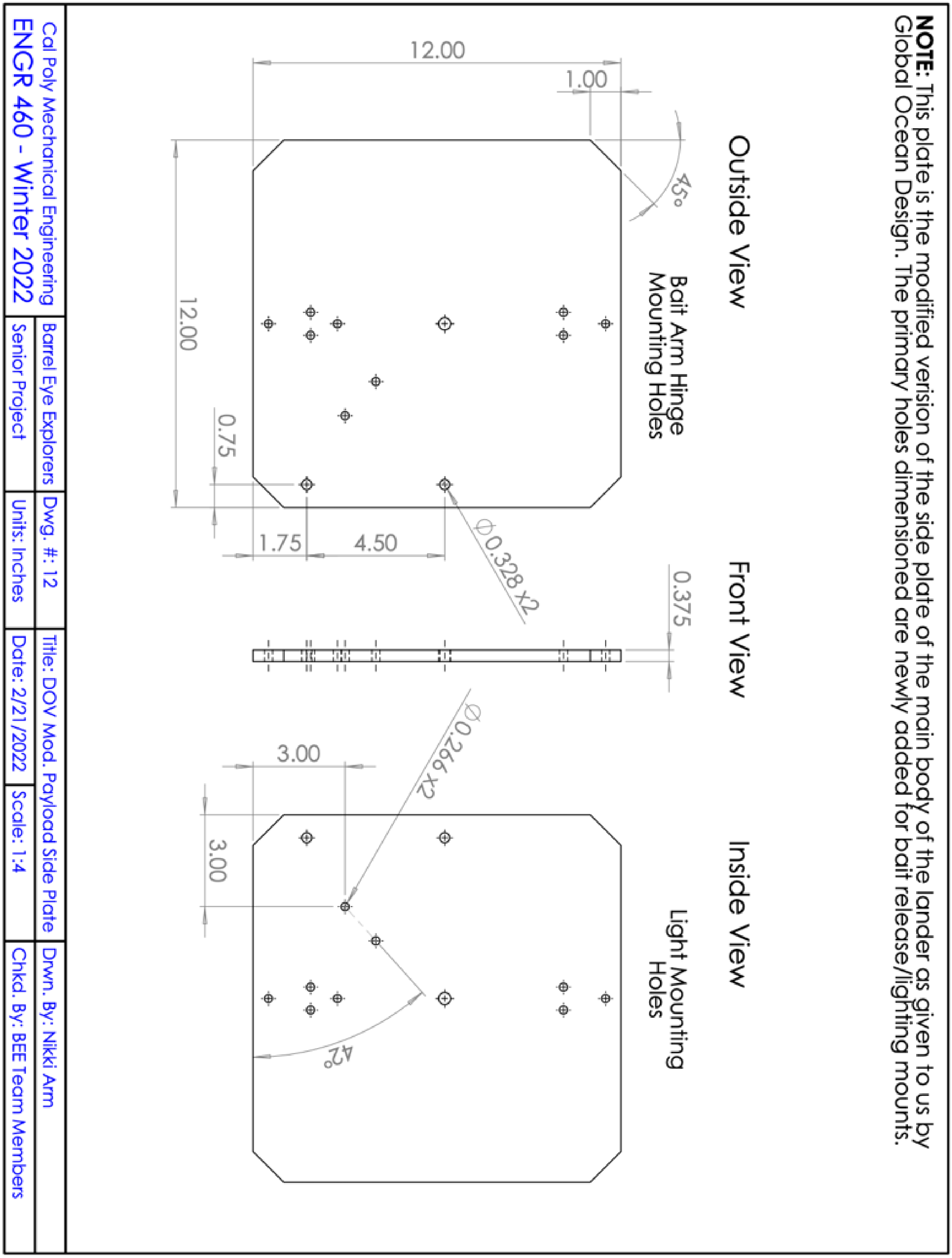
Drawing 10: DOV Bait Release Hinge



Drawing 11: DOV Modified PicoPod Side Plate



Drawing 12: DOV Modified Payload Side Plate



*C. Bill of Mat*erials

Level		Description	QTY	Cost/Unit	
1		DOV Seastang		$0.00	*
2.1		GoPro Housing Subsystem	1	$0.00	*
	3.1	Connector Hemisphere	1	$0.00	*
	3.2	Plastic Hemisphere, 10inch	1	$0.00	*
	3.3	Mounting Ring, 10in	1	$0.00	*
	3.4	Camera Pod Base Plate	1	$0.00	*
	3.5	Sony and GoPro Camera Sphere Window	1	$0.00	*
	3.6	Camera Window Sphere 10inch	1	$0.00	*
	3.7	Camera Window Body	1	$0.00	*
	3.8	Camera Window Clamp Ring	1	$0.00	*
	3.9	View Port	1	$0.00	*
	3.10	Retaining Ring	1	$0.00	*
	3.11	GoPro Hero 4	1	$0.00	*
	3.12	GoPro Camera Mount Interior Plate	1	$0.00	*
	3.13	91780A640	2	$0.00	*
	3.14	Camera Back Plate	1	$0.00	*
	3.15	Other Back Plate	1	$0.00	*
	3.16	91780A661	4	$0.00	*
2.2		LED Lights Subsystem	2	$0.00	*
	3.1	Light Body_C	1	$0.00	*
	3.2	30w LED	1	$0.00	*
	3.3	MCBH2F	1	$0.00	*
	3.4	90825A180	1	$0.00	*
	3.5	Window	1	$0.00	*
	3.6	Window Retainer	1	$0.00	*
	3.7	91221A216	8	$0.00	*
	3.8	SubConn 3 Contact, Male Micro Bulkhead Connector, Brass, 1 ft 20 AWG lead wire, 19mm TL	1	$69.70	
	3.9	SubConn 3 Contact, Female Micro Bulkhead Connector, Brass, 1 ft 20 AWG lead wire, 19mm TL	2	$79.35	
	3.10	SubConn 3 Contact, Male Micro Inline Connector on 2 ft. std. cable	2	$40.95	

Level		Description	QTY	Cost/Unit	
	3.11	SubConn 3 Contact, Female Micro Inline Connector on 2 ft. std. cable	2	$44.40	
	3.12	Subconn Micro Locking Sleeve - Female	4	$13.15	
2.3		Bait Arm Subsystem			
	3.1	T-Slotted Framing, 4'	1	$42.64	
	3.2	Bait Plate	1		
	3.3	T-Slotted Framing, End-Feed Nut, Button Head, 4 5/16"-18 Thread, Stainless Steel, Packs of 4	4	$5.80	
	3.4	T-Slotted Framing, Inline Pivot for 1-1/2" Single 1 Rail	1	$24.32	
	3.5	18-8 Stainless Steel Button Head Hex Drive 1 Screw, 5/16"-18 Thread Size, 3/4" Long, Pack of 25	1	$8.26	
2.4		18-8 Stainless Steel Button Head Hex Drive Screw	1	$0.00	*
2.5		Pull Rope and Pole	1	$0.00	*
2.6		8891T72	2	$0.00	*
2.7		PicoLander Flag	1	$0.00	*
2.8		LED Mount, FRP	2	$0.00	*
2.9		8inch sphere	2	$0.00	*
2.10		Side Float Spacer	2	$0.00	*
2.11		98871A042	2	$0.00	*
2.12		90295A188	2	$0.00	*
2.13		Plastic Nut	2	$0.00	*
2.14		Side Plate Pico Lander Payload Bay	2	$0.00	*
2.15		PicoLander Payload Bay U-Channel	2	$0.00	*
2.16		Mast Mount_REV B	1	$0.00	*
2.17		Counterweight Center Spacer	2	$0.00	*
2.18		Counterweight Retainer Washer	2	$0.00	*
2.19		Nanolander Cross Brace Stiffener	12	$0.00	*
2.20		Weight Subsystem	1	$0.00	*
	3.1	Pico Lander weight	1	$0.00	*
	3.2	Anchor chain	1	$0.00	*
	3.3	10lbs Weight	2	$0.00	*

Level		Description	QTY	Cost/Unit	
	3.4	3564t14_ring	1	$0.00	*
	3.5	2.5Lbs Barbell Weight	2	$0.00	*
	3.6	Pico lander Rope with Eyebolts and pole	1	$0.00	*
2.21		Burnwire Mount (Edgetech)	2	$0.00	*
2.22		PLATE CENTER	1	$0.00	*
2.23		U Channel_2x1 FRP	2	$0.00	*
2.24		Side Plate	2	$0.00	*
2.25		Sphere Retainer 10inch	2	$0.00	*
2.26		Styrene Sphere 10 inch	2	$0.00	*
2.27		L-Channel, Bottom	6	$0.00	*
2.28		L-Channel, BL10, Top	1	$0.00	*
2.29		91315A231	4	$0.00	*
2.30		91849A625	8	$0.00	*

NOTE: Costs denoted with an asterisk (*) mean this component for our project was donated.

D. List of Vendors, Contact Information

Global Ocean Design

7955 Silverton Ave.
Suite 1208
San Diego, CA 92126 US
+1 858 560-2913
kevin@globaloceandesign.com
www.globaloceandesign.com

Ocean Innovations

7416 Cabrillo Ave.
La Jolla, CA 92037 US
+1 8584544044
brock@o-vations.com
www.o-vations.com

McMaster-Carr

562-692-5911
562-695-2323 (fax)
la.sales@mcmaster.com
https://www.mcmaster.com

The Epoxy Experts

1871 S. Lake Place
Ontario, CA 91761
877-403-8008
support@TheEpoxyExperts.com
https://theepoxyexperts.com

E. Vendor Supplied Component Specifications and Data Sheets

SubConn® Micro Circular
21 contacts

Connector specifications

Voltage rating	300 V DC/AC rms
Current rating	5 A per contact (max 40 A per connector)
Insulation resistance	> 200 Mohm
Contact resistance	< 0.01 ohm
Wet matings	> 500
Temperature rating (water)	- 4 to 60˚C, 25 to 140˚F
Temperature rating (air)	- 40 to 60˚C, - 40 to 140˚F
Storage temperature rating	- 40 to 60˚C, - 40 to 140˚F
Qualified pressure tested	800 bar, 11,600 psi
Depth rating PEEK	300 bar, 4,350 psi

Material specifications

Connector body	Chloroprene rubber
Bulkhead body	Brass, stainless steel, titanium, anodised aluminium or PEEK
Contacts	Female sockets in gold plated brass UNS - C36000 Male pins in gold plated beryllium copper
O-rings	Nitrile
Locking sleeves	POM or stainless steel
Snap rings	Stainless steel AISI 302
Inline cable (2 ft, 60 cm)	20 AWG, 0.52 mm^2 PUR
Bulkhead and PBOF leads (1 ft, 30 cm)	20 AWG, 0.52 mm^2 white tagged PTFE
OM leads (3", 7 cm)	20 AWG, 0.52 mm^2 white tagged PTFE

Component Specifications for Ocean Innovations parts MCBH3M, MCBH3F, MCIL3M, and MCIL3F (Ocean Innovations)

SubConn
DEPENDABILITY AT EVERY LEVEL

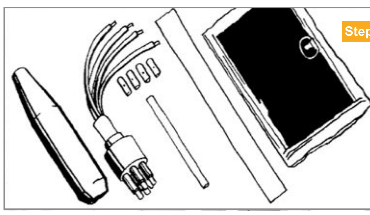
FSK assembly procedure

Introduction

The SubConn® OM series of connectors is supplied as a quick reliable and watertight solution for customers who require installation of standard SubConn® connectors on a non-standard cable or for quick, efficient field retermination.
The OM connector series mates with the compatible standard SubConn® series.

The connectors are produced with a tube brass body and 7 cm pigtail wires which are spliced and moulded to the cable using a pre-formed "Boot" and pre-packed ambient temperature curing polyurethane.

The end result is a professional, rugged and watertight termination rated to full ocean depth. The connector is available in 2 to 16 pin male and female configurations together with all the specials with the same shell size.

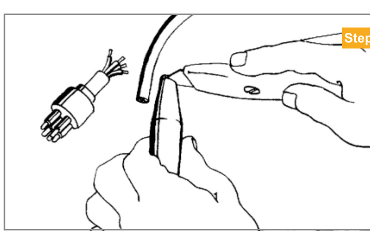


Operational steps

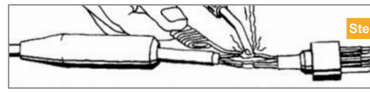
1. Ensure that the correct materials are available for the planned job

- The correct OM connector, e.g. OM6F (not included in the FSK)
- The correct "Boot" (e.g. OMBB)
- Adequate moulding material (e.g. 2131, 90 g from 3M)
- Primers (Scotchcast™ Resin Primer 5136 from 3M)*
- Acetone for degreasing*
- Crimp sleeve and heating gun
- Soldering iron, solder, side cutters, cable stripper and small paint brush

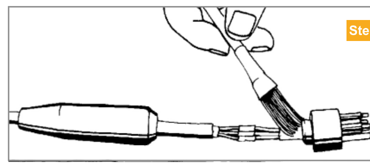
* Please notice that primers and acetone are not part of the delivery. You will need to purchase these items individually to be sent as dangerous goods or purchase them locally.



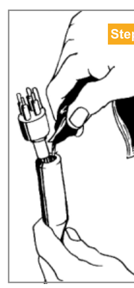
2. Cut pigtail wires on OM connector to approx. 2 cm from the brass body. Trim back tapered cable entry on boot until the cable is a snug fit (approx. 0.5 mm less than cable diameter).



3. Prepare cable to be connected by stripping 3 cm off the jacket. Solder or crimp cable wires to pigtail on OM connector and insulate using crimp sleeve, heat shrink, or electrical tape. The spliced conductors should be twisted together in the same direction as laid in the cable.



4. Degrease all moulding surfaces including cable jacket, conductors and brass body with acetone and allow to dry. Apply appropriate primer to brass body conductors, cable jacket and neoprene base of connector with a small brush and allow to dry (approx. 30 min. at 200°C). Do not touch primed surfaces after primer application.



5. Select the appropriate polyurethane twin pack (e.g. 2131, 90 g for a single moulding) and mix the PUR material according to supplier instruction. Cut off the corner of the pack and squeeze the material into the boot as shown.

6. When the boot is full of material slide it up the cable until it fits tightly over the neoprene protrusion on the back of the connector. Push the cable into the boot about 2 mm and wipe off any excess visible polyurethane material. The connector will be ready for use after 12 hours at 200°C.

Safe handling procedures

To comply with recommended health and safety procedures; ensure the use of barrier creams, gloves and a clean, well-ventilated work area.

Locking sleeve application procedure for MCDLS-F (Ocean Innovations)

F. *House of Qualities*

Engineering Requirements

Customer Requirements	Weighting (1 to 5)	Exterior Parts Pressure Rated to Target Depth	Inner Components can Handle Vacuum	Video Clarity Fits HD Parameters	Frequency of Video Every Hour for 5 min	Fitting on Boat with Crew	Weight Out of Water	Has Functioning Depth Sensor	Has Functioning Temperature Sensor	Has Functioning Salinity Sensor	Has a Sediment Sampler	Material Cost and Testing within Budget	Bait Release System (BRS)	BRS Functions to 4,200ft Deep	BRS Lasts for Time at Depth	Timed or Tethered Device to Return to Surface	Floats at Surface Out of Water	Weights use Non-Invasive Materials	Lander and Parts can Recharge and Not Degrade	Timed Weight Release Works up to Time Needed	DOV Seastang (Current)	CSRIO Australian BRUV
Depth to 1,000ft	5	9	9											3		1					5	5
Depth to 4,200ft	3	9	9											3		1					5	1
Ability to Take Video	5		3	9	3																1	5
Pressure/Depth Sensor	1	1	1					9													1	3
Temperature Sensor	1	1	1						9												1	1
Salinity Sensor	1	1	1							9											1	1
Cost Effective	5											9									5	1
Bait/Lure Species	4	1	1										9	9	9						2	5
Returns to Surface	5															9	1			9	5	5
Safely Recoverable	4					9	9									3	9				5	3
Sediment Samples	1	1									9										1	1
Anchor Weights Don't Harm the Sea Floor	5																	9			4	3
System is Repeatable	5	9	9	1	1			1	1	1	1		1	1	1	9	3		9	3	5	5
Ability for 1 or 2 People to Carry It	4					9	9														5	1
Bottom Time of 6 hours	3	1	1		3			1	1	1					3					9	5	5
Units		atm	atm	megapixles / framerate	hours	in	lbs	ft	°F	parts per thousand	yes/no	$	yes/no	feet	hours	hours	inches	yes/no	# uses	Min/hours/ days		
Targets		130	0.3	1080p at 30fps	1hr	40	90	0 - 5000	30 - 75	0 - 50	yes	1500	yes	4200	12 - 120	12 - 1000	12	yes	100	6hr		
DOV Seastang (Current)		202	0.1	N/A	N/A	36	50	N/A	N/A	N/A	no	0	no	0	0	12-120	12	yes	100	4d		
CSIRO Australian BRUV		101	0.1	4k at 30fps	1 hr	70	600	0 - 2500	N/A	N/A	no	3000 +	yes	2000	12- 1000	12 - 1000	6	yes	100	24hr		
Importance Scoring		128	142	50	29	72	72	17	17	17	14	45	41	65	50	110	56	45	45	87		
Importance Rating (%)		90	100	35	20	51	51	12	12	12	10	32	29	46	35	77	39	32	32	61		

Benchmarks: DOV Seastang (Current), CSRIO Australian BRUV

9 Strong Correlation
3 Medium Correlation
1 Small Correlation
Blank No Correlation

G. Safety Hazards Checklist

Y	N	
✓		Will any part of the design create hazardous revolving, reciprocating, running, shearing, punching, pressing, squeezing, drawing, cutting, rolling, mixing or similar action, including pinch points and sheer points?
✓		Can any part of the design undergo high accelerations/decelerations?
✓		Will the system have any large moving masses or large forces?
	✓	Will the system produce a projectile?
✓		Would it be possible for the system to fall under gravity creating injury?
	✓	Will a user be exposed to overhanging weights as part of the design?
	✓	Will the system have any sharp edges?
✓		Will all the electrical systems properly grounded?
	✓	Will there be any large batteries or electrical voltage in the system above 40 V either AC or DC?
✓		Will there be any stored energy in the system such as batteries, flywheels, hanging weights or pressurized fluids?
	✓	Will there be any explosive or flammable liquids, gases, dust fuel part of the system?
✓		Will the user of the design be required to exert any abnormal effort or physical posture during the use of the design?
✓		Will there be any materials known to be hazardous to humans involved in either the design or the manufacturing of the design?
	✓	Can the system generate high levels of noise?
✓		Will the device/system be exposed to extreme environmental conditions such as fog, humidity, cold, high temperatures, etc…?
✓		Will the system easier to use safely than unsafely?
✓		Will there be any other potential hazards not listed above? If yes, please explain below?

H. Testing Plan DVP&R

DVP&R

Item No	Specification or Clause Reference	Test Description	Acceptance Criteria	Test Responsibility	Test Stage	SAMPLES Quantity	SAMPLES Type	TIMING Start date	TIMING Finish date	TEST RESULTS Test Result	TEST RESULTS Quantity Pass	TEST RESULTS Quantity Fail	NOTES
Report Date			Sponsor									REPORTING ENGINEER:	
		TEST PLAN								TEST REPORT			
1	Burn Wires	Timed Weight Release in Shallow Water: Performed Test off of Cal Poly Pier. The purpose of this is to test whether the burn wires work correctly and if everything is water proof.	Lander returns to surface at specified time range	All	DV	1		11/4/21	11/4/21	Pass	1	0	Once timer went off, burn wire disolved in approximately 20 min
2	Bait Release	Life-Saver Tensile Test: The purpose of this is to test the tensile strenght of the different life saver candies.	Holds 10 lbs	All	DV	3		1/27/22	1/27/22	14.33	3	0	Will try gummy later
3	Bait Release	Life-Saver Dissolve Test STAGNANT: The purpose of this is to test the dissolve time of different life saver candies in stagnant water	Dissolves	All	DV	2		1/27/22	1/27/22	38 min 55 sec	2	0	Note: stagnant water, will try running water later
4	Bait Release	Life-Saver Dissolve holding 2 lbs Test STAGNANT: Test how long it takes to break the life savers with 2 lbs of weight attached to each.	holds 2 lbs	All	DV	7		1/27/22	1/27/22	28 min 10 sec	7	1	Averaged time
5	Bait Release	Life-Saver Dissolve holding 3 lbs Test STAGNANT: Test how long it takes to break the life savers with 3 lbs of weight attached to each.	holds 3 lbs	All	DV	2		1/27/22	1/27/22	22 min 31 sec	1	0	
6	Bait Release	2 Life-Saver in PARALLEL Dissolve hold 3 lbs STATIC (fruit)	holds 3 lbs in ||	All	DV	1		1/27/22	1/27/22	22 min 4 sec	1	0	
7	Bait Release	Life-Saver Dissolve 1 lbs Test FLOWING (hard candy)	Holds 1 lbs	All	DV	2		2/3/22	2/3/22	24 min	2	0	
8	Bait Release	Life-Saver Dissolve 2 lbs Test FLOWING (hard candy)	Holds 2 lbs	All	DV	2		2/3/22	2/3/22	22 min 6 sec	2	0	
9	Bait Release	Life-Saver Dissolve 3 lbs Test FLOWING (hard candy)	Holds 3 lbs	All	DV	2		2/3/22	2/3/22	17 min 24 sec	2	0	
10	Bait Release	Life-Saver Dissolve 1 lbs Test FLOWING (gummy)	Holds 1 lbs	All	DV	3		2/3/22	2/3/22	2 min 38 sec	0	3	Gummy time increased as increased number in parallel, but
11	Camera	Camera Testing: Make sure the camdo works, and can correctly sample in intervals specified	Takes pictures in designated intervals, Starts/Stops Recording	Kyle	DV	4		3/1/22	3/1/22	1 pic/ 30 sec, 1 vid/ 5 mins	2	2	
	Camera	Ful Subsystem test: check compatibility of the lights with the GoPro/Camdo system	Camera and lights are activated by the Camdo simultaneously	Kyle	DV	1		3/1/22	3/1/22	PASS	1	0	1.5 mm connection pin for the lights needed to be replaced
15	Lights	Angle of Light; test the angle of the light so we can decide what angle to mount lights at	<90 degrees	All	DV	1		4/7/22	4/7/22	FAIL	0	1	Light filled area greater than 90. Does not flood camera FOV so not an issue
16	Bait Arm	Dropping Bait Release Arm: This is to test where the bait arm falls, whether it is in front of the camera or not, and if it will rotate	Rotates 100 deg/ in view of camera	All	DV	1		4/7/22	4/7/22	PASS	1	0	
17	Camera and Lights & Baid arm	Camera and Lights; This will take place in the water at night; used to test the placement of the camera and lights		All	DV	1		4/14/22	4/14/22	PASS	1	0	
18	LED Brightness	This is to test how bright each individual LED is	2,000 Lumens	All	DV	1		4/7/22	4/7/22	PASS	1	0	
19	Buoyancy	Buoyancy Test: Many of these will need to take place in order to verify the necessary weight needed and how much the lander will	Top third of Lander sticks out of water	All	DV	1		5/12/22	5/12/22	PASS	1	0	
20	Full System	Full System Test: Cal Poly Pier	Performs as intended	All	PV	1		4/14/22	4/14/22	PASS	1	0	
21	Full System	Full System Test: Cal Poly Boat w/ Winch	Performs as intended	All	PV	1		5/26/22	5/26/22	PASS	1	0	
22	Full System	Full System Test: Cal Poly Boat w/o Winch	Performs as intended	All	PV			GOAL	6/2/22				

I. Testing Procedure and Results

1. Timed Weight Release

The timed weight release test was performed on November 4th, 2022, at the Cal Poly pier. This test was to make sure that the current lander we would be using as our base functions as intended. To pass this test, the lander must be deployed, submerged, and successfully return to the surface with no help from rope. The procedure for this test was to prepare the lander for deployment. This entails charging the batteries, setting the timer for when the batteries need to dump current into the burn wires, properly sealing the pressure spheres, and vacuuming the air from those spheres. The weights will then need to be attached to the chain, and the lander can finally be deployed into the ocean. Ropes are also attached to the lander and the weights separately before deployment. This is so that if the test is successful, both the lander and weights are properly secured and can be easily retrieved. In actual deployment when we test the full system, these ropes will not be used. Finally, the lander can be deployed into the ocean and the test can begin. As mentioned before, the test was successful. The burn wires broke, and the lander resurfaced. It is notable that the salinity was lower than average that day, and so the expected break time for the burn wire of 15 minutes was exceeded. This caused the backup burn wire and battery to begin to discharge. The time for the first burn wire to break was 19 minutes. This doesn't suggest that our timer for the backup wire needs to be adjusted, because as depth increases in the ocean, salinity also increases, and so the pre-allocated time of 15 minutes for each burn wire will be plenty at depth.

2. LifeSavers Tensile Test

The LifeSavers tensile test was performed on January 27th, 2022, on the Cal Poly Campus, Building 192 Room 201. This was to test the tensile strength of the LifeSavers hard candies to verify whether they can be used on the lander or not. This test was performed before the material for the bait arm was ordered and assembled so we had to estimate how much load the LifeSavers would hold. We exaggerated this load 3 times what we thought it would need to hold to get 10 lbs. For this test to pass, the LifeSavers candy needs to hold a load of 10lbs or more. We created a rudimentary jig that can hold the LifeSavers between two pressure points and can be used in the machine we had available. For this we drilled holes in two pieces of scrap wood that will fit in the machine's jaws, and then fed metal wire through these holes. The wires are what will be attached to the candy itself. The full setup can be seen below in *Figure I1*.

Figure I1: Instron Tensile Test setup with LifeSavers attached

The machine is then turned on. Data is then compiled onto a graph and results are read from there and can be seen in *Figure I2*.

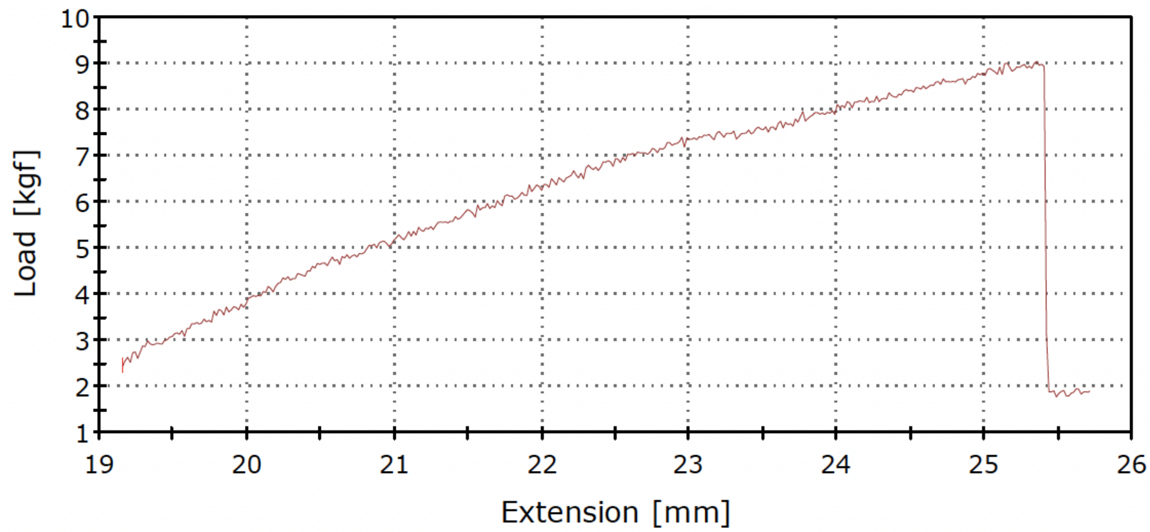


Figure I2: Graph of Load (kgf) to Extension (mm)

For this test, the x axis is used for where the break of the LifeSavers occurs, which is almost instantaneous as can be seen by the nearly vertical line towards the right of the graph in *Figure I2*.

3. LifeSavers Dissolvability: Stagnant Sea Water

The dissolvability test for stagnant sea water was performed on January 27th, 2022, at the Cal Poly Pier. The purpose of this was to test how long it took for LifeSavers to break when submerged in seawater with varying loads on them. The materials needed for this test were a bucket, sea water, 2.5 ft wooden dowel rod, weight varying between 1 and 3 lbs, rope, 10-gauge steel wire, timer/stopwatch, and finally the LifeSavers flavors that need to be tested. For this test to be successful, the lifesaver needs to hold at least 1 lb (or more) and hold for at least 10 minutes. Once the materials are gathered, the rope is then tied to the LifeSavers in two loops as pictured below in *Figure I3*. Then a weight is attached using the steel wire which is also shown in *Figure I3*.

Figure I3: LifeSavers (middle, white) attached to weight (bottom) with open loop (top) for attaching apparatus to dowel rod.

Once a few of the LifeSavers are prepared, they can be strung on the dowel. The bucket is then filled with seawater and the test can begin. The timer is zeroed, and once the timer is ready, the LifeSavers apparatus' can be submerged as imaged in *Figure I4* below. The timer is started right when the LifeSavers enter the water.

Figure I4: Testing Apparatus of two lifesavers, purple (left) and mint (right)

The data that is collected the type of lifesaver, the amount of weight attached to each, and the amount of time it takes for each candy to break. Compiled data tables can be seen below in *Tables I1* and *I2*.

Table I1: Data Collection for Stagnant Water Test (FRUIT)

Test #	Weight	Time	Time	Total Time	Type
	lbs.	min	sec	min	flavor
1	2	30	0	30.0	Purple
2	0	39	43	39.7	Purple
3	2	25	30	25.5	Yellow
4	3	24	17	24.3	Yellow
5	2	30	6	30.1	Orange
6	3	22	4	22.1	green

Table I2: Data Collection for Stagnant Water Test (MINT)

Test #	weight	Type	Time	Total	Type
	lbs.	min	sec	min	flavor
1	2	20	0	20.0	Mint
2	0	38	7	38.1	Mint
3	2	20	30	20.5	Mint
4	2	33	30	33.5	Mint
5	3	20	46	20.8	Mint
6	2	30	4	30.1	Mint

All the LifeSavers tested passed this test. The data from the above tables were then plotted on the graph below *Figure I5*.

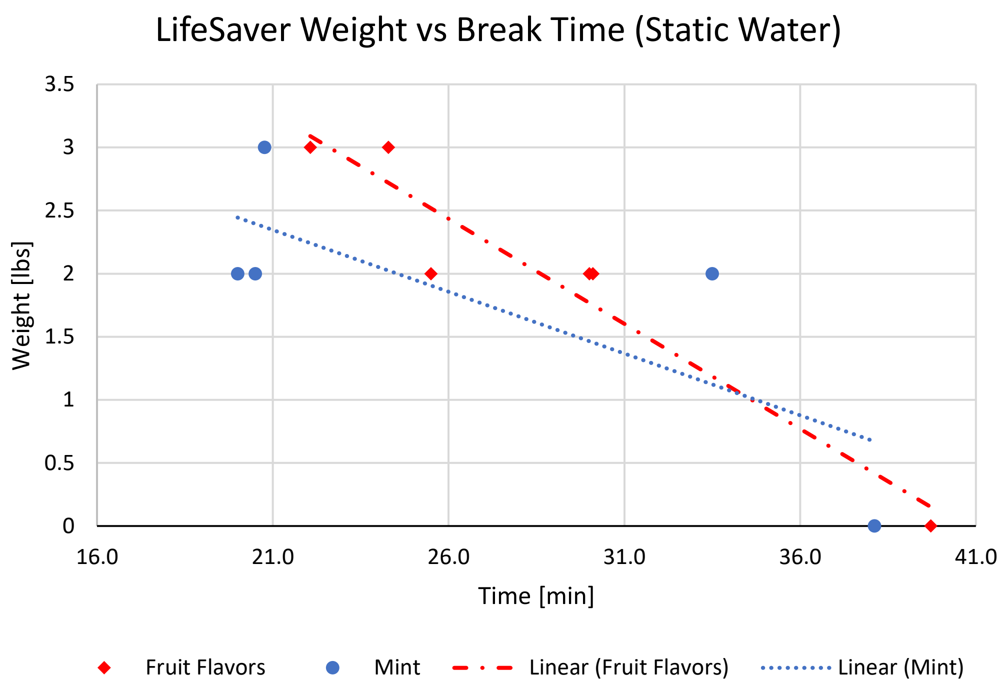


Figure I5: How long it took for each LifeSaver to break (x axis) vs how much weight was being held (y-axis) of mint and fruit LifeSavers.

We notice a trend that with increasing amount of weight, the amount of time it takes for each LifeSaver to break is decreased.

4. *LifeSavers Dissolvability: Flowing Sea Water*

The dissolvability test for flowing sea water was performed on February 3rd, 2022, at the Cal Poly Pier. The purpose of this was to test how long it took for LifeSavers to break when submerged in flowing seawater with varying loads on them, similar to the previous test, but is meant to closer simulate the actual conditions the deployment will be in. The materials needed for this test were a cooler, a cement block, a hose that supplies ocean water, a 2.5 ft wooden dowel rod, weights varying from 1 to 3 lbs, rope, 10-gauge steel wire, timer/stopwatch, and finally the LifeSaver flavors that need to be tested. For this test to be successful, the LifeSaver needs to hold at least 1 lb, (or more) and hold for at least 10 minutes. The same setup is used as in the previous test and can be seen in the above *Figure* I4. Instead of a bucket, this time a cooler is used with the edge propped up on a cement block, and a constant flow of sea water is supplied by a hose as can be seen in the following *Figure I6*.

Figure I6: Flowing water testing apparatus. 3 tests occurring at the same time, bottom most has ended and broken already

In the above image *Figure I6*, the water can be seen spilling out, and the bottom drain opened. The hose is seen to the left. Once a steady flow has been reached, as the above procedure, the LifeSavers can be submerged, and the timer started. The data collected can be seen in *Tables I3* and *I4*.

Table I3: Data Collection for Flowing Water Test (FRUIT)

Test #	weight	Time	Time	Total Time	Type	Notes
	lbs.	min	sec	min	flavor	
1	1	25	30	25.5	green	
2	2	19	0	19.0	green	
3	3	16	55	16.9	green	

Table I4: Data Collection for Flowing Water Test (MINT)

Test #	weight	Type	Time	Total Time	Type	Notes
	lbs.	min	sec	min	flavor	
1	1	22	25	22.4	Mint	
2	2	25	5	25.1	Mint	
3	3	17	54	17.9	Mint	

Results and conclusions were discussed above in *Chapter 6* and can be seen in *Figures 45 & 46*.

5. CamDo - GoPro Compatibility: Images

The CamDo and GoPro compatibility test was performed on March 1st, 2022. The purpose of this test was to make sure that the CamDo and GoPro are functioning properly. This test included two subtests. One to make sure that each were compatible, and one to test the longevity of the setup. The materials needed to perform this test were the GoPro hero 4, a Blink CamDo, and a device that can connect to the internet. Connect the CamDo to the GoPro and follow the setup instructions.

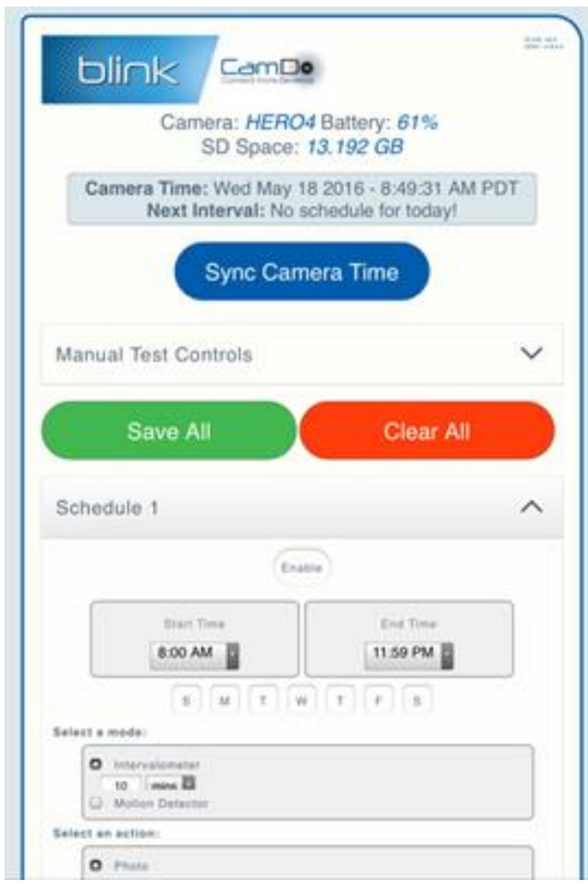


Figure I7: CamDo user interface

Once the specified intervals have been chosen, the test can begin. The first test was set to take one picture every 30 seconds for a span of 3 minutes. The passing criteria was for the camera to take a total of 6 pictures at the desired intervals. This test was successful.

The next CamDo and GoPro compatibility test was videos. The camera was setup to take a 2-minute video every 5 minutes for a span of 90 minutes. The purpose of this is to test the extent of the battery life for the GoPro. This test was also successful and the battery lasted the estimate 2 hours.

6. *Camera Field of View*

The lander has multiple subsystems that must work in unison. The goal of this test was to analyze if the GoPro camera was able to capture a clear and full view of the bait from all possible positions the bait arm can end up in. The GoPro has a wide-angle lens with a 130º field of view (FOV). The test was conducted on land and involved some assumptions of the sea floor topography which could affect the way the arm rests on the floor. During deployment, we predicted the bait arm to deploy within a 30º range relative to the lander. This range would only change if the lander encountered an extreme contour on the ocean floor. In this type of scenario, we would be more worried about the ability to retrieve the lander rather than the quality of video footage. The camera view in its fixture was adjusted to maintain the best and most versatile view of the bait arm after this test was conducted. This test was performed after the construction of the bait arm and the assembly of the camera subsystem.

This test was first conducted manually on land. We started by placing the lander on a table to allow the bait arm to move freely. We then moved the arm to different positions and measured the angle of the arm. While measuring the angle of the arm, we noted the time in the video. We then made a list of the angles when the bait arm was in view. We found that the bait arm was in the camera's field of view within range of 40º.

Figure I8: Testing the angle of the bait arm relative to the camera

The test was then verified during our full system test at the pier. The full system test involved the coordination of all subsystems on board the lander. Therefore, the camera was activated and operated properly. The goal was to view the bait arm deployed on the ocean floor when the video footage was downloaded.

While the contour of the ocean floor is relatively constant under the pier, the bait arm deployed directly into the camera's field of view. This result verifies that the lander has passed this test. In most of the contours that the lander will encounter, the bait arm will fall in the camera's field of view.

7. Light Angle

The purpose of this test was to ensure that mounting angle of the lights would maximize the light pointed towards the camera's field of view. This was also to ensure that the amount of "flood" light is minimized in front of the camera's lens to minimize particulate reflection back into the camera. To do this, we placed the lights in a dark room against a flat vertical surface (wall) and measured the angle coming out of the light when they are turned on using a protractor. To pass this test, the angle of the light must be greater than 20 degrees because less would not illuminate enough of the sea floor, and less than or equal to 90 degrees because more would flood too much light into the water column, illuminating marine snow and possibly leaving us blind.

The system failed this test. Though the angle of light is greater than 20 degrees, it is much more than 90 degrees. At 160 degrees, the light angle is much larger than we had anticipated. This proved to be both good and bad for bottom visibility. We decided that the best way to eliminate the flooding of light in the water column would be to add hoods to the lights instead of finding new lights. This will maximize the amount of light flooding the bottom and should minimize the light in the water column reflecting on the marine snow. We later tested the full system without adding hoods to the lights due to manufacturing delays and found that the wide-angle flood lights had less effect on light reflected by the marine snow than we had anticipated. Therefore, it was decided that we did not need to manufacture the hoods in time for full deployment and instead would be added to the list for future recommendations. Since the lights have such a wide area of effect, the angle was not adjusted after this test.

8. Night Test

The goal of the night test was to mimic the conditions of the deep sea as close as possible while still maintaining simplicity and ease of deployment. The night test took place on April 14th, 2022, at the Cal Poly Pier. It was dropped at 20:34 (PST) and the first burn wire was set to go off at 21:30 (PST). The initial drop can be seen in *Figure I9*. Refer to Appendix K for information on how the lander is prepared for deployment. The wires took 20 minutes to break, and the lander resurfaced at 21:52 (PST). The camera was set to go off for 30 seconds every 2 minutes. The materials that were used were the full system including the lander and weights, LifeSaver, and 2 ropes, each attached to the lander and weights respectively. Also used was raw chicken breast attached to the bait plate using zip ties. It was successful in all aspects except for a slight rope mishap – the rope got tangled on the burn wire connecting cables causing one to break. The seafloor was perfectly illuminated by the lights and the bait arm dropped successfully. For future deployments we decided to only use one rope if at all in order to avoid any tangles. In addition to this, we also decided to change the type of bait we use to squid due to marine life showing little to no interest in the chicken breast.

Figure I9: Dropping the Lander during the Night Test

9. *Buoyancy Tests*

The buoyancy tests are to ensure that the lander floats properly up to and at the surface after the mission is completed. The lander must be naturally buoyant after it releases the weights and must float in the upright position at the surface with enough of it sticking out to be spotted by crew on the boat.

Three total buoyancy tests were conducted for the lander as the prototype was changed to ensure the new design retained its buoyancy. For all three, the lander was lowered into the water in the position it would be in after the deployment. This means that the weights were released, and the bait arm was straight down. The lander was allowed to stabilize on the surface and the position was analyzed.

The first test was conducted on April 14^{th}, 2022 and was conducted after the bait arm and full camera and light system were finished. The lander did not float and was closer to negatively buoyant.

The first test results led to us adding two buoyancy spheres on either side of the lander in the upper area to cause it to float. The second test was conducted immediately after that on the same day, and the results were as desired. The lander floated with about 8 inches sticking out of the water. It also remained upright and allowed for the flag and part of the top sphere to be at or above the surface. Due to the addition of the bait arm, it was noticed the lander floated with a slight forward/right lean but was close enough to vertical to be within the design parameters.

The last test occurred on May 12th, 2022 and occurred after the small counterweights (2.5lb each) near the weight system were replaced with their new versions (2lb each). This test showed that there was no major change in buoyancy behavior to the last buoyancy test and the lander was still floating properly as a finished prototype as can be seen in Figure I10 below.

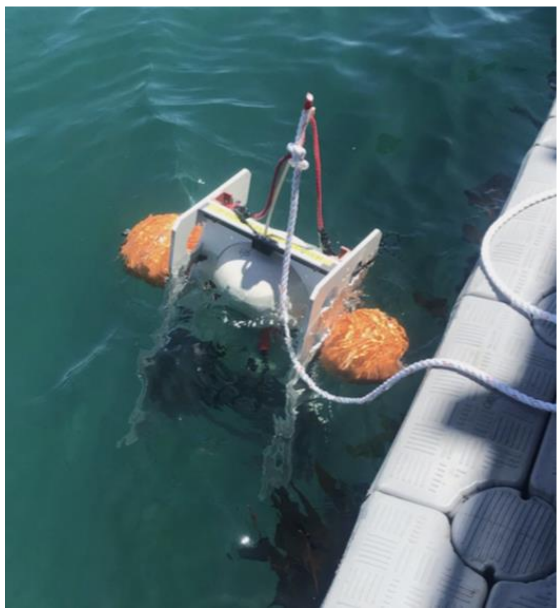


Figure I10: The Final Buoyancy test conducted for the Lander with all Parts of the Finished Prototype on Board.

10. *Full System Test (FST) Boat with Backup Line*

The purpose of the Full System Test with a boat is to make sure that the system can handle deeper pressures. The test consists of dropping the lander at deeper depths using a boat. This test was performed on the morning of May 26th, 2022 off the coast of Avila beach in San Luis Obispo. The materials needed for this deployment were the full lander system, LifeSavers, toolbox, grease, vacuum pump, boat, squid, zip ties, and rope that can reach the full deployment depth. We left the harbor at 08:15 (PST). Squid was attached to the bait arm with zip ties. The camera and lights were set to repeatedly go on for 20 minutes and be off for 10 minutes. The camera was set to go off at 09:15 (PST) and so we aimed to get it in the water at 09:16 (PST). We had a user error (light battery was left unplugged) and had do disassemble the buoyancy sphere with the camera inside. Because the interval was set to 20 minutes, we were able to fix and reassemble everything within 10 minutes and deployed the lander at 09:24 (PST) with both the camera and lights now on and working. The first burn wire was set to go off at 10:15 (PST) and the second was set to 10:50 (PST). The lander resurfaced at 10:34 (PST) and the backup burn wire was not needed. In order to successfully pass this test, the lander needed to collect data and resurface when we programmed it to. After the lander was retrieved from the ocean, the boat and lander were cleaned with fresh water in order to prevent future saltwater corrosion. The lander was brought back to campus and disassembled so the camera could be accessed. The camera took videos at the exact interval it was set to, and the lights functioned perfectly. The camera was pointed towards the bait arm during the entire deployment and the bait arm deployed immediately after it hit the bottom. Although the deployment was only an hour and a half, there was much fauna seen at the bottom including flounders, octopi, sea stars, a crab, and even a chimaera (links to footage can be found in Chapter 6). Future steps for a following test, is buy a bigger SD card so we can have a longer deployment and to deploy it at its full depth (4,000ft), without a backup line.

J. Gantt Chart

For access to the complete Gantt Chart, please access our TeamGantt page here: https://rb.gy/slwbwd.

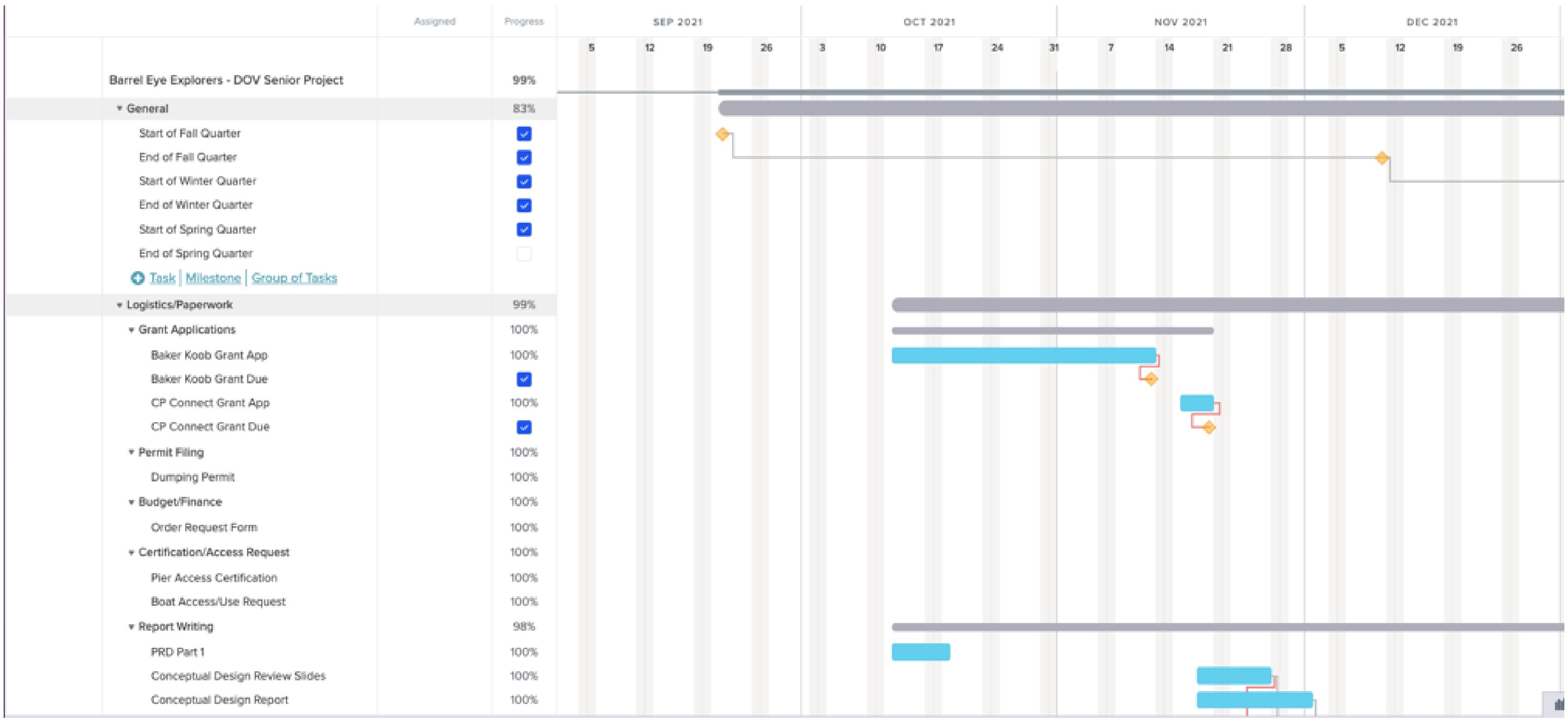


Figure J1: Gantt Chart - Part 1

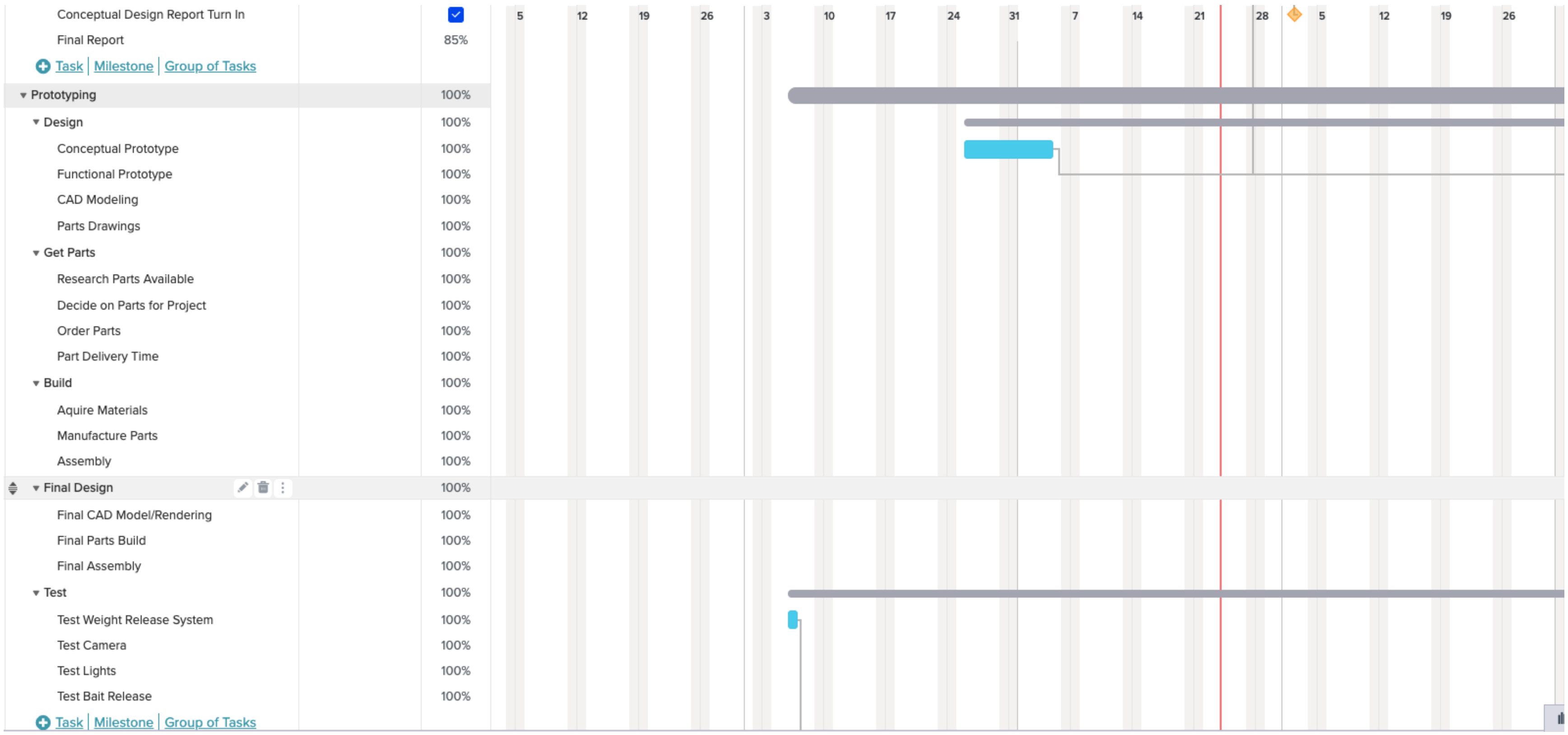


Figure J2: Gantt Chart - Part 2

Figure J3: Gantt Chart - Part 3

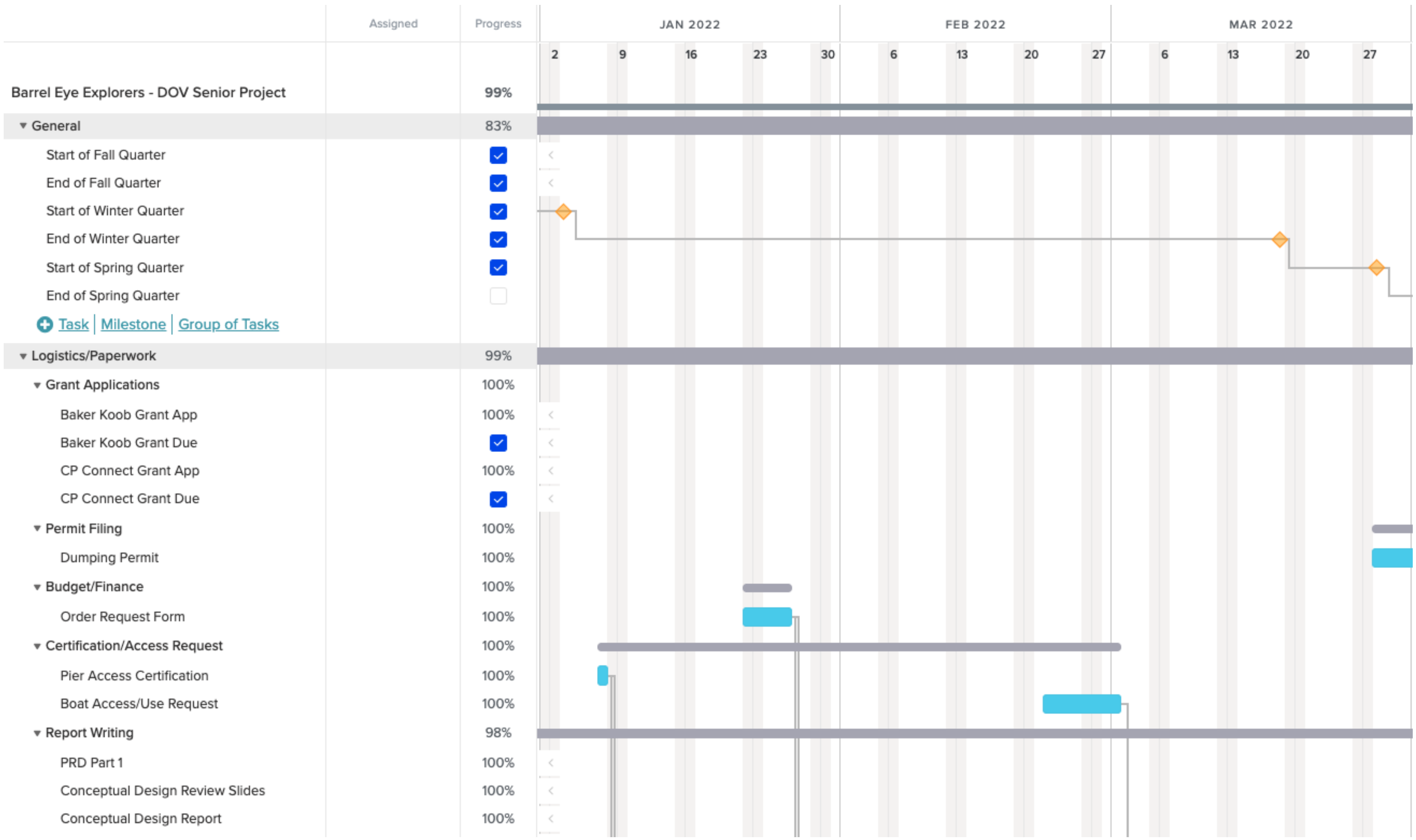


Figure J4: Gantt Chart - Part 4

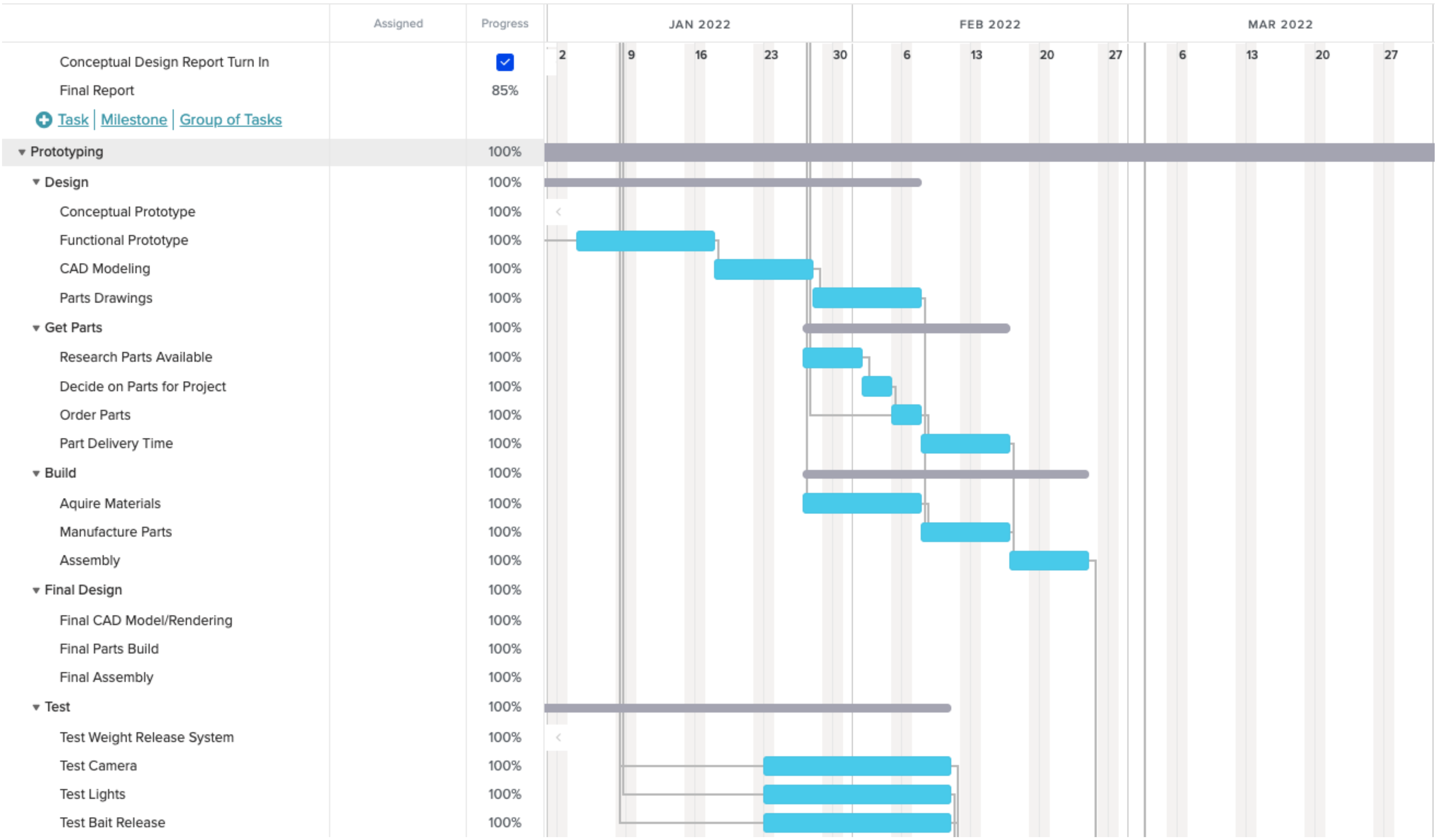


Figure J5: Gantt Chart - Part 5

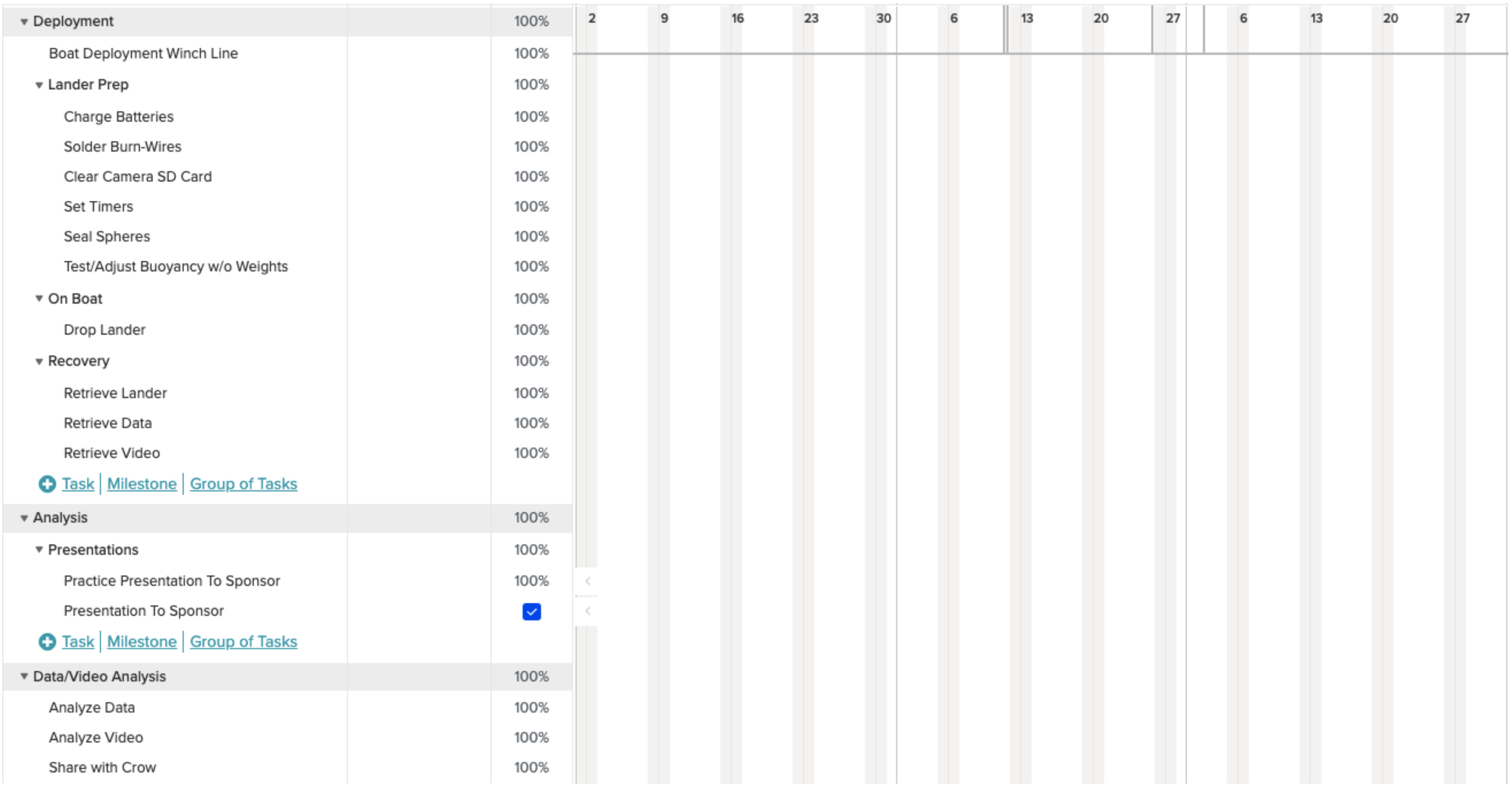


Figure J6: Gantt Chart - Part 6

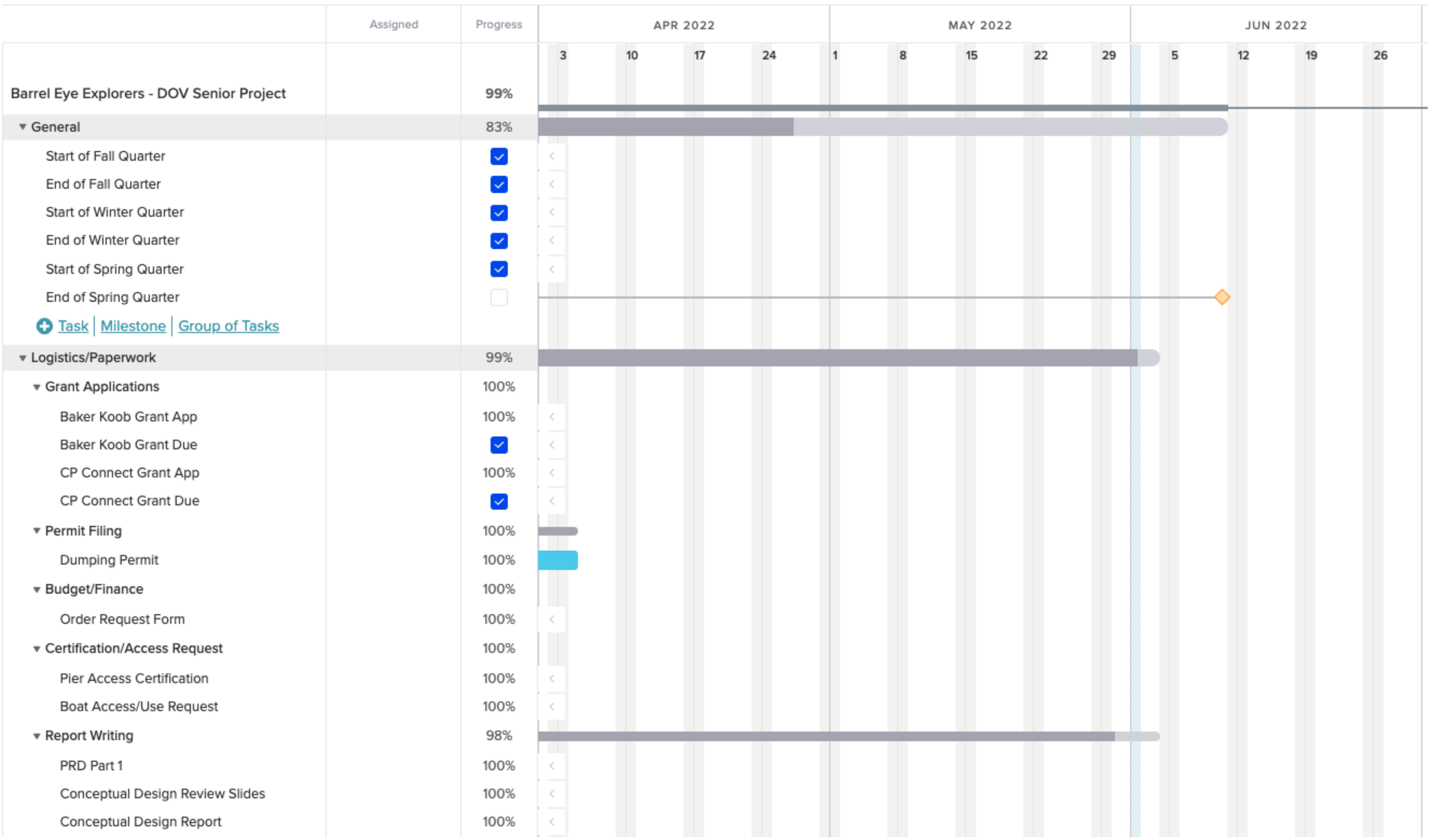


Figure J7: Gantt Chart - Part 7

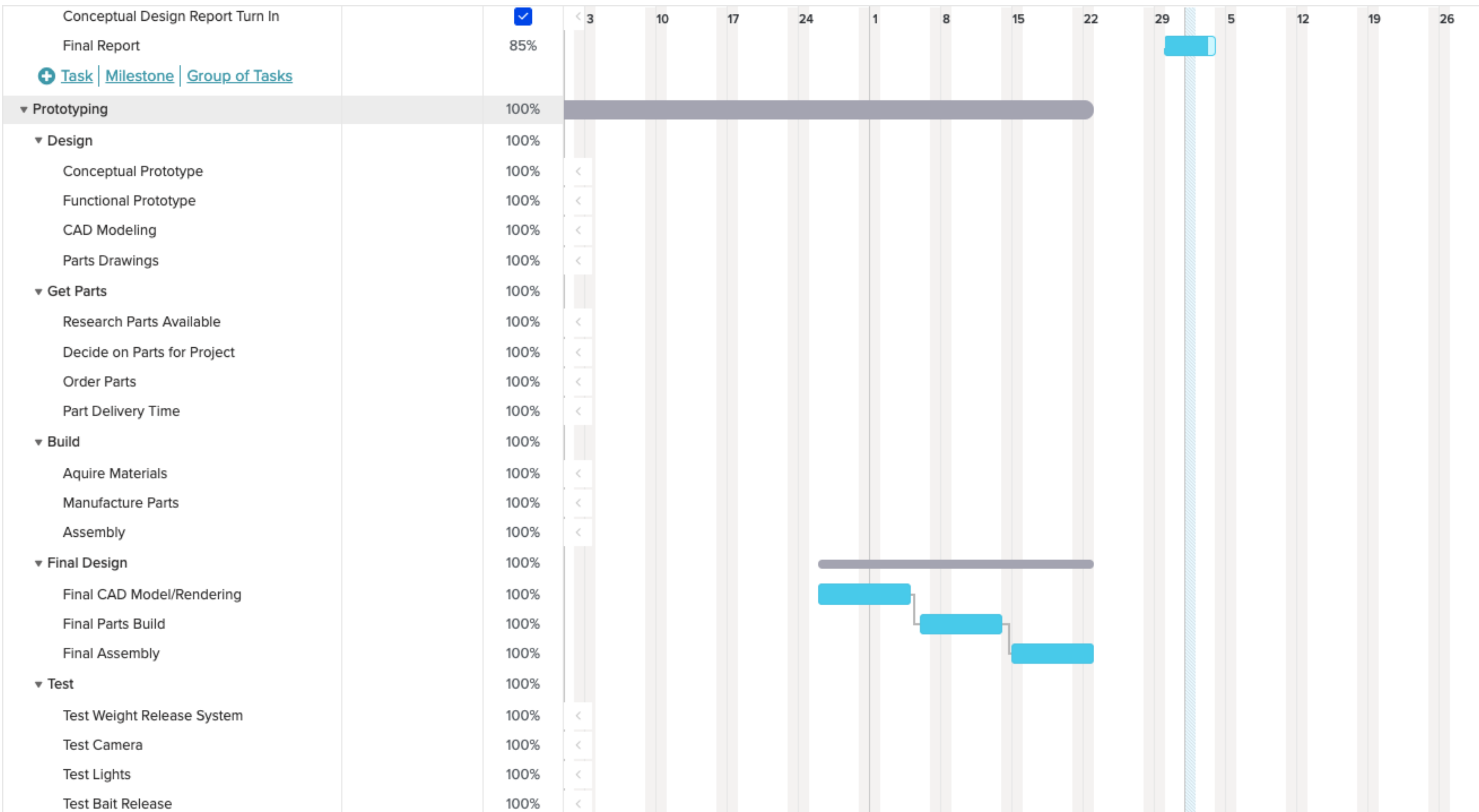


Figure J8: Gantt Chart - Part 8

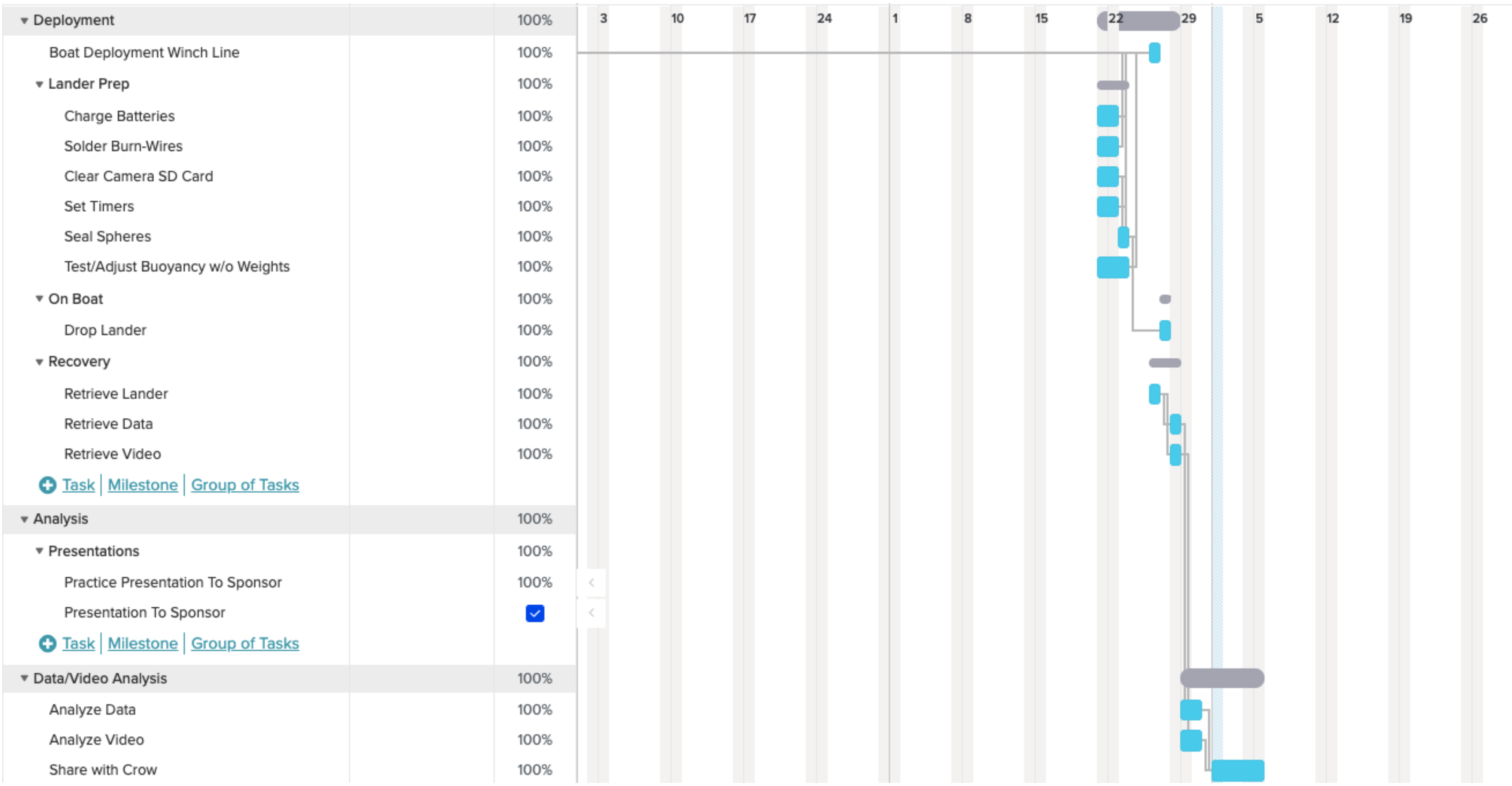


Figure J9: Gantt Chart - Part 9

K. Product Guide for User

Below is a list of steps/considerations for users when operating the lander. This section is divided into the periods of time when the step must take place in reference to each deployment.

Set-Up (On Land)

Prior to each deployment, you must do the following:

1. Charge Batteries
    a. Two Burn Wire Batteries
    b. Large LiPo Battery for Lights
        i. Be sure to charge through the BMS
    c. Back-Up Battery for GoPro/CamDo
    d. GoPro Internal Battery

2. Set Timers
    a. Timers are capable of being set up to 4-Days in Advance
    b. Keep in mind the burn wires will take 10-25 minutes to burn through (this time is dependent on salinity, wire gap length, and other environmental conditions).
    c. It is important the timers are set prior to the batteries being plugged into the circuit: it is the same circuit connection that triggers a beeping noise that triggers the burn wires, so if the circuits are closed when a button is hit it will trigger the battery to discharge through the circuit.

3. Set CamDo Time Settings
    a. Plug CamDo into the GoPro Hero 4
    b. Use the CamDo remote to activate the WIFI
    c. Connect to the CamDo WIFI
    d. Enter 192.168.1.1 into a web browser on a phone or computer
    e. Select the day and time
    f. Select the mode and interval to capture footage
    g. Hit "Save" and "Sync Camera Time" to program the CamDo

4. Plug in Internal Cables
    a. Plug in Each Burn Wire Battery
    b. Plug in the Light Battery/BMS
    c. Plug in the CamDo into the GoPro
    d. Plug in the 1.5mm AUX plug into the CamDo
    e. Plug in the extra battery pack to the CamDo

5. Seal Spheres
    a. Clean each O-ring, O-ring groove, and sealing surface with alcohol and KimTech wipes. Repeat cleaning process until wipes come back clean.
    b. Cover O-ring with Silicone Grease

c. Place O-ring inside Groove
d. Place Half-Sphere with flat surface on top of O-ring
e. Attach Vacuum Pump to Sphere
f. Pull a Vacuum of -0.5 to -0.6 Bar
g. Detach Vacuum Hose
h. Clean O-ring, groove, and surface for cap as done in step (a)
i. Secure Cap onto Valve
j. Repeat for Other Sphere

Deployment (On Boat)

Prior dropping the lander overboard, you must do the following:

1. Attach External Cables
    a. Burn wires mounted at base of lander frame
    b. For all External Plugs, use food grade Silicone Spray on rubber port to ensure watertight seal.
    c. Plug Burn Wires into Electrode Cable
    d. Plug Electrode Cable into Burn Wire Control Sphere
    e. Plug Lights into Cables
    f. Plug Light Cables into Light/Camera Sphere
    g. Coil excess cable lengths around internal beams/structures of the lander to ensure they do not risk them snagging on anything during deployment.

2. Attach Bait
    a. Use zip ties to attach your chosen bait to the bait plate.
    b. Be sure to cut off excess zip tie lengths.
    c. Use as much bait as possible to fill the plate.
    d. Try to pierce each piece of bait at least once to better secure to the plate, simply looping around could cause the bait to slip out of the loop.

3. Attach LifeSaver Ring
    a. Tie one loop of rope through the LifeSaver and one of the upper holes on the lander side plate.
    b. Tie another loop of rope through the LifeSaver.
    c. Use a bolt on the side of the bait arm to secure the loose rope loop to the arm and hold it aloft.

4. Attach Weights
    a. Be sure to use Zinc-Oxide between any threaded metal attachments. This prevents rusting between the surfaces.
    b. Secure one end of chain through the yellow burn wire loop.
    c. Put chain through loop attached to the top of the weights.
    d. Secure the other end of the chain through the yellow burn wire loop on the other side of the lander.

Recovery (On Boat)

After you see the lander breach the surface, you must do the following:

1. Navigate the boat to come alongside the lander.
    a. Be careful - it is better to overshoot and need to come back around several times rather than accidentally run into the lander.

2. Use a boat hook to catch the upper rope loop of the lander.
    a. Pull the lander to the side of the boat
    b. Carefully haul the lander back on board
    c. Use at least two crew to do this – be careful to watch your footing and center of gravity to ensure no one falls overboard.

3. Dispose of excess Bait
    a. Cut off the zip ties
    b. Throw any remaining bait overboard

Clean-Up/Analysis (On Land)

After returning to shore, you must do the following:

1. Wash off the Lander and any other Gear with Fresh Water
    a. Excess salt can dry on the surfaces and lead to corrosion if left for extended periods of time.

2. Detach External Cables
    a. Remove any cable from the outside of the lander before transit.
    b. This is to prevent cables from getting pinched and possibly damaged.

3. Release Seals On Spheres
    a. Unplug any Batteries
    b. Turn Off Timers
    c. Remove Camera + CamDo

4. Recover Footage from GoPro
    a. Remove the SD Card
    b. Plug into Computer
    c. Download Videos

Between Deployments (Consumables)

Several parts of the lander are consumed with each deployment. Because of this you must ensure between deployments that you are fully stocked on these parts:

1. Burn Wires
    a. Since burn wires are a custom-made part, it is best to make them in bulk with an easy to attach piece of wire.

   b. After each deployment simply cut off the used burn wire(s) and solder on a new one – be sure to use Marine Grade Heat Shrink when covering the wire connection.

2. Weights
   a. 20lbs of iron or equivalent cement/iron shot weights must be purchased for each deployment.
   b. Each must have chain and loop of the appropriate length to ensure the lander floats the proper distance above the sea floor such that the bait arm rests in view of the camera.

3. LifeSavers
   a. A mint LifeSaver is used on each deployment.
   b. A complete ring with no cracks or chips is important to ensure the LifeSaver stays intact during descent.

4. Bait
   a. Bait of your choice must be acquired shortly before each deployment.
   b. Type of bait depends on the location and desired species you would like to lure.
   c. Do research to determine what kind of bait to get for your application.
   d. Squid and shrimp are common standards for bait in marine research due to their wide range of predators and strong smell allowing creatures to be lured from farther away.

L. Senior Project Expo Poster