DEEP OCEAN VEHICLE APPLICATIONS AND MODIFICATIONS

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ABSTRACT
Deep Ocean Vehicle Applications and Modifications
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This project had two primary goals: (1) to explore opportunities to further a deep-ocean vehicle’s reach using alternative pressure spheres, and (2) to implement an existing deep-ocean vehicle (lander) in active scientific research.

I gained a greater understanding of the limitations and design choices made for existing pressure spheres using Finite Element Analysis (FEA). My simplified FEA model predicted sphere failure for the existing 30% Fiber Glass 70% Nylon injection molded spheres at an external pressure of 3,954psi or 2,690m ocean-depth (only a 7.38% error compared to the tested minimum failure depth), so I determined it a valid model. I also explored alternative designs and materials that could be used for pressure spheres in deep-sea applications. Existing pressure sphere models filled with an incompressible fluid failed at 12,670psi or 8,621m ocean-depth - over three times the depth of the same sphere filled with air. Next, I varied the sphere thickness of existing spheres to determine its impact on depth rating. While the increased thickness did provide an increase in depth rating, there were diminishing returns as the sphere was made thicker. I deemed both of these design options infeasible for our application.

To consider the use of laminated composite spheres, the addition of an equatorial ring was required to manufacture O-ring seals safely and reliably. A simple cylindrical equatorial ring model using a stainless-steel ring had a predicted failure at 3,017psi or 2,053m ocean-depth. While this model predicted failure at 637m shallower than the sphere without the ring, it was the only ring material tested to reach the rated depth for the existing pressure spheres (2km), so I concluded stainless-steel is the best ring material. A spherical stainless-steel equatorial ring design was then analyzed which predicted failure at 3,915psi or 2,664m ocean-depth – only 8.3% less than the original sphere with no ring. Because of its successful performance and near identical results to the original model, I determined a stainless-steel spherical equatorial ring is the best option for laminated composite sphere sealing.
Finally, I analyzed three different kinds of laminated composite pressure spheres: two carbon fiber and one fiber glass. Each laminate was designed to be quasi-isotropic and as close to 0.8” thick as possible to keep it consistent with the original sphere design. The sphere made of 584 Carbon Fiber with a lay-up of: $([-45/45/0/90]_6)_s$ was found to predict failure at 10,000psi or 6,804m ocean-depth, more than 2.5 times that of the original sphere. Next, a model made of 282 Carbon Fiber with a lay-up of: $([-45/45/0/90]_{11})_s$ predicted failure at 9,242psi or 6,289m ocean-depth – more than 2.3 times as deep as the original pressure spheres. Lastly, a sphere of 7781 Fiber Glass with a lay-up of: $([-45/45/0/90]_{11})_s$ predicted failure at 6,630psi or 4,511m ocean-depth – about two-thirds the depth of the 584 Carbon Fiber composite, but more than 1.6 times the depth of the original sphere. While real-life applications of these materials would include design modifications and manufacturing imperfections which would lower their maximum depth rating, these results are highly encouraging and show that all three materials could be viable options for future production.

Additionally, through partnership with Dr. Crow White and his marine science undergraduate students, I completed numerous deployments for a Before and After Controlled Impact (BACI) study on the area of the proposed windfarm off the coast of Morro Bay, CA. Many modifications were made to the existing lander which enabled it to successfully be implemented in these studies including a new bait containment unit, light color filters, a GPS tracking device, and a large vessel recovery device. A total of 5 pier deployments and 3 boat deployments were conducted by my team over the course of 6-months. Planning for these deployments included accounting for budgeting, weather, permitting, and multi-organizational logistics while working with both NOAA and the Cal Poly marine operations staff.

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1 INTRODUCTION

1.1 STATEMENT OF PURPOSE

This master’s thesis served two primary objectives: (1) to explore opportunities to further an existing deep ocean vehicle’s reach using different pressure spheres, and (2) to implement this deep-ocean vehicle (lander) in active scientific research.

The first objective allowed me to gain a greater understanding of the limitations and material design choices made for existing pressure spheres, as well as how to explore the design of composite pressure spheres for use in deep-sea applications.

The second of these tasks focused on working with Dr. Crow White of the Marine Science Department at Cal Poly and mentoring two of his undergraduate students on how to use and implement the lander in their research activities. My communication, project management, organizational, and teaching skills have all been greatly improved by this work. Additionally, I learned the logistics of planning and executing at sea deployments while accounting for budget, weather, permitting, and external organization protocols.

Figure 1-1: Photographs of Pre-Existing Lander from Senior Project [1]
1.2 BACKGROUND

The deep-ocean vehicle (DOV) used in this project takes the form of 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 [2]. Landers are composed of two primary components: (1) the basic delivery system, and (2) the scientific payload [3]. Typically, landers are designed to be modular such that different scientific payloads may be attached or removed from the delivery system [3]. 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 [3].

![Diagram of DOV Seastang](image)

*Figure 1-2: Labeled Photo360 Render of DOV Seastang from Senior Project [1]*
Free vehicles were first used in a deep-sea scientific study by Maurice Ewing (Lamont) and Allyn Vine (WHOI) [4]. They were inspired by Professor Auguste Piccard’s proposal for the bathyscaphe (a deep-sea submarine which used gasoline in its floats) [4]. 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 [4].

I began work on the lander for this project, DOV Seastang, in the summer of 2021 as a part of my summer internship at Global Ocean Design working with the company owner, Kevin Hardy. Kevin is an expert in the field of ocean engineering having worked at Scripps Institute of Oceanography for 40 years before retiring and starting his own company building deep-sea landers. The lander we built in this internship was the first ever Picolander built by the company and contained an operational Dual-Burn-Wire release systems safe up to 2 km below sea-level. DOV Seastang was then donated to Cal Poly for continued use in scientific research as a part of my senior project.

During the 2021-2022 school year, I worked on the lander as a part of my Interdisciplinary Senior Project through the College of Engineering. As a part of this project, my teammates and I designed, built, and implemented a Scientific Payload on the lander for Dr. Crow White in the Marine Science Department. Dr. White hoped to use the lander as a Baited-Remote Underwater Vehicle (BRUV) to study the sea floor in the area of the proposed windfarm off the coast of Morro Bay, California in a Before-and-After Controlled Impact (BACI) study. To accomplish this, my team developed both a bait-release system and camera/lights system for the lander to allow it to document creatures while on the sea floor [1].

Now, Dr. White has recruited two undergraduate students to his lab who I am mentoring to teach them how to operate and up-keep DOV Seastang for their research. Danika Cornejo (Marine
Science, Class of 2024) and Maya Netto (Biology, Class of 2025) are responsible for developing the BACI survey methodology and results analysis tools for Dr. White’s proposed study. As a part of this work, the three of us have worked together to execute several test deployments of the lander off piers and boats to generate “proof-of-concept” results in order to apply for grants to fully fund the future project.

Additionally, I am working with Dr. Andrew Davol along with other mentors to analyze the possible use of composite materials for deep-sea pressure vessels and determine its feasibility in use on future landers. I completed this by first analyzing existing pressure spheres and comparing Finite Element Analysis (FEA) results to prior testing completed on these spheres by Global Ocean Design. Once modeling techniques were validated, I was able to begin using this model with different material properties to assess their ability to withstand the pressures of deep-sea environments.
2 EXISTING PRESSURE SPHERE ANALYSIS

2.1 SPECIFICATIONS + PROPERTIES

The first objective of this thesis was to explore opportunities to further the lander’s reach using alternative pressure spheres. To do this, however, we must first understand the capabilities of the existing pressure spheres made by Global Ocean Design. There are currently three different types of pressure spheres made for the landers: two nylon injection molded spheres with different amounts of glass fiber, and one made of solid glass. Details on these sphere types can be found in Table 3-1 below. DOV Seastang currently uses the White or Olive spheres with a depth rating of 2 km below sea level. Because of this, we use this material as our baseline to compare my modified designs to.

Table 2-1: Existing 10-inch Diameter Sphere Types

<table>
<thead>
<tr>
<th>Sphere Name</th>
<th>Material Make-Up</th>
<th>Depth Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green</td>
<td>15% Glass Fiber</td>
<td>1 km</td>
</tr>
<tr>
<td></td>
<td>85% Nylon</td>
<td></td>
</tr>
<tr>
<td>White or Olive</td>
<td>30% Glass Fiber</td>
<td>2 km</td>
</tr>
<tr>
<td></td>
<td>70% Nylon</td>
<td></td>
</tr>
<tr>
<td>Glass</td>
<td>100% Glass</td>
<td>10 km</td>
</tr>
</tbody>
</table>

The official name of the material the 2 km spheres are made of is called Durethan BKV 30 H (Polyamide 6, 30% Glass-Reinforced) by LANXESS – Energizing Chemistry [5]. While its full material data sheet can be found in Appendix J, a summary of its key properties for modeling can be found in Table 2-2 below. In this summary, I only used values labeled as “Conditioned”, not “Dry as Molded” since Conditioned “[r]efers to an equilibrium moisture content in a standard laboratory atmosphere of 73°F and 50% relative humidity” while Dry as Molded “[r]efers to a
moisture content less than 0.2% by weight” [5]. This means the properties with 50% humidity more accurately reflect the conditions our spheres will experience in the ocean with 100% humidity. One property that was unavailable from LANXESS was the material’s Poison’s Ratio, since this value was needed for my comparative modeling, I sourced it from an online data sheet for Nylon 66/6, 30% Glass Fiber Reinforced material from MatWeb [6] which contained matching material property values for those given by LANXESS. The MatWeb material data sheet is also available in the Appendix J.

Table 2-2: 30% Glass, 70% Nylon Material Properties Summary Table [5] [6]

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>0.049</td>
<td>lb/in³</td>
</tr>
<tr>
<td>Water Absorption: 24-Hour Immersion</td>
<td>1.0</td>
<td>%</td>
</tr>
<tr>
<td>Water Absorption: Equilibrium (73° F) in Water</td>
<td>7.0</td>
<td>%</td>
</tr>
<tr>
<td>Tensile Stress at Break</td>
<td>14,500</td>
<td>lb/in²</td>
</tr>
<tr>
<td>Tensile Modulus</td>
<td>812,000</td>
<td>lb/in²</td>
</tr>
<tr>
<td>Flexural Strength</td>
<td>24,600</td>
<td>lb/in²</td>
</tr>
<tr>
<td>Flexural Modulus</td>
<td>725,000</td>
<td>lb/in²</td>
</tr>
<tr>
<td>Poison’s Ratio</td>
<td>0.352</td>
<td>-</td>
</tr>
</tbody>
</table>

Now that we know the material the sphere is made of, it is important to know the key dimensions of the sphere for the purpose of accurately modeling its behavior. Full SolidWorks drawings of the existing pressure spheres can be found in Appendix G, but below is a basic sketch of the pressure sphere’s cross section and a table containing key dimensions.
Before going to market with their lander technology, Global Ocean Design completed their own testing of the pressure spheres to compare with the manufacturer specifications and confirm their
safety at depth. Kevin Hardy was gracious in providing me with their test results in order to compare them to my FEA models to verify the model’s validity. Full copies of the implosion test results and methodology can be found in Appendix K, but a summary of their results can be found in the table below.

Table 2-4: 10-inch Sphere Pressure Test Summary [7]

<table>
<thead>
<tr>
<th>Sphere Type</th>
<th>Manufacturer Max Depth (m)</th>
<th>Manufacturer Working Depth (4hr) (m)</th>
<th>Manufacturer Working Depth (1 year) (m)</th>
<th>Test Implosion Pressure (psi)</th>
<th>Final Depth Rating (m)</th>
<th>Factor of Safety</th>
</tr>
</thead>
<tbody>
<tr>
<td>White</td>
<td>4,500</td>
<td>3,800</td>
<td>2,300</td>
<td>4,700</td>
<td>3,175</td>
<td>2,000</td>
</tr>
<tr>
<td>White</td>
<td>4,500</td>
<td>3,800</td>
<td>2,300</td>
<td>4,800</td>
<td>3,243</td>
<td>2,000</td>
</tr>
<tr>
<td>Olive</td>
<td>4,500</td>
<td>3,800</td>
<td>2,300</td>
<td>4,400</td>
<td>2,973</td>
<td>2,000</td>
</tr>
<tr>
<td>Olive</td>
<td>4,500</td>
<td>3,800</td>
<td>2,300</td>
<td>4,350</td>
<td>2,939</td>
<td>2,000</td>
</tr>
<tr>
<td>Olive</td>
<td>4,500</td>
<td>3,800</td>
<td>2,300</td>
<td>4,300</td>
<td>2,905</td>
<td>2,000</td>
</tr>
<tr>
<td>Average</td>
<td>4,500</td>
<td>3,800</td>
<td>2,300</td>
<td>4,510</td>
<td>3,047</td>
<td>2,000</td>
</tr>
</tbody>
</table>

As you can see, the spheres consistently failed well below the original manufacturer maximum depth rating of 4,500 meters, and even below its 4-hour working depth of 3,800 meters. On average, the spheres failed at 3,047 meters below sea level. Wanting a Factor of Safety of 1.5 on such a critical element of their landers, Global Ocean Design decided on a final depth rating of 2,000 meters for these spheres.

For each of these pressure tests, the same test procedure was followed. Each sphere had an interior blocking placed within it to reduce the implosion force, meaning there is less likelihood of damaging the pressure test chamber upon implosion. This Styrofoam blocking can be seen in
Figure 2-2 below. Once filled, the Sphere is sealed using its standard O-ring and purge port with the remaining 3 ports filled with blank plugs as shown in Figure 2-3.

![Figure 2-2: Pressure Sphere Interior Blocking](image)

![Figure 2-3: Olive Sphere Ready for Test](image)
Each sphere was then loaded into the pressure chamber and pressurized at a rate of 7.5 psi/sec (5 m/sec) until failure. The pieces of the sphere were then collected and sent back to Global Ocean Design for reassembly and analysis.

Figure 2-4: Sidus Test Chamber with Sphere Approaching Failure [7]

Figure 2-5: Olive Sphere Implosion Reassembly [7]
Once reassembled, we were able to analyze the sphere for any weak point that may have led to failure. While some parts were found to fail due to unmixed materials leading to variation of material properties within the sphere wall, most failure occurred in locations of voids formed during the manufacturing process. While it appears that the failures begin at these voids, it was promising to see that not all cracks in the sphere propagated through the ports used to run cables through the sphere. This means that when a sphere is properly made, the increased stress surrounding these holes should have minimal impact on the sphere’s final failure pressure.

Figure 2-6: Exterior Implosion Reassembly [7]
Looking at the shape of the recovered pieces and break pattern created by the sphere’s failure, I concluded that the 30% Glass 70% Nylon injection molded composite experienced brittle failure. This makes sense as most composites fail through this method and not ductile failure since they fracture rather than yield. Because of this, we made the decision to analyze the spheres using Rankine Failure Theory which assumes failure occurs in a material when the maximum or minimum principal stress reaches the failure strength of the material [8]. With all this knowledge about how the existing pressure spheres fail, I was able to begin developing my Finite Element Analysis (FEA) model to further analyze sphere failure.

2.3 FINITE ELEMENT ANALYSIS

For my pressure sphere analysis, it was decided that the best way to analyze the spheres consistently and cost effectively was to utilize Finite Element Analysis (FEA) to simulate the pressures faced by the spheres at depth. For this I used the program Abaqus as I had prior experience with the program from my undergraduate studies. Abaqus is a program made by Simulia [9]. Abaqus as a system has no units built into it, this means that the values entered
(including dimensions as well as material properties) all must be self-consistent [10]. This can become difficult to keep track of, so I developed an Excel spreadsheet specifically to track my values and units that I enter into the program. The full spreadsheet can be found in Appendix L, but relevant summary tables are also included with several Abaqus models discussed below. While some entries in Abaqus are more complex, all can be composed of three base units: Length (L), Force (F), and Time (T). For example, $Pressure = \frac{F}{L^2}$. This means the values entered for these must all be composed of the same base units. The units I use in my models are as follows.

<table>
<thead>
<tr>
<th>Fundamental Unit</th>
<th>English Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Length</strong></td>
<td>L</td>
</tr>
<tr>
<td><strong>Force</strong></td>
<td>F</td>
</tr>
<tr>
<td><strong>Time</strong></td>
<td>T</td>
</tr>
</tbody>
</table>

The values of specific inputs will be noted by each relevant model in the coming sections along with their corresponding units.

### 2.3.1 ALUMINUM MODEL

For this analysis, I first began by developing an Aluminum model of the pressure spheres. This was done to verify the model ran with no flaws and that the general magnitudes of the resulting stresses seemed plausible before integrating the specific material properties of the existing spheres. For this model, we decided to use an ultra-simplified version of the sphere where it consisted of two parts, both solid hemispheres of the same outer diameter (OD) and thickness (T) as discussed in Section 2.1. Unlike the model in 2.1 however, this initial model was designed with no O-ring groove. To make the simulation as simple as possible it was set up as an axisymmetric model to reduce computation time. An axisymmetric model takes advantage of a part’s rotational
symmetry to only model the minimum number of elements. This is done by allowing the user to model a 3-D part in just two dimensions where each slice of the part would look the same around its axis of symmetry. Since material properties, part shape, and boundary conditions are constant around the entire pressure sphere, use of an axisymmetric model is valid. All values used in this model and their corresponding units are shown in the table below. As a note, the vacuum pressure corresponds to the -0.6 bar vacuum pulled on the pressure spheres to seal them while above water and the external pressure corresponds to the water pressure at a depth of 2,000m below sea-level.

Table 2-6: Simple Sphere Aluminum (6061) Model Assigned Values

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outer Diameter</td>
<td>10</td>
<td>in</td>
</tr>
<tr>
<td>Wall Thickness</td>
<td>0.8</td>
<td>in</td>
</tr>
<tr>
<td>Young’s Modulus</td>
<td>1.00e+07</td>
<td>lbf/in²</td>
</tr>
<tr>
<td>Poison’s Ratio</td>
<td>0.33</td>
<td>—</td>
</tr>
<tr>
<td>Vacuum Pressure</td>
<td>-8.70226</td>
<td>lbf/in²</td>
</tr>
<tr>
<td>External Pressure</td>
<td>2939.18</td>
<td>lbf/in²</td>
</tr>
</tbody>
</table>

It should also be noted that ductile metals normally utilize Von Mises stress analysis to predict failure, however since this model is simply a proof of concept for model behavior, we will be analyzing the minimum/maximum principal stress as we plan to do with the 30% Glass 70% Nylon material.

The figure on the next page shows the axisymmetric assembly of this model with the axis of symmetry shown as the yellow dashed line. Abaqus automatically uses the Y-axis as the axis of
symmetry in its models, so the drawings of the parts were made accordingly. A surface-to-surface contact interaction was assigned at the interface of the hemispheres and the lower-most point on the bottom hemisphere was fixed to prevent the models from moving during simulation while still allowing them to deform.

Figure 2-8: Abaqus Simple Sphere Assembly

Next the loads were applied to the model, in this case a small internal vacuum pressure was placed within the sphere (depicted as orange arrows in the figure on the next page) and a larger external pressure was placed on the outer surface of the sphere to represent the pressure cause by the water at the ocean’s depth (depicted as purple arrows). These loads were applied in two separate steps, first being the internal pressure which was ran as a complete model before adding the external pressure to ensure all ran smoothly.
Before the model could be run though, the parts had to be meshed. The curved edges were seeded with elements sized at approximately 0.15 with curvature control enabled. The maximum deviation factor \((0.00 < h/L < 1.0)\) was set to 0.1 as well as the minimum size factor \((0.0 < \text{min} < 1.0)\). The flat surfaces were seeded with elements sized at approximately 0.1, which is slightly smaller to account for more variation in stresses happening through the thickness of the sphere than around its circumference. The element shape was set to Structured Quad elements with minimal mesh transitions. The resulting mesh looks as follows.
With the model set up complete, we were able to run the full simulation. The values most of interest to us in this analysis are the Maximum and Minimum Principal Stresses ($S$, Max. Principal & $S$, Min. Principal), the Contact Opening (COPEN) and the Contact Pressure (CPRESS). Full figures of these results can be seen on the following pages but below is a table showing the maximum and minimum result for each of these properties. Positive and negative values of stress simply show whether a part is in tension (+) or compression (-) and it is in fact the magnitude of stress which we care most about. In the case of an external pressure sphere, we would expect the entire vessel to be under compression stress.
Table 2-7: Simple Sphere Aluminum (6061) 2km Depth Results Summary

<table>
<thead>
<tr>
<th>Property</th>
<th>Max. Value</th>
<th>Min. Value</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max. Principal Stress</td>
<td>-2.255e+02</td>
<td>-2.816e+03</td>
<td>lbf/in²</td>
</tr>
<tr>
<td>Min. Principal Stress</td>
<td>-9.439e+03</td>
<td>-1.073e+04</td>
<td>lbf/in²</td>
</tr>
<tr>
<td>Contact Opening</td>
<td>-2.260e-05</td>
<td>-2.579e-05</td>
<td>in</td>
</tr>
<tr>
<td>Contact Pressure</td>
<td>+1.071e+04</td>
<td>+9.442e+03</td>
<td>lbf/in²</td>
</tr>
</tbody>
</table>

Figure 2-11: Abaqus Simple Sphere Aluminum Max. Principal Stress
Figure 2-12: Abaqus Simple Sphere Aluminum Min. Principal Stress

Figure 2-13: Abaqus Simple Sphere Aluminum Contact Opening
From this model, we can see that the stress distribution within the pressure sphere aligns with our expectations for an externally loaded pressure vessel. This means that the largest stress occurs on the internal surface of the pressure sphere (in this case \(-1.073e+04 \text{ lbf/in}^2\)) while the smallest stress occurs on the external surface of the pressure sphere (\(-2.255e+02 \text{ lbf/in}^2\)). Additionally, we see that the opening of the sphere is shown as extremely small negative values (on average \(-2.420e-05 \text{ in}\)), meaning there is in fact no opening, but instead overlap in the parts during the simulation. Additionally, we can see that the largest overlap in the surfaces occurs on the internal side of the sphere while the smallest occurs on the outer side of the sphere. This aligns with the contact pressure being largest on the inner surface of the sphere, therefore pushing the two faces together the most on this side. Lastly, the contact pressure being largest on the inside surface of the sphere (\(+1.071e+04 \text{ lbf/in}^2\)) and smallest on the outside edge of the sphere (\(+9.442e+03\)), agrees with the higher stress experienced on the inside of the sphere due to the compressive load being applied to the sphere by the surrounding water.

### 2.3.2 30% GLASS 70% NYLON MODEL

The next step was to begin modeling with the actual material used on the existing pressure spheres. For this, I began by using the exact same simplified model shape as the Aluminum simulation done above. I used the same mesh as well, so the only difference was the material properties. All values used in this model and their corresponding units are shown in the table below. Like with the aluminum model, the vacuum pressure corresponds to the -0.6 bar vacuum.
pulled on the pressure spheres to seal them while above water and the external pressure corresponds to the water pressure at a depth of 2,000m below sea-level.

Table 2-8: Simple Sphere 30% Glass, 70% Nylon Model Assigned Values

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outer Diameter</td>
<td>10</td>
<td>in</td>
</tr>
<tr>
<td>Wall Thickness</td>
<td>0.8</td>
<td>in</td>
</tr>
<tr>
<td>Young's Modulus</td>
<td>8.12e+05</td>
<td>lbf/in²</td>
</tr>
<tr>
<td>Poison's Ratio</td>
<td>0.352</td>
<td>-</td>
</tr>
<tr>
<td>Vacuum Pressure</td>
<td>-8.70226</td>
<td>lbf/in²</td>
</tr>
<tr>
<td>External Pressure</td>
<td>2939.18</td>
<td>lbf/in²</td>
</tr>
</tbody>
</table>

After running this new simulation, we can confirm whether its results are beginning to align with the known test data. For this, we will be looking at the same values as we did in the aluminum model. Full figures of these results can be seen on the following pages but below is a table showing the maximum and minimum result for each of these properties.

Table 2-9: Simple Sphere 30% Glass, 70% Nylon 2km Depth Results Summary

<table>
<thead>
<tr>
<th>Property</th>
<th>Max. Value</th>
<th>Min. Value</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max. Principal Stress</td>
<td>-2.254e+02</td>
<td>-2.816e+03</td>
<td>lbf/in²</td>
</tr>
<tr>
<td>Min. Principal Stress</td>
<td>-9.439e+03</td>
<td>-1.073e+04</td>
<td>lbf/in²</td>
</tr>
<tr>
<td>Contact Opening</td>
<td>-2.588e-04</td>
<td>-2.948e-04</td>
<td>in</td>
</tr>
<tr>
<td>Contact Pressure</td>
<td>+1.071e+04</td>
<td>+9.456e+03</td>
<td>lbf/in²</td>
</tr>
</tbody>
</table>
Figure 2-15: Abaqus Simple Sphere 30% Glass, 70% Nylon 2km Depth Max. Principal Stress

Figure 2-16: Abaqus Simple Sphere 30% Glass, 70% Nylon 2km Depth Min. Principal Stress
From this model, we can see that the stress distribution within the pressure sphere as well as the resulting contact pressure are nearly identical to that in the aluminum model. This makes sense as the resulting stress and pressure are not affected by the material properties, only the load conditions. The material properties only affect the deformation of the sphere which we can see here goes from $-2.420e-05$ inches on average in the aluminum model to an average of $-2.768e-04$ inches in the glass-nylon model. This is an entire order of magnitude difference showing that these spheres are significantly more deformed under pressure than an aluminum sphere would be. This is exactly what we would expect from the material, so confirms our preliminary model is working well.
2.3.3 MESH CONVERGENCE STUDY

With our preliminary model confirmed to work, the next step is to conduct a mesh convergence study. Since running simulations with finer meshes results in larger computational loads and therefore more computation time, it is ideal to have as large a mesh as possible. However, large meshes can lose accuracy due to oversimplification of the geometry. Because of this, a mesh convergence study is completed to compare mesh sizes in order to select the "best" mesh for the job. This best mesh is selected as the largest mesh size with the smallest change in value of critical results between it and the next mesh size. For this study, we will be using the same material properties for 30% Glass 70% Nylon and load cases as discussed in the last section but will vary the mesh size to see how it impacts the results. The six mesh sizes can be seen in the figure below while dimensions of elements can be found on the table on the next page.

![Figure 2-19: Abaqus Simple Sphere Mesh Comparison: Coarse to Fine (#1-7)](image-url)
Below is a table denoting the average size of each element in the meshes tested as well as the corresponding values of our critical results from each simulation. The finer the mesh, the more precise the results were however this also came with the tradeoff of longer run times. For example, while meshes #5 and #6 took 10-20 minutes to run, mesh #7 took several hours.

**Table 2-10: Mesh Convergence Study Results Table**

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.50</td>
<td>0.75</td>
<td>-8.751e+2</td>
<td>-1.051e+4</td>
<td>-1.42e-3</td>
<td>1.037e+4</td>
<td>9.681e+3</td>
</tr>
<tr>
<td>2</td>
<td>0.25</td>
<td>0.50</td>
<td>-5.829e+2</td>
<td>-1.058e+4</td>
<td>-8.92e-4</td>
<td>1.051e+4</td>
<td>9.578e+3</td>
</tr>
<tr>
<td>3</td>
<td>0.20</td>
<td>0.25</td>
<td>-4.529e+2</td>
<td>-1.062e+4</td>
<td>-4.63e-4</td>
<td>1.059e+4</td>
<td>9.525e+3</td>
</tr>
<tr>
<td>4</td>
<td>0.15</td>
<td>0.20</td>
<td>-3.634e+2</td>
<td>-1.066e+4</td>
<td>-3.69e-4</td>
<td>1.064e+4</td>
<td>9.497e+3</td>
</tr>
<tr>
<td>5</td>
<td>0.10</td>
<td>0.15</td>
<td>-2.254e+2</td>
<td>-1.073e+4</td>
<td>-2.77e-4</td>
<td>1.071e+4</td>
<td>9.456e+3</td>
</tr>
<tr>
<td>6</td>
<td>0.05</td>
<td>0.10</td>
<td>-1.080e+2</td>
<td>-1.079e+4</td>
<td>-1.82e-4</td>
<td>1.077e+4</td>
<td>9.422e+3</td>
</tr>
<tr>
<td>7</td>
<td>0.001</td>
<td>0.005</td>
<td>6.588e+0</td>
<td>-1.085e+4</td>
<td>-9.191e-6</td>
<td>1.084e+4</td>
<td>9.392e+3</td>
</tr>
</tbody>
</table>

For our mesh selection we will be looking at our most important result – the minimum principal stress. This is the value which will inevitably tell us if the sphere fails and at what depth it does so. Additionally, we know that the stresses within the sphere change much faster in the radial direction than it does around the circumference (which should be identical). So, we will be defining the element size based on its radial node spacing. Since the minimum principal stress is our most critical value, we not only want to compare how it changes between meshes, but how it compares to mechanical theory predictions. The theoretical value for the minimum principal stress was calculated using a 3-D Mohr’s circle on the radial and circumferential stresses of the
system. The circumferential stress was calculated using the equation for stress in a Thick Spherical Pressure Vessel as laid out in the “Stress Analysis Manual” from the Air Force Flight Dynamics Laboratory in October 1986 [11]. The equation of interest to us is the one for circumferential stress (labeled as \( F_t \) in their equations and diagram shown below).

![Figure 2-20: Thick Spherical Pressure Vessel [11]](image)

As shown in the diagram above, the values used in this calculation are denoted as follows:

\[
F_t = \text{Circumferential Stress} \\
\begin{align*}
a &= \text{Inside Radius} \\
b &= \text{Outside Radius} \\
p_i &= \text{Inside Pressure} \\
p_o &= \text{Outside Pressure} \\
r &= \text{Radius of Interest}
\end{align*}
\]

The circumferential stress at the innermost surface \( r = a \) will be the largest compressive stress in the sphere for an external pressure vessel, and therefore is our theoretical minimum principal stress. Using the equation on the next page with the sphere dimensions and loading conditions used for our model, we calculate the circumferential stress to be \(-10,848\) psi. Additionally, we know that on the internal surface, the radial stress is simply \( F_r = -p_i \), meaning the radial stress is \(8.702\) psi.
\[ F_t = \frac{p_o b^3(2r^3 + a^3)}{2r^3(a^3 - b^3)} - \frac{p_i a^3(2r^3 + b^3)}{2r^3(a^3 - b^3)} \]

*Equation 2-1: Circumferential Stress of a Thick-Walled Sphere [11]*

We can then use these stresses to calculate the maximum and minimum principal stresses using a 3-D Mohr’s circle. For this analysis, we used a polar coordinate system for the sphere, giving us the following values for stresses. Note: the shear stresses were assumed to be zero since all stresses resulted from pressures on the sphere which always act perpendicularly to the surface and would therefore result in no out of plane stresses.

\[
\begin{align*}
\sigma_r &= 8.702 \text{ psi} \\
\sigma_\theta &= -10,848 \text{ psi} \\
\tau_r &\theta = \tau_\theta &\phi = 0 \text{ psi}
\end{align*}
\]

For each plane \((r - \theta, r - \varphi, \text{ and } \theta - \varphi)\), we can calculate the average stress \((\sigma_{avg})\) to find the center of its Mohr’s circle, the circle’s radius \((R)\), the maximum and minimum principal stresses for that plane \((\sigma_{max}, \sigma_{min})\), and the maximum shear stress \((\tau_{max})\). These can all then be used to draw a complete 3-D Mohr’s circle where the circle intersection points on the \(\sigma\)-axis denote the maximum and minimum principal stresses. Below are sample equations for the \(r - \theta\) plane.

\[
\begin{align*}
\sigma_{avg} &= \frac{\sigma_r + \sigma_\theta}{2} \\
R &= \sqrt{\left(\frac{\sigma_r - \sigma_\theta}{2}\right)^2 + \tau_r \theta^2} \\
\sigma_{max/min} &= \sigma_{avg} \pm R \\
\tau_{max} &= \frac{|\sigma_{max} - \sigma_{min}|}{2}
\end{align*}
\]

From these equations we found the following Mohr’s circle with the below values:

\[
\begin{align*}
\sigma_{max} &= 8.702 \text{ psi} \\
\sigma_{min} &= -10,848 \text{ psi} \\
\sigma_{avg} &= -5,419.6 \text{ psi} \\
\tau_{max} &= 5,428.3 \text{ psi}
\end{align*}
\]
As you can see from our Mohr's circle above, the final theoretical value for the minimum principal stress is $\sigma_{\text{min}} = -10,848 \text{ psi}$. This value can be used to compare my mesh convergence study results in order to select the best mesh for all future analysis. Full hand calculations for both the radial and circumferential stress as well as the principal stresses using Mohr's circle can be found in Appendix M.

Now that we have our theoretical value for comparison, we can begin looking at mesh selection. On the next page is a summary table of the minimum principal stress results for each mesh and how much they vary from each other, as well as from the theoretical value. Additionally, we have provided plots of these same values compared to radial node spacing to best understand how mesh size impacts our results.
Table 2-11: Mesh Convergence Study Minimum Principal Stress Results Table

<table>
<thead>
<tr>
<th>Mesh #</th>
<th>Radial Node Spacing</th>
<th>Min. Minimum Principal Stress (psi)</th>
<th>Percent Difference from Previous Mesh (in)</th>
<th>Percent Error from Theoretical (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.50</td>
<td>-1.051e+4</td>
<td>-</td>
<td>3.114%</td>
</tr>
<tr>
<td>2</td>
<td>0.25</td>
<td>-1.058e+4</td>
<td>0.664%</td>
<td>2.469%</td>
</tr>
<tr>
<td>3</td>
<td>0.20</td>
<td>-1.062e+4</td>
<td>0.377%</td>
<td>2.100%</td>
</tr>
<tr>
<td>4</td>
<td>0.15</td>
<td>-1.066e+4</td>
<td>0.376%</td>
<td>1.732%</td>
</tr>
<tr>
<td>5</td>
<td>0.10</td>
<td>-1.073e+4</td>
<td>0.655%</td>
<td>1.086%</td>
</tr>
<tr>
<td>6</td>
<td>0.05</td>
<td>-1.079e+4</td>
<td>0.558%</td>
<td>0.533%</td>
</tr>
<tr>
<td>7</td>
<td>0.001</td>
<td>-1.085e+4</td>
<td>0.555%</td>
<td>-0.020%</td>
</tr>
<tr>
<td>Theoretical</td>
<td></td>
<td>-1.0848e+4</td>
<td>-0.020%</td>
<td>0.000%</td>
</tr>
</tbody>
</table>

Figure 2-22: Plot of Min. Minimum Principal Stress vs Mesh Size
As you can see from the above graphs and table, Mesh 7 with a radial node spacing of 0.001 was nearly identical to our theoretical calculations with only a 0.02% error. While this is fantastic, its several-hour run time makes it extremely impractical for our analysis purposes. So, I made the
decision to eliminate this mesh as an option. While Mesh 5 had a smaller run time than Mesh 6, the difference in run time was minimal compared to Mesh 7. Additionally, Mesh 6 was the only mesh aside from Mesh 7 to have less than 1% error from the actual theoretical value. For these reasons, Mesh 6 was selected as the optimal mesh for this paper’s analysis.

2.3.4 COMPARISON TO TEST RESULTS

Now that we have a final mesh for our model, we can simulate the failure conditions experienced in Section 2.2 to compare to real world application. If our model shows failure at the same point as was experienced by the spheres in real life, this means that with proper material properties entered into our model, it should be accurate at predicting failure of any other material or design we use with this mesh and model.

To begin this analysis, I started by running a model to the average failure pressure experienced by the spheres in Section 2.2, which was 4,510 psi. From this we found that the minimum principal stress distribution in the stress looks as follows.

![Minimum Principal Stress at Average Sphere Failure Pressure](image)

*Figure 2-25: Minimum Principal Stress at Average Sphere Failure Pressure*
We know from Section 2.1 that the material used in the spheres (30% glass, 70% nylon) has a tensile stress at break of 14,500 psi. As you can see in the above figure, almost all of the spheres cross section is experiencing a compressive stress of greater than 14,500 psi. In fact, the smallest magnitude minimum principal stress experienced by the sphere is at 14,420 psi which is very nearly at failure as well. To be conservative in our future analysis, we would not want our spheres to experience failure stress at any point in our model. Therefore, we would want to find the pressure at which the minimum principal stress values are all smaller than 14,500 psi. To determine what this pressure would be for our model, we need to run it at lower external pressures.

The next pressure we ran the sphere at was the lowest failure pressure experienced by any of the test spheres in Section 2.2, 4,300 psi. As you can see in the below figure, about one third of the sphere’s cross section is experiencing a minimum principal stress greater than 14,500 psi. While this is much closer to what we would determine to be failure for our model, we still need to run smaller pressure values to find an exact failure point.

![Figure 2-26: Minimum Principal Stress at Minimum Sphere Failure Pressure](image-url)
After several runs of gradually adjusting the external pressure load on our model, we eventually found a pressure at which the first part of the sphere experienced a failure stress of 14,500 psi. This external pressure was 3,954 psi which equates to an ocean depth of 2,690 meters. This is 215 meters shallower than the earliest failing sphere from Global Ocean Design’s experiments but is still 690 meters deeper than what the pressure spheres are rated too. Since models are supposed to be ideal, it is highly preferred that our model predicts failure sooner than the spheres experienced in real life than later. Since its failure point only has 7.38% error compared to the real minimum failure location, this validates our model as accurate and reliable. Additionally, any error caused by our model failing sooner than the test specimens would only result in a larger factor of safety being applied to the sphere than is needed for its safe operations.

![Diagram](image)

*Figure 2-27: Minimum Principal Stress at Minimum Sphere Failure Pressure*

### 2.3.5 O-RING GROOVE EFFECTS

Now that we know my simplified model can accurately predict sphere failure for the existing pressure spheres, we wanted to analyze the simplifications made in my model to see how they
affect various results. To begin this process, I started by making an axisymmetric model that included the O-ring groove and ran it to a 2km depth. This design was chosen because while O-ring seals are designed to minimize stress while maintaining pressure seals, we wanted to see how it might affect the contact opening and pressure of the hemisphere interfaces. The model I built followed the same dimensions outlined in Section 2.1 and used the same material properties as listed in Table 2-8. I generally used the same mesh settings as those described by Mesh 6 in the Mesh Convergence Study (0.05 radial node spacing and 0.1 circumferential node spacing), however around the O-ring groove I biased the mesh to have node spacing of 0.01. The mesh was generated using Quad elements as a free mesh using a medial axis algorithm and minimizing mesh transition. The final mesh or this model can be seen in the figure below.

![Figure 2-28: Abaqus Simple Sphere with O-Ring Groove Mesh](image)

After running the model, we can see that the minimum principal stress gets very extreme values on the corners of the O-ring groove as shown in the figure on the next page. This is not surprising due to stress concentrations in this simplified shape of the O-ring groove, but since a real O-ring
groove would not have these sharp corners, we do not need to worry about these stress results and can instead focus on the contact opening and pressure.

![Figure 2-29: Minimum Principal Stress for O-Ring Groove Model](image)

Looking at the contact opening and pressure results on the next page, we can see some very interesting results. In our original model, all contact opening results showed small interferences across the contact surface, with a larger interference at the internal edge and less at the external edge. While the entire face remains in interference for our O-ring groove model, we can see that the interference is significantly less (on the order of $10^{-5}$ rather than $10^{-4}$). Additionally, we can see that the majority of the contact surface has a smaller interference while the area directly around the O-ring groove has significantly higher interference. This makes sense since the area of the O-ring groove provides no support against the pressure of the top hemisphere pushing down on the lower hemisphere, causing a larger force to be applied to the nearby surface and hence greater interference. This is also reflected in the contact pressure results where the pressure is highest near the edges of the groove and virtually non-existent within the groove itself. The magnitude of the contact pressure is consistent with that from the simple model.
Figure 2-30: Abaqus Simple Sphere O-Ring Groove Contact Opening

Figure 2-31: Abaqus Simple Sphere O-Ring Groove Contact Pressure
Overall, we can see that while the O-ring groove does have an impact on the sphere’s contact pressure and opening results, it is not significant enough to concern us for future changes. For this reason, it is safe to neglect the O-ring groove in most future models.

2.3.6 QUARTER MODEL

While our simplified axisymmetric models were sufficiently accurate for predicting real life failure, we wanted to see how the addition of the electrical port holes in the pressure sphere would affect the FEA results. To do this, I created a quarter model of the pressure sphere to take advantage of symmetry in the part to cut down on computation time. This model included the addition of one electrical port hole which has a diameter of 0.368" and is positioned 30° up from the central axis on the lower hemisphere. This model was meshed using the same mesh size determined in the mesh convergence study (0.05 radial node spacing and 0.1 circumferential node spacing), with the addition of 0.05 node spacing present on the edges of the hole. The figure below shows the mesh of this model. There was no O-ring groove present in this model.

![Figure 2-32: Abaqus Simple Sphere Quarter Model with Electrical Port Mesh](image)

After running this model as is, we found that the hole led to an asymmetry in the pressure application causing extreme deformation and stresses at the lower center point of the sphere.
where the pinned boundary condition was applied to the model. To eliminate this problem, we added a 3D planar disk to the model on the inner surface of the hole which allowed us to apply both the internal and external pressures to the model while allowing the sphere to deform normally. This disk was attached using a Tie constraint to the internal surface of the sphere. Below is a close up of the mesh for the electrical port hole both with and without the planar disk.

![Figure 2-33: Abaqus Electrical Port Mesh With (Left) and Without (Right) Planar Disk](image)

We ran this model with the same 2km depth conditions as the axisymmetric models for the mesh convergence study as well as the O-ring groove model. We can see from the results shown in the figure on the next page that adding the hole certainly increases the stresses within the sphere. While the axi-symmetric model showed a Minimum Principal Stress of -1.079e+4 psi, this model shows nearly double the maximum stress at -2.151e+4 psi. Additionally, rather than the minimum stress occuring on the internal sphere surface as it did in the simple axisymmetric model, this time the minimum principal stress occurs at the surface of the hole as seen in the figure below. Note that two of the views shown are cut on a plane through the center of the hole in order to better show what is happening on the spheres cross-section.
Figure 2-34: Minimum Principal Stress for Quarter Model with Electrical Port
Top-Right and Bottom Views are Cut Through Hole Center
We then looked at the contact surface of the hemispheres and can see that the average contact opening is -1.63e-4 inches which is very close to the axisymmetric model which has a value of -1.82e-4 inches. As you can see in the figure below, the largest interference occurs on the inside surface of the sphere while the smallest occurs on the outside. This also aligns with what we see in our axisymmetric model.

Additionally, we can see that the contact pressure results are very similar to that of the axisymmetric model with the quarter model having a minimum contact pressure of 9.414e+3 psi (compared to 9.422e+3 psi) and a maximum of 1.080e+4 psi (compared to 1.077e+4 psi). As you can see in the figure on the next page, the contact pressure gradient is basically the inverse of the contact opening with the largest pressure being in the same place as the largest interference – on the inside surface of the sphere. This is the same as the axisymmetric model and there is no discernable difference caused across the surface by the addition of the electrical port hole.
Because the contact opening and pressure results are nearly unchanged from the axisymmetric model, we do not need to worry about using the quarter model for their prediction in future analysis. Additionally, while the stress results are greatly impacted with nearly doubled the minimum principal stress compared to the axisymmetric model, our simple sphere axisymmetric model was found to be highly accurate, and conservative compared to real life test results for the pressure spheres. For this reason, we have decided that all future analysis may safely be completed using only the axisymmetric model.

As a note, we recognize that this quarter model does not reflect the real-life stress concentrations experienced by the sphere. This is because it doesn’t include the stainless-steel plug which would fill the hole, or any of the threads which hold this plug-in place. However, since we determined our axisymmetric model viable for future analysis, we do not need to make these additions to our model for future analysis.
3 ALTERNATIVE SPHERE DESIGNS + MATERIALS

3.1 ALTERNATE DESIGNS

While there are many considerations to make regarding how to enable our existing lander to go deeper, a large portion of these options can fall into the category of alternative design approaches. These involve somehow varying the size, shape, or other conditions involving the pressure spheres to affect the stresses seen on the pressure spheres at depth. Many of these options have been analyzed for their viability below.

3.1.1 FILLED WITH INCOMPRESSIBLE FLUID

One design alternative we explored was the idea of filling the pressure sphere with an inert, incompressible fluid. This idea stemmed from an experiment Kevin Hardy conducted at Global Ocean Design where he filled a 1km rated sphere 90% full of water before pulling a vacuum on it and putting it in the pressure chamber. To his surprise, the sphere never failed and successfully went all the way to Mariana Trench depth (about 11km) which is the deepest known part of the ocean. Because of this, we decided to explore what would happen if we were able to get the ideal case of the sphere being 100% filled with an incompressible fluid.

For this analysis we used the axisymmetric model from Chapter 2, with the difference of there being no internal pressure applied to the sphere. Instead, we fixed the internal surface in place to represent the surface of the incompressible fluid it would be touching instead. We decided to run both a simple sphere model and an O-ring groove model since one of our primary concerns about having the incompressible fluid inside would be that the seal of the sphere’s surfaces might pop open when the spheres deform. The simple sphere model was used to look at the overall stress distribution while the O-ring groove model was used to look at contact opening and pressure results.

Below you can see the minimum principal stress results for this model. Interestingly, while the original air filled model showed a Minimum Principal Stress of -1.079e+4 psi, this model only
has a minimum principal stress of \(-3.363 \times 10^3\) psi. This is an entire order of magnitude difference and shows us that filling a sphere with an incompressible fluid drastically reduces the stresses seen in the spheres.

![Color scale for minimum principal stress](image)

**Figure 3-1: Abaqus Incompressible Fluid Filled Sphere 2km Depth Min. Principal Stress**

While the principal stress was the primary value of interest for this model, it was also interesting to see how the contact pressure and opening were affected in this model. As you can see in the figures on the next page, while the gradient of opening and pressure changes had been very consistent in the air-filled model, this fluid filled model has a much more constant value across the majority of the surface. Specifically, we can see that it isn’t until a very small distance from the internal surface that either of these values experience significant change.
Now that we determined the stress results seem promising, it was time to check the O-ring groove model to confirm there was no opening appearing on the contact surface before testing just how deep this modification would allow our sphere to go. As you can see in the figures on the next pages, the stress results on this model show a large stress concentration on the O-ring groove, however this is not a concern for the same reasons discussed in Section 2.3.5. Next, we can see that while the contact opening and pressure results have changed from the air-filled model, the opening values remain negative across the entire surface which indicated interference and no opening at the contact surface. With this promising result, we are now able to use the simple sphere axisymmetric model to test its ultimate depth rating.
Figure 3-4: Abaqus O-Ring Groove Incomp. Fluid Filled Sphere 2km Depth Min. Princ. Stress

Figure 3-5: Abaqus O-Ring Groove Incomp. Fluid Filled Sphere 2km Depth Contact Opening
Using the same process as we did in Section 2.3.4 to compare our analysis to real life test results, we began to gradually increase the external pressure applied to our model. With each increase we compared the minimum principal stress value experienced in the model to the materials tensile stress at break (14,500 psi as depicted in Section 2.1). The model ultimately showing failure had an external pressure of 12,670 psi which equated to 8,621 meters of ocean depth! This is over three times the maximum depth of the exact same sphere under air-filled conditions (3,954 psi or 2,690 meters below sea level). Additionally, as you can see in the figures on the next page, the contact opening remains in interference with no opening for sphere failure.
at this depth. This is an astonishing improvement and should be considered as a possibly viable alternative design approach for future applications.

Figure 3-7: Abaqus Incompressible Fluid Filled Sphere Failure Min. Principal Stress

Figure 3-8: Abaqus Incompressible Fluid Filled Sphere Failure Contact Opening
While the idea of filling a sphere with an incompressible fluid is viable for giving it a deeper depth rating, it would still present challenges with everyday use. Specifically, it would be both difficult, messy and time consuming to fill and drain the spheres every time we want to charge batteries or change out memory cards. Additionally, for the camera sphere, this would require the camera being submerged within the fluid. So, while an inert fluid may be selected to not interfere with the electronics (like mineral oil) this could still have the potential of interfering with the camera’s view capabilities. Additionally, while the sphere doesn’t fail the inclusion of an incompressible fluid within the sphere does provide the possibility that the pressure applied to the external surface of the sphere may be transferred to the internal components. Since many of its components are highly sensitive to pressure, more testing would need to be done to determine the internal pressure effects on the lander’s electrical components. For these reasons, we should continue to explore other options.

3.1.2 SPHERE THICKNESS

The next idea to affect how deep the pressure spheres could go, would be to change the sphere thickness. This poses a problem for the existing sphere, however, in that no matter which direction you expand the sphere (internal or external) it runs into other parts of the lander. If you expand the sphere’s thickness internally, you will run into electrical components which are already touching the internal edges of the sphere. If you expand the sphere thickness externally,
you will need to make a new lander frame of larger dimensions to accommodate it. While neither of these options are great, for the sake of testing all options, let's consider a design where you expand the sphere thickness externally since it would be easier to make a new frame than to purchase entirely new and smaller electronics.

For this test, all spheres will have a constant internal diameter (8.4 inches) and the outer diameter will increase to increase the sphere’s thickness. Each of these spheres will be run to failure depth to analyze its new maximum depth rating. We began by increasing the sphere thickness from 0.8 inches to 1 inch since this size would likely be able to still fit in the existing lander frame with only minor modifications, then continued to increase in half inch increments. Below is a table depicting the key input values of the spheres which remained constant across all models for this test.

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Internal Diameter</td>
<td>8.4</td>
<td>in</td>
</tr>
<tr>
<td>Young’s Modulus</td>
<td>8.12e+05</td>
<td>lbf/in²</td>
</tr>
<tr>
<td>Poison’s Ratio</td>
<td>0.352</td>
<td>-</td>
</tr>
<tr>
<td>Vacuum Pressure</td>
<td>-8.70226</td>
<td>lbf/in²</td>
</tr>
<tr>
<td>External Pressure</td>
<td>Failure</td>
<td>lbf/in²</td>
</tr>
</tbody>
</table>

These models were also run with the same mesh requirements found in the Mesh Convergence Study of 0.05 radial node spacing and 0.1 circumferential node spacing. On the next page is a table depicting the key results for these spheres.
### Table 3-2: Wall Thickness Test Results Table

<table>
<thead>
<tr>
<th>Sphere #</th>
<th>Wall Thickness (in)</th>
<th>Max. External Pressure (psi)</th>
<th>Max. Depth Rating (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.8</td>
<td>3,954</td>
<td>2,691</td>
</tr>
<tr>
<td>2</td>
<td>1.0</td>
<td>4,593</td>
<td>3,125</td>
</tr>
<tr>
<td>3</td>
<td>1.5</td>
<td>5,827</td>
<td>3,965</td>
</tr>
<tr>
<td>4</td>
<td>2.0</td>
<td>6,695</td>
<td>4,556</td>
</tr>
<tr>
<td>5</td>
<td>2.5</td>
<td>7,325</td>
<td>4,984</td>
</tr>
<tr>
<td>6</td>
<td>3.0</td>
<td>7,790</td>
<td>5,301</td>
</tr>
</tbody>
</table>

From these results we can see that while the increased thickness does provide an increase in depth rating, we begin to get diminishing returns as we make the sphere thicker. This can be further shown through the graph below depicting the maximum depth of a sphere against its wall thickness.

![Graph of Wall Thickness vs Maximum Depth](image)

*Figure 3-10: Graph of Wall Thickness vs Maximum Depth*
This data set is so closely aligned to the polynomial trendline that we are able to use this data to create an equation to predict the required wall thickness for the lander to perform at a certain depth. The Excel sheet used to generate this equation can be found in the Appendix.

\[ T = 2 \times 10^{-7} d^2 - 0.001d + 1.9096 \]

*Equation 3-1: Required Wall Thickness (T) as a Function of Maximum Depth (d)*

Using this method, if we want a sphere that can go to Mariana Trench Depth (11km) we would need a sphere that is 15.11 inches thick. Meaning it has a total external diameter of 38.62 inches, which is far too large to be worthwhile.

Overall, we can say that increasing the wall thickness is a viable method to increase the pressure spheres depth capabilities. However, due to the diminishing returns seen in this method and the large required increased size of the entire lander frame as a result, this method is not optimal for our purposes. This means a design that maintains the spheres current size must be found.

3.1.3 CYLINDRICAL EQUATORIAL RING

While this next design might not be critical to the application of spheres made out of existing materials, it could be useful for the use of laminated composites which will be explored in the next section. Since laminated composites would result in the contact surface being comprised of the fiber end-grain, it would be very difficult to install an O-ring groove on this surface without damaging the composite lay-up. This problem could be solved however if we input an equatorial ring made of a different material capable of being machined with O-ring grooves on either side. A prototype of one such ring has been made by Kevin Hardy at Global Ocean Design which was machined out of Delrin to fit the existing 10-inch spheres. This ring, however, has never been tested or used in application. For this reason and to ensure the addition of an equatorial ring does not significantly impact the pressure sphere’s depth rating, we have created the following model incorporating it into the design. A full SolidWorks Drawing of this ring can be found in Appendix P, but below is a drawing of the ring’s cross-sectional shape. The external diameter of the ring is 10 inches.
For our first simulation, we assumed the ring to be made of the same 30% Glass 70% Nylon composite as the rest of the sphere body. The O-ring grooves on the ring were neglected to focus the analysis on overall stress distribution. The mesh for the equatorial ring was generated with quad elements with 0.05 spacing while the spheres used the same mesh decided on from the mesh convergence study (0.05 radial spacing and 0.1 circumferential spacing). The final mesh can be seen below with the equatorial ring highlighted in red.
As you can see from the figure below, the equatorial ring experiences significantly more stress than the rest of the pressure spheres. Unfortunately, this means that the addition of the equatorial ring actually significantly decreases the spheres pressure rating. The model below was ran to failure which occurs at 2,351 psi or just under 1,600 meters of ocean depth.

![Figure 3-13: Abaqus Simple Sphere with Cylindrical Ring Failure Min. Principal Stress](image)

The next two figures depict the contact opening and pressure values for the surfaces between the top hemisphere and the top equatorial ring surface, however it should be noted that these are identical results to those for the bottom hemisphere and lower equatorial ring surface. As you can see in these figures, the contact opening remains negative across the surface while the pressure remains positive, indicating that the opening has an interference and therefore remains closed all the way to failure.
Figure 3-14: Abaqus Simple Sphere with Cylindrical Ring Failure Contact Opening

Figure 3-15: Abaqus Simple Sphere with Cylindrical Ring Failure Contact Pressure
Because of this significantly lower failure than the existing pressure spheres (which failed at 3,954 psi or 2,690 meters below sea level, so 1,090 meters difference), we next decided to test the sphere having an aluminum equatorial ring instead of one made of the same material. This sphere survived deeper than the one with the glass/nylon ring, but still failed shallower than the sphere by itself with a maximum external pressure of 2,882 psi or 1,961 meters below sea level.

In this model, the center ring still failed first due to Aluminum 6061’s maximum tensile strength of 18,000 psi [12]. At this depth, the glass/nylon sphere has a minimum principal stress of -12,470 psi which is not yet at failure for the material.

It should be noted that ductile metals utilize Von Mises stress analysis to predict failure, so the aluminum ring is analyzed using this stress (S, Mises) while the 30% Glass 70% Nylon hemispheres are analyzed using the minimum/maximum principal stress.

![Abaqus Aluminum Cylindrical Ring Failure Von Mises Stress](image)

*Figure 3-16: Abaqus Aluminum Cylindrical Ring Failure Von Mises Stress*
Part of this increased stress in the equatorial ring here is caused by the contact stress caused by the difference in deformation between the aluminum ring and composite sphere. If we remove contact between the inside lip of the ring and the internal surface of the sphere, the parts actually pass through each other and the ring only experiences a von mises stress of 13,410 psi.
Since the ring was still failing first, we decided to try a much stronger but still corrosive resistant material for the equatorial ring: 304 Stainless-Steel which has a maximum tensile strength 89,923.4 psi [13]. As you can see in the first figure on the next page, the stainless-steel ring comes nowhere near failure with a Von Mises stress of only 24,720 psi at the same depth that the glass/nylon hemispheres reach failure with a minimum principal stress of -14,500 psi. This occurs at an external pressure of 3,017 psi or a depth of 2,053 meters below sea level. While this is still 637 meters shallower than the sphere without the ring, it is the first model with the ring to reach the rated depth for the existing pressure spheres of 2 km below sea level. For this reason, stainless-steel would be the best equatorial ring material to consider for woven fiber spheres.

Just like with the aluminum ring, the stainless-steel ring is ductile so was analyzed using Von Mises stress to predict failure while the 30% Glass 70% Nylon hemispheres are analyzed using the minimum/maximum principal stress.
Figure 3-19: Abaqus Stainless-Steel Cylindrical Ring Failure V. Mises Stress at Sphere Failure

Figure 3-20: Abaqus Stainless-Steel Cylindrical Ring Min. Principal Stress at Sphere Failure
The contact pressure and contact opening results for this model are also shown below, we can see that on the horizontal seal surface the sphere remains in interference and never opens.
3.1.4 SPHERICAL EQUATORIAL RING

After discussing the results of the cylindrical equatorial ring with Dr. Davol, he suggested the idea of creating a spherical equatorial ring instead. This design would consist of the face cuts happening on a radial line such that with the ring included the new sphere remained the same shape as the original sphere without the ring. Essentially taking a sphere and cutting it into three pieces instead of two, just with the third being a small symmetrical piece in the middle. The idea behind this is keeping the pressure sphere the same shape of an ideal sphere would theoretically reduce the contact stresses seen at the interaction between the surfaces. Following this idea and keeping a small lip on the inside of the ring similar to the original design we ended up with a ring with a 8-inch internal diameter, but instead of horizontal contact surfaces, they were radial to align with a 10-inch outer diameter sphere. These parts were meshed using the same node spacing as described for the cylindrical ring in the last section. You can see the shape of this model and its corresponding mesh in the figure below. A full SolidWorks drawing for both the ring and modified hemispheres can be found in Appendix P.
To get an idea of how this shape would differ from the cylindrical data, we began by running a model where both the sphere and the ring were comprised of the 30% Glass, 70% Nylon material of the existing spheres. The results were still less successful than the original two part sphere which had a maximum external pressure of 3,954 psi or maximum depth of 2,690 meters, however they succeeded in outperforming the cylindrical stainless-steel ring (max pressure of 3,017 psi or a depth of 2,053 meters). The maximum external pressure that could be applied before failure on the spherical equatorial ring was 3,053 psi, which equates to a maximum depth of 2,077 meters below sea level.
As you can see in the figures on the next page the contact opening remains negative and therefore shows interference across the entire surface, ensuring the sphere did not open before failure. Additionally, the contact pressure displays as expected with the maximum pressure corresponding to the location of the most interference.
Figure 3-26: Abaqus Simple Sphere with Spherical Ring Failure Contact Opening

Figure 3-27: Abaqus Simple Sphere with Spherical Ring Failure Contact Pressure
Since this change of shape did so well, we decided to then run the simulation changing the spherical equatorial ring back to stainless-steel to see how this affected the maximum depth of the pressure sphere. The results were actually very close to that of the original two part sphere model (max. pressure of 3,954 psi or depth of 2,690 meters), coming in with a maximum external pressure of 3,915 psi or a depth of 2,664 meters. Only 26 meters less than the original, an 8.3% difference! The model showing the overall stress can be seen below while one depicting only the minimum principal stress for the modified hemispheres can be seen at the top of the next page.

Just like with the cylindrical rings, the stainless-steel spherical ring is ductile so was analyzed using Von Mises stress to predict failure while the 30% Glass 70% Nylon hemispheres are analyzed using the minimum/maximum principal stress.

![S, Mises (Avg: 75%)](image)

Figure 3-28: Abaqus Stainless-Steel Spherical Ring Von Mises Stress at Sphere Failure
Following that figure, are the contact opening and contact pressure results for this model. As you can see from the contact opening, the sealing surface between the ring and the sphere remains in interference across the surface indicating no openings at depth. Additionally, on this model, you can see that the inner lip of the stainless-steel ring never actually comes in contact with the inside surface of the sphere as its contact opening remains positive the whole time.
The contact pressure shown on the following figure behaves as we expect with maximum pressure at the maximum interference on the sealing surface.
Because of its successful performance and near identical results to the original axisymmetric model, a stainless-steel spherical equatorial ring is the best option for laminated composite sphere sealing.

### 3.2 ALTERNATE MATERIALS

Since keeping the lander size and weight the same are critical for easy operation, the next best option is to investigate alternative materials that can be used while keeping the pressure spheres the same size. Since steel, titanium, and glass spheres are all currently existing but highly expensive options, we wanted to investigate an alternative that doesn't already exist on the market – woven fiber/epoxy materials.
For this we considered three different composites: two carbon-fiber epoxy weaves and one fiberglass epoxy weave. These materials were selected for analysis under the consultation of Paul Kuhl, Engineering Manager and composites expert at General Atomics. The material properties for each material can be found in the summary table on the next page and full material data sheets can be found in the Appendix. The properties listed in the table on the next page were tested and compiled at General Atomics and provided to me by Paul Kuhl [14].

These composites properties are all tested at low temperatures consistent with the temperatures found at ocean depths (1-4 degrees Celsius [15]). While this may seem to be a very small temperature range, after a certain depth, the ocean temperature has very little temperature decrease over a large depth. This is because, while the high pressures allow for near freezing water temperatures without the water turning to ice, most of the warmth in the ocean comes from sunlight and at these depths there is no light that reaches the depths. A diagram showing the temperature of ocean water at various depths can be seen below.

![Graph of Ocean Temperature vs Depth](image)

*Figure 3-33: Graph of Ocean Temperature vs Depth [15]*
### Table 3-3: Composite Material Properties [14]

<table>
<thead>
<tr>
<th>Property</th>
<th>584 3K-8HS/BT250E-1</th>
<th>282 3K-PW/BT250E-1</th>
<th>7781FG/BT250E-1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
<td>HexForce 8 Harness Satin 3K Carbon Fiber &amp;</td>
<td>HexForce Plain Weave 3K Carbon Fiber &amp;</td>
<td>HexForce 8 Harness Satin Fiber Glass &amp;</td>
</tr>
<tr>
<td></td>
<td>Toray Prepreg Resin Epoxy</td>
<td>Toray Prepreg Resin Epoxy</td>
<td>Toray Prepreg Resin Epoxy</td>
</tr>
<tr>
<td>CPT (in)</td>
<td>0.0169</td>
<td>0.0094</td>
<td>0.0095</td>
</tr>
<tr>
<td>E1 (MSI)</td>
<td>7.87</td>
<td>7.89</td>
<td>3.56</td>
</tr>
<tr>
<td>E2 (MSI)</td>
<td>7.87</td>
<td>7.89</td>
<td>3.56</td>
</tr>
<tr>
<td>G12 (MSI)</td>
<td>0.49</td>
<td>0.46</td>
<td>0.5</td>
</tr>
<tr>
<td>G13 (MSI)</td>
<td>0.49</td>
<td>0.46</td>
<td>0.5</td>
</tr>
<tr>
<td>G23 (MSI)</td>
<td>0.49</td>
<td>0.46</td>
<td>0.5</td>
</tr>
<tr>
<td>ν12</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
</tr>
<tr>
<td>Ten Stress 1  (psi)</td>
<td>92,600</td>
<td>112,120</td>
<td>58,900</td>
</tr>
<tr>
<td>Comp Stress 1  (psi)</td>
<td>74,500</td>
<td>70,130</td>
<td>58,900</td>
</tr>
<tr>
<td>Ten Stress 2  (psi)</td>
<td>92,600</td>
<td>112,120</td>
<td>58,900</td>
</tr>
<tr>
<td>Comp Stress 2  (psi)</td>
<td>74,500</td>
<td>70,130</td>
<td>58,900</td>
</tr>
<tr>
<td>Shear Stress  (psi)</td>
<td>14,360</td>
<td>14,140</td>
<td>8,000</td>
</tr>
</tbody>
</table>
3.2.1 LAY-UP ORIENTATION

All these materials will be tested using the same lay-up prescription. The goal for this lay-up is to create a quasi-isotropic material in order to best withstand the uniform pressure environment it will be used in. To do this, we needed to create a layup that followed a few rules: First, it needed to be symmetrical. Second, the angle of rotation between the lamina needed to be the same. For example, a laminate made of 0º-, 60º-, and 120º-oriented unidirectional plies would be quasi-isotropic, but so would 0º, 90º, +45º, and -45º-oriented unidirectional plies. Lastly, each lamina must (1) contain the same fiber-resin ratio; (2) have the same layer thickness; and (3) contain the same fiber type and geometry [16]. From the information provided to me by General Atomics in the table on the last page, we know the thickness of each lamina for the different materials selected. To keep the material comparison consistent for this test, each laminate will (1) be as close to 0.8” thick as possible while remaining quasi-isotropic; and (2) be composed of 0º, 90º, +45º, and -45º-oriented plies where the 0º and 90º directions are both circumferential around the sphere as defined in the figure below. 0º goes in the in plane circumferential direction and 90º goes in the circumferential direction around the axis of symmetry for our axisymmetric model.

Figure 3-34: Lamina Angle Definition Sketch
For determining the layups for each composite, we first began by calculating how many layers of each material were needed to make at least a 0.8” thickness laminate. To do this we divided 0.8” by each material’s lamina thickness and then rounded up to the next largest whole number. In order to keep the laminate symmetric, we then rounded this number up to the next closest whole number equally divisible by four (the number of lamina orientations we will be having). Lastly, we calculated the resulting sphere thickness for each material and wrote out the appropriate lay-up code for each material in the table below.

<table>
<thead>
<tr>
<th>Material</th>
<th>584 3K-8HS/BT250E-1</th>
<th>282 3K-PW/BT250E-1</th>
<th>7781FG/BT250E-1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lamina Thickness (in)</td>
<td>0.0169</td>
<td>0.0094</td>
<td>0.0095</td>
</tr>
<tr>
<td># of Lamina in 0.8”</td>
<td>47.34</td>
<td>85.10</td>
<td>85.10</td>
</tr>
<tr>
<td>Closest Whole # of Lamina</td>
<td>48</td>
<td>86</td>
<td>86</td>
</tr>
<tr>
<td>Closest # of Symmetric Lamina</td>
<td>48</td>
<td>88</td>
<td>88</td>
</tr>
<tr>
<td>Laminate Thickness (in)</td>
<td>0.8112</td>
<td>0.8272</td>
<td>0.8360</td>
</tr>
<tr>
<td>New OD (in)</td>
<td>10.0224</td>
<td>10.0544</td>
<td>10.0720</td>
</tr>
</tbody>
</table>

For each model, the internal diameter of the sphere remained the same (8.4 inches) while the outside diameter changed according to the new laminate thickness as shown in the table above.
For each laminated composite model, a simple sphere was chosen to reduce computation time since even this model took several hours for each iteration to run. Additionally, this allowed us to compare directly to the simple sphere models of the existing spheres. This decision was made while acknowledging the fact that any changes to this model (like the inclusion of electrical port holes or an equatorial ring) would have a more drastic impact on the laminated composites than it did on the existing materials. For example, the inclusion of a hole would normally create a stress concentration in any material, but in a laminated composite the value of increased stress can be more than double that of an isotropic material. We did our best to combat this problem by creating a quasi-isotropic laminate, however this only creates in plane isotropic behavior and does not account for out of plane stress changes. For this reason, all findings in the following sections should be considered ideal and would require further analysis and testing in addition to larger factors of safety before being put into operation.

To incorporate composite lay-ups into Abaqus, I needed to use a 3D model rather than an axisymmetric one. To do this, I created a simple quarter model of the sphere as can be seen in the figure below. Each model’s OD is changed according to the table above and is meshed with 0.05 radial node spacing and 0.10 circumferential node spacing as was determined in the mesh convergence study. A complete mesh of one of these models can be seen below.

*Figure 3-35: Abaqus Simple Sphere Quarter Model for Laminate Composite Analysis*
While in past models we determined failure by analyzing the minimum principal stress values in the sphere, that approach will not work for this laminated composite. That is because the failure data we have for the materials depicted in Table 3-3 are tested in the fiber direction. In order to find these values, we must see the stress values oriented in the same direction as the fibers. Thankfully with the quarter model used here, this is easy to do as the stress in the X-direction (S11) is in line with the 90° fibers. For this reason, all failure analysis below will be comparing S11 stress values to the predicted failure stress data provided to us by General Atomics [14].

3.2.2 CARBON FIBER + EPOXY: 584 3K-8HS / BT250E-1

Figure 3-36: Abaqus Ply Stack Plot for 584 Carbon Fiber Sphere
The first material we tested was one of the Carbon-Fiber / Epoxy lamina, specifically it is 584 HexForce 8 Harness Satin 3K Carbon Fiber laminated using Toray BT250E-1 Prepreg Resin Epoxy. As described in the last section, this lay-up consisted of 48 lamina, each with a thickness of 0.0169 inches, providing the sphere with a total thickness of 0.8112 inches. This is only 1.39% larger than the existing pressure spheres, meaning that this sphere could be easily swapped into place on the lander without needing to redesign other components. The final lay-up orientation was as follows: [[-45/45/0/90]_6s. A figure demonstrating the complete lay-up in Abaqus can be seen above.

As you can see from the following figures, the fibers in this sphere failed at its maximum compressive stress of -74,500 psi [14]. This failure occurred with an external pressure of 20,436.5 psi or an ocean depth of 13,906 meters – over five times the depth of the current pressure spheres. This is incredible as this would predict the sphere would be safe well to Mariana Trench Depth of 11 kilometers! As discussed before, the real-world application of this sphere would include the use of an equatorial ring as well as the inclusion of electrical port holes and possible view ports – all of which would increase stress experienced by the material and therefore decrease its maximum depth rating. Additionally, this does not account for any imperfections in the layup including the creation of voids or porosity during manufacturing, both of which would further decrease its pressure capabilities. That said however, as an ideal model, this indicates that 584 Carbon Fiber shows great potential as being able to enable our lander to go to greater depths than is allowed by the current pressure spheres.

Additionally, you can see both the contact opening and contact pressure results for this model. The contact opening remains negative the whole time, indicating the sphere never opens and remains sealed until failure. Additionally, we can see that the contact pressure remains positive with the maximum pressure on the inside surface of the sphere and the minimum on the outside. This is what we would expect to see as we did in past models.
Figure 3-37: Abaqus Quarter Model for 584 Carbon Fiber Failure Stress in Fiber Direction

Figure 3-38: Abaqus Quarter Model for 584 Carbon Fiber Stress Failure Contact Opening
While the failure results predicted by stress in the fiber direction are phenomenal, there are two other factors we must also consider for laminated composites. These are the Tsai-Hill and Tsai-Wu failure criterion. Both of these theories predict failure throughout the laminate, usually caused by delamination between its layers. For both of these indexes, failure is predicted as a fraction of experienced stress over failure stress. When this fraction becomes greater than or equal to one, this predicts model failure.

For this model, both the Tsai-Wu and Tsai-Hill failure criterion were well above the maximum value of 1, meaning this model is well above failure for both methods. Tsai-Hill had a value of 1.741 and Tsai-Wu had a value of 2.004 as can be seen in the figures on the next page. We then re-ran these models until both Tsai-Hill and Tsai-Wu resulted in values less-than or equal to 1. Using this method, failure for the 584 Carbon Fiber composite was ultimately predicted at an external pressure of 10,000 psi or 6,804 meters below sea level as seen below. This is about half the depth predicted by the stress failure alone, which shows just how critical it is to consider these failure models when analyzing laminated composites. While this model predicts failure shallower than stress alone would have determined, it is still more than 2.5 times the depth of the existing spheres, and therefore 584 Carbon can be considered viable for this application.
Figure 3-40: Abaqus Quarter Model for 584 Carbon Fiber Tsai-Hill at Stress Failure

Figure 3-41: Abaqus Quarter Model for 584 Carbon Fiber Tsai-Wu at Stress Failure
Figure 3-42: Abaqus Quarter Model for 584 Carbon Fiber Tsai-Hill at Tsai-Wu Failure

Figure 3-43: Abaqus Quarter Model for 584 Carbon Fiber Tsai-Wu Failure
The next material we tested was the other Carbon-Fiber / Epoxy lamina, specifically 282 HexForce Plain Weave 3K Carbon Fiber laminated using Toray BT250E-1 Prepreg Resin Epoxy. As described in the beginning of the Lay-up Orientation section, this lay-up consisted of 88 lamina, each with a thickness of 0.0094 inches, providing the sphere with a total thickness of 0.8272 inches. This is only 3.34% larger than the existing pressure spheres, meaning that this sphere could be easily swapped into place on the lander without needing to redesign other components. The final lay-up orientation was as follows: $[[-45/45/0/90]_s]$. A figure demonstrating the complete lay-up in Abaqus can be seen above.
As you can see from the following figures, the fibers in this sphere failed at its maximum compressive stress of \(-70,130\) psi [14]. This failure occurred with an external pressure of 19,506 psi or an ocean depth of 13,273.1 meters – almost five times the depth of the current pressure spheres and only 633 meters shallower than the 584 Carbon was predicted to fail due to stress in the fiber direction. Just like with the 584 Carbon, this stress model incredibly predicts the sphere would be safe to Mariana Trench Depth of 11 kilometers! The same disclaimer must be applied to these results as was stated for the 584 Carbon: real world factors (including design modifications and manufacturing imperfections) would cause the stress experienced by the material to be higher than shown in this ideal model and therefore would lower its maximum depth rating.

Additionally, you can see both the contact opening and contact pressure results for this model. Again similarly to 584 Carbon, the contact opening remains in interference across the entire surface, indicating the sphere never opens and remains sealed until failure. Likewise, we can see that the contact pressure remains positive with the maximum pressure on the inside surface of the sphere and the minimum on the outside. This is all as expected and follows the trends of past models.

![Abaqus Quarter Model for 282 Carbon Fiber Failure Stress in Fiber Direction](image)

*Figure 3-45: Abaqus Quarter Model for 282 Carbon Fiber Failure Stress in Fiber Direction*
Just like with the Carbon 584 model, the failure results predicted by stress in the fiber direction are phenomenal, but we too must consider the Tsai-Hill and Tsai-Wu failure criterion. For this model, both the Tsai-Wu and Tsai-Hill failure criterion were well above the maximum value of 1. Tsai-Hill had a value of 1.704 and Tsai-Wu had a value of 2.110 as can be seen in the figures on the next page. This means this model is well above failure for both methods, so we then re-ran these models until both Tsai-Hill and Tsai-Wu resulted in values less-than or equal to 1. Using
this method, failure for the 282 Carbon Fiber composite was ultimately predicted at an external pressure of 9,242 psi or 6,289 meters below sea level. The models for this can be found below. Just like with the Carbon 584 model, this is about half the depth rating found using stress values alone. However, this is still 2.3 times deeper than the existing Glass/Nylon sphere is predicted to go. This means that Carbon 282 is also a valid option to consider replacing the existing spheres.

Figure 3-48: Abaqus Quarter Model for 282 Carbon Fiber Tsai-Hill at Stress Failure

Figure 3-49: Abaqus Quarter Model for 282 Carbon Fiber Tsai-Wu at Stress Failure
Figure 3-50: Abaqus Quarter Model for 282 Carbon Fiber Tsai-Hill at Tsai-Wu Failure

Figure 3-51: Abaqus Quarter Model for 282 Carbon Fiber Tsai-Wu Failure
The last material we tested was the Fiber-Glass / Epoxy lamina, specifically 7781 HexForce 8 Harness Satin Fiber Glass laminated using Toray BT250E-1 Prepreg Resin Epoxy. As described in the beginning of the Lay-up Orientation section, this lay-up consisted of 88 lamina, each with a thickness of 0.0095 inches, providing the sphere with a total thickness of 0.8360 inches. This is only 4.40% larger than the existing pressure spheres, meaning that this sphere could be easily swapped into place on the lander without needing to redesign other components. The final lay-up orientation was as follows: $[[-45/45/0/90]_{11}]$. A figure demonstrating the complete lay-up in Abaqus can be seen above.
As you can see from the figures on the next page, the fibers in this sphere failed at its maximum compressive stress of -58,900 psi [14]. This failure occurred with an external pressure of 16,510 psi or an ocean depth of 11,234 meters. Like with the stress-only Carbon Fiber models, this would predict that the sphere would be safe well to Mariana Trench Depth of 11 kilometers! Just as with both carbon fiber models above, real world factors like design changes and manufacturing imperfections would need to be analyzed and tested for because they would result in a larger stress experienced by the material than is predicted in this ideal model. This would of course mean the true depth rating of this material would be lower than predicted here. However, this model still predicted fiber stress failure at a depth more than four times that of the existing pressure spheres, so still indicates that this material should be considered as a viable option to enable the lander to go to greater depths in future applications.

Additionally, you can see both the contact opening and contact pressure results for this model below. The contact opening, just like in the carbon fiber models above, remains negative the whole time, meaning the sphere never opens and remains sealed until failure. Similarly, we can see that the contact pressure remains positive with the maximum pressure on the inside surface of the sphere and the minimum on the outside. This is what we would expect to see.

*Figure 3-53: Abaqus Quarter Model for 7781 Fiber Glass Failure Stress in Fiber Direction*
Just like with the Carbon Fiber models, the failure results predicted by stress in the fiber direction are fantastic, but again we must consider the Tsai-Hill and Tsai-Wu failure criterion. For this model, both the Tsai-Wu and Tsai-Hill failure criterion were well above the maximum value of 1. Tsai-Hill had a value of 2.335 and Tsai-Wu had a value of 2.490 as can be seen in the figures on the next page. This means this model is well above failure for both methods, so we then re-ran these models until both Tsai-Hill and Tsai-Wu resulted in values less-than or equal to 1. Using
this method, failure for the 7781 Fiber Glass composite was ultimately predicted at an external pressure of 6,630 psi or 4,511 meters below sea level. The models for this can be found below. This is less than half the maximum depth predicted by stress alone but is still almost twice the depth of the existing pressure spheres. While 7781 Fiber Glass may not be as great as the Carbon Fiber materials analyzed, it is still a viable option for new pressure spheres.

Figure 3-56: Abaqus Quarter Model for 7781 Fiber Glass Tsai-Hill at Stress Failure

Figure 3-57: Abaqus Quarter Model for 7781 Fiber Glass Tsai-Wu at Stress Failure
Figure 3-58: Abaqus Quarter Model for 7781 Fiber Glass Tsai-Hill at Tsai-Wu Failure

Figure 3-59: Abaqus Quarter Model for 7781 Fiber Glass Tsai-Wu Failure
3.2.5 MATERIAL SUMMARY + COMPARISON

While there are real-life factors that would impact the results of these models, all three materials give promising results. The table below highlights the depth at which each of these materials failed as well as how this compares to the original 30% Glass 70% Nylon sphere. As you can see, all three laminated composites were able to go deeper than the existing model with the carbon fiber weaves going more than twice as deep. More analysis and testing would be needed before implementing any of these materials into use, but all show promise as being an intermediate-depth option when compared with the existing pressure spheres made by Global Ocean Design.

Table 3-5: ~10-inch Sphere Model Failure Comparison

<table>
<thead>
<tr>
<th>Sphere Type</th>
<th>Sphere Material</th>
<th>Model Failure Pressure</th>
<th>Percent Change from Original</th>
</tr>
</thead>
<tbody>
<tr>
<td>Original</td>
<td>30% Glass + 70%Nylon Injection Molded</td>
<td>3,954 psi 2,690 m</td>
<td>0.00%</td>
</tr>
<tr>
<td>584 Carbon Fiber + Epoxy</td>
<td>584 HexForce 8 Harness Satin 3K Carbon Fiber BT250-1 Toray Prepreg Resin Epoxy</td>
<td>10,000 psi 6,804 m</td>
<td>152.91%</td>
</tr>
<tr>
<td>282 Carbon Fiber + Epoxy</td>
<td>282 HexForce Plain Weave 3K Carbon Fiber BT250-1 Toray Prepreg Resin Epoxy</td>
<td>9,242 psi 6,289 m</td>
<td>133.74%</td>
</tr>
<tr>
<td>7781 Fiber Glass + Epoxy</td>
<td>7781 HexForce 8 Harness Satin Fiber Glass BT250-1 Toray Prepreg Resin Epoxy</td>
<td>6,630 psi 4,511 m</td>
<td>67.68%</td>
</tr>
</tbody>
</table>
All the models above had their failure predicted using Tsai-Wu failure criterion. This makes sense as Tsai-Wu criterion has been found to be accurate for composites in compression while Tsai-Hill has been found to produce higher strength ratios [17]. For this reason, the predicted failure depths in the table above can be trusted.

As was mentioned in Table 2-1, the existing pressure spheres have depth options of 1, 2, or 10 kilometers below sea level which is a massive jump of 8 km. What if someone wants a vehicle that can go 5km below sea level, or even just 3 km? Well, right now they would need to make the choice of opting for the 10 km rated glass sphere (which can be very expensive) or not reaching their full depth. While the fabrication costs of these new spheres would not be cheap, they might be able to provide an intermediate price point that would allow a depth rating larger than the 2 km of the existing spheres.

As discussed in the earlier sections, the real-world application of this sphere would include the use of an equatorial ring as well as the inclusion of electrical port holes and possible view ports. All these features would increase the stress experienced by the material and therefore decrease its maximum depth rating. The stress concentrations created by such changes are also known to have a greater impact on laminated composites than standard isotropic materials so are not to be taken lightly. Additionally, these models do not account for any imperfections in the layup including the creation of voids or porosity during manufacturing, both of which would further decrease its pressure capabilities. All this means that further testing and analysis of these materials would need to be completed before further application is pursued, but these preliminary results are all very promising for their capabilities!
4 LANDER MODIFICATIONS + APPLICATIONS

4.1 LANDER MODIFICATIONS

While working with Maya Netto and Danika Cornejo, we determined through their research that a few key changes needed to be made to the lander in order to have the most scientifically sound study. The first of which is that the bait needed to be contained to prevent it from being fully removed from the lander to guarantee the lander remained “baited” for the full 90-minute window of the deployment study [18] [19] [20] [21]. The second was the wavelength of light used on the lander needed to be specified as different colors of light impact what species can see the light and therefore are deterred from approaching the lander [22]. Working with Maya and Danika to ensure the solutions adhered to the rigorous scientific standards needed for their research, the following solutions were found.

Additionally, while working with NOAA to complete deep-water deployments off their larger research vessels it was determined two other modifications needed to be made: (1) the activation and testing of our GPS tracker so the lander could be located for recovery in case of early return or strong currents causing drifting; and (2) the development of a specific recovery device in order to recover the lander off of a large vessel where crew could not easily reach into the water.

Figure 4-1: SolidWorks Assembly of DOV Seastang from Senior Project [1]


4.1.1 *BAIT CONTAINMENT*

To address the issue of bait containment, there were two options suggested by Dr. White: (1) To develop a solid bait container (suggested in the form of a PVC pipe) with holes small enough to allow water and the smell of the bait to pass through, but preventing animals all access from the bait; or (2) utilizing a pre-made bait bag which would contain the bait from being “stolen” by one hungry animal, but would not stop the lured animals from accessing it entirely.

Early on, Dr. White showed his preference for the solid container, but expressed concerns about its ability to be cleaned as remnant bait between deployments could lead to error in scientific findings. Because of this preference, this was the first option we explored. We first attempted to locate a PVC pipe of the right size to fit on the lander’s existing bait arm that had threaded ends for end caps. This proved to be very difficult as very few pipes of the right diameter came threaded and of those that did, they were all far too long for our purposes. We discussed the option of turning out own threads on the lathe since we would already be needing to drill holes in the pipe to allow bait to mix with the surrounding water. While this was a good option, we were unable to find end caps of the proper diameter to match any PVC pipe we found. Additionally, we began to worry that drilling holes in the pipe would leave burs on the inside surface which would be hard to remove and could become additional traps for old parts of bait to be stuck in. Because of these concerns, combined with the increasing cost and difficulty of this solution, we decided to further investigate the use of bait bags before making a final decision.

*Figure 4-2: Sketch of Pipe Bait Container Design*
While Maya researched the mesh bait bags more, she discovered that they were the standard in most of the scientific studies her and Danika were basing their methodology on. With further analysis, we found that not only were PVC mesh bags easily washable due to their material but were also deemed disposable in many research papers due to their inexpensive cost. So, if necessary, we would be able to account for the cost of a new bait bag for each deployment study. With this in mind, we found an appropriately sized bait bag, and at only $7 per bag, decided to purchase three for testing. It was quickly found by our team that the bait bags were easy to clean and sturdy. The mesh of the bag also made it easy to zip-tie the bag onto the existing bait plate through the mounting holes on the plate. So, after confirming with Dr. White that this was an acceptable solution, we decided to use mesh bait bags for our bait container.

![Figure 4-3: PVC Mesh Bait Bag](image)

![Figure 4-4: Lander with New Bait Bag](image)
4.1.2 LIGHT COLOR FILTERS

The next modification needed for the lander was to control what wavelength of light was used for recording video footage as research showed that certain light colors created biases in sampling results. Since the existing lights were very bright white LEDs that were custom made to be pressure safe, we knew replacing them would be difficult. Additionally, there was debate between different scientific papers as to whether red or blue light was better for BRUV studies. Because the exact wavelength of light needed was not yet known, we decided putting color filters on top of the existing lights would be the best solution.

First began research into different types of light filters, we found that basically all light filters were referred to as “gel light filters” which concerned us that this “gel” would dissolve in the saltwater we would be placing them in for extended periods of time. However, further research informed us that the use of “gel” in the name is actually an antiquated carry over from when these sheets used to be made of gelatine. Today they are made of polycarbonate, polyester, or other types of heat-resistant plastics [24]. This was great news as it also meant that the new plastic filters would likely be corrosion resistant in oceanic conditions.

With the use of light filter gels confirmed as viable, we began researching different filters and verified what wavelengths we wanted to test. Maya and Danika confirmed that the exact wavelength seemed to be variable, as long as they were in the right color spectrum. So, we settled on a vibrant blue and vibrant red that were ordered. Specifically, we ordered two Rosco Roscolux 20x24” sheet filters from B&H Foto & Electronics Corp: one #80 Primary Blue and one #26 Light Red as shown in the figure below [25].
Once we got the filters, the next step was determining how we would attach them to the lander’s lights. We considered gluing them directly onto the face of the lights but were concerned that all marine grade adhesives we were finding would also block light due to their dark colors and high opacity. Additionally, we were still unsure which color to use so wanted to find a solution that could be temporary and allow us to easily swap between light filters while remaining secure enough to not worry about it dislodging while underwater. The first idea I had was to cut the filters to the same size as the face plate with holes placed around its circumference where the bolts to hold the faceplate on could go through. This way the filter could be placed between the light’s face plate and the primary diffuser without adhesive while still being secure at depth. While this would still allow the light filters to be exchangeable, this would require entirely dismantling the light anytime you wanted the filter color changed which is a long, time-consuming process since the fully assembled light must be filled with mineral oil to remain pressure safe at depth.
With the new added requirement of not needing to disassemble the existing light structure, I began to think about an external fixture I could use to hold the filter to the lights. I wanted this fixture to be easy to attach and remove from the existing light structure without the need for additional hardware, so had the idea for a plastic frame I could pop on and off the existing lights that had a space for a light filter to be held on the surface of the light. I decided on a three-pronged frame to provide enough stability around the cylinder while minimizing the number of legs to make them easy to maneuver around the existing structures holding the light to the lander frame. I began taking key measurements of the existing lights and sketched out a rough design of what I had in mind so I could begin transferring it into SolidWorks.
I decided the easiest way to manufacture this part would be to laser cut it in three shapes: (1) the front face plate in the shape of a basic circle, (2) the security ring which held the filter in place and added stability to the legs, and (3) the L-shaped legs which would clip onto the light cylinder to hold the entire part in place. When looking to prototype the design, I found several pieces of clear acrylic in the Mustang '60 machine shop's scrap bin which had more than enough material left for making my parts. Specifically, I found one mostly unused sheet of 0.075” clear acrylic I decided to use for the face plate and two partially used sheets of 0.2” clear acrylic I would use for the support ring and legs. With this material in mind, I made SolidWorks models of the light filter caps and parts and first tested how it fit with the existing lander model to ensure the leg placement would not interfere with existing fixtures and plugs. Full SolidWorks drawings of these parts and combined assembly can be found in Appendix E.
With the design verified digitally, the next step was to create 2-D DXF files of the components that could then be cut out on the laser cutter. It was very fun manufacturing the parts as I got to teach Maya and Danika how to use the laser cutter and seeing their satisfaction of making parts combined with the excitement of ideas for future projects was very rewarding. Once the parts were all cut, we assembled them using super glue as our adhesive of choice and left them to dry as seen in the figure below.
Once the light filter caps were dry, we cut circles of both the red and blue light filter gels that were the same diameter as the inside of the caps. We then took the red-light filters and placed them inside the caps before popping them onto the lander. It was a snug fit, but the acrylic was pliable enough to allow the legs to bend away from the cylinder body before popping back into place to properly latch onto the lander. With all parts in place, we then conducted a dry land test where we activated the lights and were able to see the final product as shown in the next figure. As you can see in the figure on the next page, the filter did a great job at changing the light from a standard white light to a very visibly red color. The only issue is that there was a small amount of white light leaking out the sides of the caps in the small gap between the light filter and the front face of the light. To fix this problem, we ended up spray painting the sides of the light filter caps opaque black which successfully removed this issue.
4.1.3 GPS TRACKING

The next step in preparing for at sea deployments was to activate and test our GPS tracker. The lander had been equipped with a SPOT Trace Satellite Tracker with GPS during its original creation at Global Ocean Design, but this device had never been set-up or activated as it used a subscription system so was only needed when at-sea deployments were planned [27]. The set up and activation process was a bit tedious, and it took 24 hours after online activation for SPOT to begin actively tracking and communicating with its satellite.
We knew the tracker would not function while the lander was below the surface of the ocean because of the interference caused by the water, but the goal of this tracker was to be able to pinpoint the lander’s location once it had surfaced at the end of its deployment. This was critical because for the NOAA deployments we would be dropping the lander in the water, then the vessel would continue to other locations to complete their own research before returning to recover the lander at the end of its deployment window. Since the ship would be leaving the site, there became a chance that the lander could surface before the vessel returned. If this happened the surface currents and winds are much stronger than the currents at depth, meaning it is very easy for the lander to begin to drift away from its drop location. In the event this does occur, we wanted a way to locate the lander that wasn’t reliant on sight as it was already difficult to spot at a distance due to its small size. For this reason, we decided to test the accuracy of the SPOT Trace through a game of Hide-and-Seek.
For this test, we all met at the Bonderson building on campus where we first turned on the SPOT Trace and verified it connected to the satellite, displaying its location on the tracking app on my phone as shown in the figure below. Once that was verified, Maya then took the SPOT Trace while Danika and I remained at the Bonderson building. We then gave her 15 minutes for her to go hide anywhere on campus. After that Danika and I would use the SPOT app on my phone to locate her. She was told if we hadn’t found her in 45 minutes to all meet back at the Bonderson building to re-group. Thankfully though, this contingency plan was not needed as once the 15 minutes were up, we very quickly found her on the map and were back together within 5 minutes of her time ending. The location was extremely accurate, showing Maya’s hiding spot within 2 feet of her actual location which is more than sufficient for locating our lander on the ocean’s surface.

Figure 4-14: SPOT Trace Initial Function Test
4.1.4 LARGE VESSEL RECOVERY DEVICE

The last major modification to the lander was the addition of a recovery device for deploying the lander off large vessels like the ones we would be going out on with NOAA. In past use, the lander had only been deployed off small vessels where I had been able to pull the lander close with a boat hook, then simply reach over the side of the ship and lift it out of the water by hand. This, however, would not work on the R/V Fulmar or R/V Shearwater because the decks of these ships were several feet above the water’s surface. Because of this, we needed to develop a system for deploying and recovering the lander from large vessels. A full methodology for these operations can be found in Appendix F, but here we will discuss the development of our specialized recovery device.
These issues of large-scale recovery first became known when discussing R/V Fulmar plans with NOAA Ship Coordinator Jean de Margiac. While we had devised a deployment plan that we felt would be successful, we were not entirely sure how best to approach recovery. Because of this I reached out to Kevin Hardy at Global Ocean Design to get his insights on large vessel operations. Kevin has deployed many landers on even larger ships than the ones we would be going out with NOAA on, so I knew he would have experience we could draw from. This proved to be true as Kevin was able to provide me with sketches depicting deployment and recovery operations for the lander off such a large ship as well as instructions on how to make the specialized recovery device he developed.

Figure 4-16: DOV Seastang Deployment Sketch [28]
The next step was to acquire all the materials needed to build the device, which was incredibly easy since Kevin provided pictures of the necessary supplies in his communications as well. For this we needed: a fiberglass telescoping pole (8 feet long when condensed but capable of extending to 24 feet), large carabiner hooks (110lb rating), strong recovery line, and masking tape. With all parts acquired, we found it was incredibly easy to assemble. First, we tied one end of the rope onto the carabiner clip. Then, we taped the clip onto the end of the telescoping pole. Lastly, we taped the rope to the pole at 1.5-2-foot intervals.
The first testing we did with the device was in our project room. For this, we assembled the device then practiced standing on the far side of the room while clipping the carabiner onto the lander’s recovery bale. This was great practice as it taught me the nuance of specific angles and placement of the carabiner that worked best for catching the lander. Once clipped, we then attempted to tear the pole off the system by breaking the masking tape. This failed since the tape wrapped around the pole was too strong. With a bit more investigating and testing, we found that while you needed the tape pieces long enough to get a secure grip on the pole on either side of the rope, they had to be short enough not to overlap because it was this overlap that was providing enough strength to make the masking tape unbreakable. With this system now tested we then worked our way up in its testing by first using it to recover the lander from a pier deployment, then an in-port test on the R/V Fulmar, and eventually put it into full use on the R/V Shearwater for open water deployments.

![Large Vessel Recovery Device](image1)

*Figure 4-18: Large Vessel Recovery Device*

While on NOAA’s vessels, we learned of two devices that are very similar to the one we made with their own benefits. The first we learned about on the Fulmar was referred to by the crew as the “Happy Hook”. Its official name is the Hook & Moor [29], and is a unique boat hook that doesn’t use an actual hook or carabiner, but can loop a rope directly through whatever it is you want to grab. The other was a special kind of boat hook already designed as a carabiner. This hook was kept in its open position by a latch and once the target is hooked, you could pull the rod
and the carabiner pops off the rod closing onto its target. This is the Sea-Dog Snapping Boat Hook.

![Figure 4-19: Hook & Moor Boat Hook Operations [29]](image1)

With all the modifications complete and the lander fully ready for research grade deployments, it was time to put it all into action.
4.2 LANDER APPLICATIONS

The most rewarding part of this thesis for me was getting to deploy the lander I had spent the last three years working on to perform its intended function while mentoring two undergraduate scientists. It is through this process that I have been able to see the true rewards for all my previous work pay off, and I’m so excited to see the project I love so much continue to grow and take on a life of its own where I know it will continue to thrive even once I am no longer around.

4.2.1 TRAINING DANIKA + MAYA

One of the biggest parts of this project has been my mentorship of Danika Cornejo and Maya Netto, the two undergraduate students working in Dr. White’s lab on his Wind Energy Area (WEA) research project. Mentoring these two has been an amazing experience and has truly enhanced many skills which will be key to my future career. Everything from science and engineering communication, project development, marine operations, organizational skills, and of course leadership skills have all been used and improved as I have grown and learned throughout this process. I truly could not have asked for a better pair of mentees to work with, both are so extremely talented and passionate that I know they will both continue to excel at whatever they put their minds to!

4.2.1.1 ENGINEERING + MANUFACTURING SKILLS

The only true requirement Maya and Danika had when it comes to learning engineering skills as a part of their job in Dr. White’s lab was the basic use, operations, and up-keep of the lander itself. I was thrilled to find though that both wanted to take full advantage of this interdisciplinary project and were very interested in learning as much as they could about the engineering and manufacturing disciplines. Because of their interest, the first thing I recommended they do was to get their Red Tags from the Mechanical Engineering machine shops. This basic safety training grants them access to the machine shop, gives them eligibility for future training if interested, and gives them an initial hands-on experience working in the machine shop and using hand tools. As a senior shop technician, I frequently administer these safety trainings so once they found a time
that worked for both their schedules, I excitedly volunteered to be one of the techs who administered this Red Tag. While they both had been a bit hesitant and nervous in the lead up to the training, they both warmed up quickly to the environment and it was great to be able to help guide them and ease their concerns while teaching them proper safety protocols in the machine shop.

Once this training was under their belt, I began teaching them more on how to use various hand tools and answering their questions as they arose. As a part of the lander operations and up-keep, they were required to use many hand tools for assembly and maintenance of the vehicle. Additionally, since the use of burn-wires is critical to the lander's operation and at least one burn wire is used each deployment, it was critical they learn to solder in order to attach new burn wires to the lander even without me present. Danika especially took to wanting to master this skill and while she is still learning she has made fantastic progress and is showing great aptitude for it!

I also did my best to incorporate both Maya and Danika into the engineering design process when making the modification to the lander as discussed in Section 4.1 above. I worked with them to develop a needs list, went through the brainstorming process with them and worked with them to decide on all final design choices through analyzing the pros and cons of the possible solutions. While I was responsible for any detail work in the design (sketching and modeling the final design caps) they had been involved in determining that an easily removable cap was the best solution and were highly involved in the manufacturing and assembly of the final parts including learning to use the laser cutter.

4.2.1.2 LANDER OPERATIONS AND UP-KEEP

The primary reason for my mentorship of Danika and Maya was to teach them how to use and operate DOV Seastang. This included many elements on the lander, and while this was initially daunting for them to approach, I'm happy to say that with a bit of time and patience both excelled and are now fully capable of operating and maintaining the lander without me! Every time we do a
deployment, I can see their confidence level grow and enjoy that I can now just stand back and watch them work – knowing they will succeed.

The first step in this process was familiarizing them with the lander’s capabilities. This can be summarized in three main categories: (1) the Burn-Wire Weight Release System, (2) the Camera/Lights System, (3) the Bait Release System. Once familiar with the system types, I would then break down how each system works and explain to them the information they needed to know for operation and maintenance purposes. I then completed an entire pier deployment where I walked them through what I was doing at each step in the process, answering questions as we went. Next, we performed a pier deployment together where they began getting more hands-on experience with the lander, followed by a “solo” deployment where they performed all the set up and deployment operations without me. During this final test, I was still present and watched over them so I could intervene if something critical were to be forgotten, but thankfully this turned out not to be necessary. These tests will be discussed more in the next section. During their training, I aided Maya and Danika in creating an official “Lander Checklist” and “Packing List” to aid them in future deployments they may complete without me. This was developed from the most recent version of the lander’s Operations Sheet with added notes or clarification as they saw fit and both lists can be found in Appendix D.

The Burn-Wire Weight Release System is the most critical system of the entire lander. If a different system fails, it creates a lack of proper data retrieval, but if this system fails it means the lander doesn’t return to the surface and is entirely lost. Because of its critical nature, this is the system we began with and spent the most time going over operations for. The lander body was designed to be naturally buoyant but has a set of drop weights attached to its base that cause it to sink. These drop weights are controlled through a dual burn-wire system. Each burn-wire is attached to one end of a chain and the weights are looped through this chain such that if either burn-wire snaps, the weight slides off the chain and is “dropped” from the lander. When the timer goes off, it sends an electrical current through the wires which then conducts through the salt-water to an electrode on the outside of the lander. A small section of the burn wire then corrodes.
through oxidation and eventually snaps. Having the two burn-wires acts as a fail-safe system such that if one burn-wire fails, we have the second as a back-up. The burn-wires are controlled on a dual-timer system where each timer can be set at a time up to 4 days prior to the release time. These timers are normally spaced out so there is time to recover the lander between burn times in an attempt to preserve resources since once a wire is burned (even partially) it must be replaced. The other critical detail for this system is while setting the burn wire timers. When doing this, you must make sure the batteries are unplugged from the system because the beeping noise caused by pressing buttons can trigger the same circuit as the timer’s alarm going off which would cause the batteries to prematurely discharge.

![Figure 4-21: Burn-Wire Weight Release Control Sphere](image1)

![Figure 4-22: Burn-Wires: New (Left), Partially Corroded (Middle), & Snapped (Right)](image2)
The Camera/Lights System is the most complicated system in the lander. It consists of a GoPro Hero 4 camera controlled by a CamDo Blink controller which is used to set the frequency and length of photos and videos. The light system is also connected to the CamDo and is set to turn on and off in synch with the video camera. The GoPro and CamDo are powered through one smaller external battery as they draw more charge than a normal GoPro battery can sustain through a single deployment while the lights are hooked up to a separate large LiPo battery as they take far more energy to stay on. The lights are custom made pressure safe LEDs that can have their color controlled by the use of color filters described in Section 4.1. To set the CamDo you must first plug in a control switch to the CamDo to activate its WiFi signal. Then you connect your device to the WiFi and can set the days/times you want the camera and lights to operate and the desired footage details (media type, modes, frequency, and length). You then Enable these times and Save All choices in the browser before synching the camera time and disconnecting. Now, if all parts are plugged in correctly, the camera will operate as desired and will be in synch with the lights. It is also important to note that the LiPo battery for the lights is maintained using a Battery Management System (BMS) that must be plugged in to the battery at all times (during operation and charging) as it maintains the battery health and ensures all cells contain even charge.

Figure 4-23: Camera/Light Control Sphere
The next most important system is the Bait Release System. While deceptively large, the low-tech solutions used in this system make it the easiest to operate. The purpose of this system is to deploy bait to lure local fauna to approach the lander while at depth to increase the biodiversity seen on lander footage. Because of this the Bait Arm is designed to place the bait in view of the camera, its exact position in view can be controlled by changing the length of the chain attached to the lander’s drop weights as this is responsible for how far off the ground the lander floats. The bait arm begins in an upright position on the lander where the top of the arm is tied to the lander frame using a small amount of polychord with a LifeSaver candy ring held between the two pieces of string. This is to hold the arm upright during descent, but the LifeSaver then dissolves in the water causing the arm to release and lower the bait into view after the lander has reached the seafloor. The full details about the use of the LifeSaver can be found in the corresponding senior project report including all data and testing of this mechanism [1]. The LifeSaver is perfect for this use but can be damaged through strong impulse hits so is best to leave off during transit and only attach just before deployment. In addition, there is a small bolt at the base of the bait arm which acts as a stand-off to hold the arm slightly away from the lander body to both protect the vessel and ensure the arm has enough gravitational force pulling it down into its proper position. This bolt can be easily removed and reattached as needed to reduce the space the lander takes up during transit (something our team used frequently this year to fit the lander in our cars). The last step before the bait mechanism is ready for deployment is to place the bait of choice in the bag at the end of the arm on the bait plate. The bait plate serves the additional purpose of being a known dimension at the same frame as most species seen in video allowing scientists to use it as an accurate way to measure the size of the creatures seen.
There are a few other miscellaneous parts of the lander the undergraduate students were trained to set-up including the GPS Satellite Tracker (discussed more in Section 4.1), the lander’s visibility flag (held in place with a single bolt and made from high-visibility material with a reflective strip for spotting on the surface), as well as the lander’s recovery bale (a sturdy rope attached to the lander’s frame and held above the lander with a thin composite rod to keep it easily accessible for recovery upon surfacing). With knowledge of all these elements, Danika and Maya were finally able to learn how to do a complete assembly of the lander. This included the proper sealing of pressure spheres with critical steps of cleaning O-Rings and O-Ring grooves, applying silicone grease, and pulling a vacuum on the sphere to -0.6 bar. They also learned best practices with any external metal fixtures where zinc-oxide is applied between any threaded fixtures (like the nuts and bolts that hold the burn-wires in place) to block salt water from entering these gaps and therefore reduces the corrosion of the metal over time. With the lander fully assembled, they were ready to complete a full deployment.
The only information left for Maya and Danika to be taught was the need to replenish consumables (parts used up during each deployment and in need of replacing). These consumables include Drop-Weights (and associated Chain), Burn-Wires, and LifeSavers. LifeSavers are the easiest consumable as they can be bought in bulk for very cheap, the only thing they need to be careful of is inspecting each ring for chips or cracks prior to use on the
lander. Parts with these flaws cannot be used on the lander but make a great snack while working in the lab or helping to reduce seasickness while aboard a ship. The weights themselves are 20lb cast iron weights which can easily be bought for deployments, the only real requirement of the weight is it must have a location where chain can be affixed to it (like a hole in the center). Chains need to be cut to length using bolt cutters with appropriate connectors to attach the chain to the burn wires as well as the heavy-duty welded rings used to hold the weight to the lander. Lastly, the most time-consuming process is the creation of burn-wires which require a many-step process to manufacture. Bolt cutters are used to cut steel cable to length, then the ends are stripped as well as a small section in the middle (which will corrode, its width affects how long it takes to burn). The ends are then crimped together along with a piece of marine grade wire. The crimped part is then coated in marine grade electrical sealant before also being covered with marine grade heat shrink to prevent water leakage into its connection. A rubber grommet is then attached to part of the burn wire loop using a zip tie. The loose piece of marine grade wire can be soldered onto the lander in place of the current burn wire and the rubber grommet is then used to protect the bolt that holds the burn wire in place on the side of the lander.

Figure 4-27: Lander Consumables
4.2.2 COMMUNITY OUTREACH EVENTS

4.2.2.1 UNITED BY EXCELLENCE

On October 26th, our group participated in Cal Poly's United by Excellence program. As Dr. White explained to us, United by Excellence is a one-day event hosted by the Office of Admissions. It is designed to provide access to educational resources, equitable learning experiences, and higher education preparation to underrepresented and historically underserved student scholars interested in pursuing higher education. The session we helped host was tied into Admissions' Latinx/e heritage event. I, Danika, Maya, Dr. White, and Sierra Bentti (Marine Science, Class of 2024, another of Crow's students he began bringing into the lander project) presented to 8 groups, each made up of 4 high school students from underrepresented communities and taught them about our research. To do this, we showed them the lander in person, explaining how it functions, and played highlight reels of footage for them as we explained the impacts this research had on our knowledge of the deep sea. Together, we represented the biology department and took turns presenting and interacting with students. This was also my first-time meeting Sierra and her first time seeing the lander in person.

Figure 4-28: United by Excellence Presentation Team

4.2.2.2 CAL POLY PIER OPEN HOUSE

The next day, on October 27th, we woke up bright and early and got to the pier to set up our stall for Open House. Here we had a very similar set up to that from United by Excellence where we
showed the lander and highlights reel, but with the addition of the poster made by my senior project team [1]. Both the highlights reel and poster used can be found in Appendix S. Danika, Maya, and I collectively presented to the local community, encouraging more enthusiasm from the public for our research. Overall, I had a great time, and everything went off without a hitch. In total we had 2,120 visitors to the pier, 500 of which arrived within the first hour of opening. My favorite interaction was with one little girl (7 or 8 years old) who, upon finding out what our project was, got the widest eyes and biggest smile – literally shaking with excitement – and said, “I LOVE THE DEEP-SEA!” She loved hearing about the lander, and I don’t think could have moved faster when I directed her to our videos she could watch.

Figure 4-29: Cal Poly Pier Open House [32]

Figure 4-30: Cal Poly Pier Open House Presentation Team
4.2.3 DEPLOYMENTS

The most exciting parts of this project were performing actual lander deployments both off the pier and at sea. While I had previously deployed the lander many times, this was the first time I had the opportunity to deploy the lander off large vessels and in deep-water. As a part of this I had the phenomenal experience of working with NOAA on coordinating deployment operations, filing operation permits, and going to sea on their research vessels as well.

Below are short technical summaries of each deployment conducted, full deployment details can be found in Appendix Y.

4.2.3.1 PIER DEPLOYMENTS

4.2.3.1.1 PORT SAN LUIS PIER

While we had access to the Cal Poly pier and have used it in the past for test deployments as a part of my senior project, we had found the height of the pier made it difficult to deploy the lander due to the need to hoist it 10-15 feet into the air to reach the lower-level platform. While this was doable in senior project, it had also led to an incident where the lander had hit the underside of the pier damaging one of the counterweights and its visibility flagpole. The flagpole had been snapped but was able to be repaired, while the counterweights had to be scrapped and new ones needed to be made. To prevent this risk of damages and make deployment operations easier, the team made the unanimous decision to instead deploy from the Port San Luis Pier in Avila. These deployments were completed on the piers lower-level floating platform used for boarding small watercraft and were positioned in a way to ensure the platform could still be used by the rest of the public without interfering with the lander operations.
4.2.3.1.1 TRAINING DEMONSTRATION

The first deployment we completed was a training demonstration deployment where I completed a full deployment (set-up through clean-up) as Danika and Maya watched and asked questions, explaining the lander’s base operations and showing how to use it. This deployment not only allowed them to learn how the lander operates but gave them a better idea of its uses and limitations while developing their survey experiment methodology for Dr. White. This deployment was completed prior to any modifications made to the lander as discussed in Section 4.1 and was part of the team’s basis in determining what modifications needed to be made for their research.

4.2.3.1.1.2 DRY-LAND DEPLOYMENT

After developing Maya and Danika’s basic engineering skills and familiarizing them with hand tools, I ran them through a dry-land deployment which is where we complete all the preparations leading up to a deployment, and clean-up/analysis for after, but the lander never leaves the
project room. This was a great first practice for getting more hands-on experience with the lander and its components without the stress of travel and unpredictable environments.

4.2.3.1.3 TEAM PIER DEPLOYMENT

With a dry-land deployment under their belts, we then set about completing a group deployment where they were hands-on and actively involved in the lander’s set-up, assembly, deployment, recovery, clean-up, and analysis. A large part of this deployment was familiarizing them with how to operate the lander and safely ensure its function and return in marine environments as discussed in Section 4.2.1.2 above. Additionally, it provided them with experience maneuvering the lander manually, transporting it, and increased their confidence levels in the lander’s reliability and function.

![Figure 4-32: Team with Lander for Pier Deployment](image)

They also had the opportunity to experience imperfect conditions. As you can see in the figure below, the visibility of the water this day was low such that there were times we couldn’t see the bait arm, let alone any fish at its base.
Now that they had a deployment under their belts, it was time to begin preparing them for their next milestone – a solo deployment. This deployment would be completed with me present and watching, able to step in incase a catastrophic mistake that would permanently damage the lander was going to be made, but otherwise be hands off and quiet – letting them prove to
themselves they are capable of doing the deployment without me. With this goal in mind, I started answering all their questions and having them take notes about how to complete a deployment. I helped them develop a Packing List for what to bring with them on deployments and a Deployment/Recovery Checklist highlighting key steps along the way. The basis of these was the existing Operations Sheet I created with my senior project team and updated for NOAA, then Maya and Danika worked together to tweak it as they thought would be most helpful to their understanding by adding notes as we talked through procedures together and asking questions along the way. Once their checklist was done and final questions were asked, it was time for them to begin their solo deployment.

While completing this deployment, Danika and Maya worked very well together and did a great job. I’m very happy that any questions they had for me during this test were able to be answered in a way where they either remembered or found the answer to their own question. Overall, this test was a success! The burn wires went off successfully, the lander came back on its first burn, and they completed nearly everything by themselves – the only time I put my hands on the lander was when asked to help hold something at their request since sometimes a third set of hands makes the job a lot easier.

That said, there were a few things that did not go according to plan. The first was that they did not document what time they had set the burn-wire timers for and got it mixed-up such that the lander came up half an hour earlier than they expected. This was however in line with the time I remembered them initially discussing at the beginning of their lander set up, so I know if they had taken the extra couple seconds to document burn times, this error would not be repeated. Having them experience however, will help with their memory of documenting such decisions in future operations. More importantly, and more disappointingly to them, was that the camera and lights did not turn on or record during the deployment. This was unfortunate because this was the first deployment since adding the light filter caps to the lander, and they were excited to see how it worked underwater, but was not a big loss in my books as we learned an important detail I had been unaware of before: If you unplug the CamDo after setting camera times, it will reset the
device and you will need to resynch it and start that step over after reattaching it to the GoPro. Afterwards, I discussed with them their thoughts on the operations and had two main take aways: (1) they now felt a lot more confident in how to operate the lander; and (2) they wished we had done a solo “dry deployment” test run on campus first. In hindsight, this makes a lot of sense, and I can definitely understand how a solo “dry deployment” as an intermediary step would have been beneficial so will be sure for any future students and scientists to add this step into my plans for their training.

![Figure 4-34: Danika and Maya’s Solo Deployment](image)

4.2.3.1.1.5 BLUE LIGHT FILTER TEST

This was supposed to be the completion of our pier deployments for the summer, however, as will be discussed in the next section, there were some complications in our plans to go to sea with NOAA in July. Unfortunately, we were unable to go to sea on the R/V Fulmar due to poor weather conditions making the area unsafe for operation at the time. However, because of this we decided to complete a final pier deployment on the day we were supposed to go to sea with Fulmar in order to test our light filters. Since Maya’s research showed that blue light was better for shallow water studies, we swapped the light filters back to blue instead of the red we had planned on using with NOAA and set out for the pier. The deployment went smoothly, and we used this
opportunity to practice utilizing the large vessel recovery device we developed in preparation for
deep-water operations which also went well. We learned when analyzing the footage that the blue
lights are so bright and vibrant, they can sometimes wash out the fish making it difficult to
determine the species seen. We believe this was partially caused due to the turbidity in the water
at the pier making poor visibility conditions and more particles in the water to reflect the blue light.

Figure 4-35: Pier Deployment Blue Light Filter Test
4.2.3.1.2  CAL POLY PIER

4.2.3.1.2.1  PRACTICE DEPLOYMENT

While we had originally planned on not doing any deployments off the Cal Poly Pier, this decision changed in late October at the request of Dr. White. He wanted us to work with another one of his undergraduate students, Sierra Bentti (Marine Science, Class of 2024), who was developing lesson plans for high school curriculum and was going to use lander footage as a part of her lessons. Because of this, when I returned to campus for the Cal Poly Pier Open House on October 27th, we decided to do a deployment as well.

The day before, Maya, Danika and I prepared the lander for the deployment after open house. For this, we set-up the camera and burn-wire timers as well as decided on an exact deployment time. We also decided to use a new battery set up suggested to us by Kevin to enable longer video recordings. For this we removed the internal GoPro battery and instead relied entirely on the back-up battery it was plugged into. This was done because past deployment recordings were being cut short of our 90-minute goal at 88-minutes due to the battery dying, and Kevin informed me that when the original battery was in place it would over-ride the backup battery and not have it be used by the system. Once everything was set up, we loaded Maya’s car with everything needed for Open House and the deployment before dropping everything off at the pier.

Once Open House was complete and we finished helping with clean up, we were joined by Sierra as well as Kyle Walsh (one of my Senior Project team members) and Jake Roth (current Cal Poly Marine Science student) who all helped us complete our pier deployment. Because I have long standing shoulder problems, I knew I would not be able to reliably hold the lander’s weight while lowering and lifting the lander from the pier’s lower platform, which is why I called in reinforcements to assist in our operations. Kyle and Jake helped spot Maya and Danika in lifting and lowering the lander into the water and Kyle was able to give them great advice from having deployed the lander in this location many times. Jake unfortunately had to leave after the deployment began, but everyone else stayed around for the entire operation. Things went great
overall, with deployment and recovery going relatively smoothly and a great learning experience for Danika and Maya.

![Team Photo During Lander Pier Deployment](image)

**Figure 4-36: Team Photo During Lander Pier Deployment**

There were a few takeaways from this deployment: (1) We decided for our NOAA deployments to return to our original battery set up since the backup battery had died on us prior to the lander ending up in the water. We believe this occurred since we set the times for the deployment more than 24 hours in advance. However, I have done this in the past with the GoPro battery attached and did not have this issue, so we think the back-up battery had less power than the built-in option. (2) We successfully determined that Maya and Danika can deploy the lander off the Cal Poly pier but believe at least 3 people capable of lifting the lander are required to do a deployment off the pier safely (for both people and lander safety). (3) We determined that it would be best not to have the lander’s visibility flag attached, nor the support rod for the lifting bale. This is because these poles are very fragile and can easily be caught on the underside of the pier during recovery. Additionally, the lander is easily visible from the platform without the flag and the recovery rope is already attached to the bail (meaning it doesn’t need to be held aloft for a boat hook to grab).
4.2.3.2 BOAT DEPLOYMENTS

4.2.3.2.1 NOAA DEPLOYMENTS

The most exciting deployments we completed as a part of this project were done in coordination with the National Oceanic and Atmospheric Administration (NOAA). Dr. White was able to connect me with one of his friends who now works at NOAA, Dr. Lindsey Peavey, it was thanks to her that we were able to make all these operations possible. Lindsey knew we had a tight budget but was also working on research with her own team that would be taking place along the central coast, including within the Wind Energy Area (WEA) itself. Because of this, Lindsey and I worked together with the rest of the NOAA operations team to find ways for us to tag along on their already scheduled operations to complete our lander deployments and conduct our research in conjunction with them.

4.2.3.2.1.1 R/V FULMAR - JULY

The first trip we planned was to go to sea with Lindsey and her team on the R/V Fulmar in July of 2023. The plan for this trip was to go out with them for two days, the first completing a shallow water test in the Monterey Bay National Marine Sanctuary (MBNMS) while the crew serviced a data buoy (MB05), and the second being inside the WEA while the team serviced another buoy in
the area. This planning was all happening simultaneously with the training Danika and Maya were receiving from me and happening in parallel to our pier test deployment operations and manufacturing of lander modifications. While the plan for us to join on the Fulmar had been set months in advance, the true operations planning began in the few weeks leading up to the actual deployment date.

![Figure 4-38: NOAA's R/V Fulmar Ship [33]](image)

The first of these planning meetings was coordinating with Jean de Marignac, the Field Operations Coordinator for the Fulmar trip. As a part of this, I provided Jean with a Specifications Sheet I made for the lander and an updated version of the lander's Operations Sheet to share with the crew. Additionally, I had a phone meeting with Jean where I explained to him how the lander operates, what my teams' needs were for the deployments, and most importantly how the deployment and recovery operations would function. This was the most complicated part of our discussion and raised the most questions since the Fulmar is a far larger vessel than those I had deployed the lander off of in the past (a 67-foot ship instead of the Cal Poly TL Richards which is a 26-foot boat). On smaller vessels, I had been able to manually lift the lander over the side of the boat and place it in the water by hand, as well as use a boat hook to bring the lander next to the boat before lifting it back on deck manually. This, however, would not be possible on the Fulmar
or any other large vessels we deploy the lander off of due to the deck being significantly higher above the water’s surface. Jean and I developed a plan for lowering the lander into the water using a line with one end tied to the ship, and the other end loose and looped through the lander’s recovery bale. With this we could then slowly lower the lander overboard by letting out more line from the loose end, and letting go once it was in the water and the free end would then simply slide out of the loop as the lander sunk. We were unfortunately unsure what the best recovery method for the lander would be however, so at his advice I reached out to my mentor Kevin Hardy at Global Ocean Design who I built the original lander with to get his advice since I knew he had deployed landers off larger vessels before. As discussed in Section 4.1, Kevin advised I create a new large vessel recovery device which we could then use on the Fulmar to recover the lander safely. A full description of these plans and the final decided operations can be found in Appendix F.

When first making plans for the Fulmar trip, there was a miscommunication within NOAA where we had been told we did not need any permits for our planned operations. However, two weeks before our planned deployments we learned that in order to deploy on the first day in the MBNMS we would in fact need a permit. At this point Dr. White was out of town through our deployment dates on vacation with his family, so I stepped up and took the lead role in filing for the permit. Lindsey was a great help to me as I had never filed for a permit before, and she also worked with Sophie De Beukelaer (NOAA Permit Coordinator) to help expedite our permit application and thankfully we were able to get our permit before the cruise. Documentation of the entire permitting process can be found in Appendix C. Sadly, however, we were unable to use the permit for this cruise as poor weather rolled into the central coast at the time of our boat trip. While at first the cruise was simply delayed by a few days, it was ultimately cancelled due to unsafe operating conditions at sea making it hazardous for my team to execute any lander operations. To make up for this though and give my team a chance to both meet Lindsey, her team of scientists, and the Fulmar crew we organized a time to meet them in port in Morro Bay to complete a practice run of deployment and recovery operations for the lander off the vessel.
Even though we did not get out to sea on the Fulmar, we had a fantastic experience meeting everyone on board and it was a great learning experience for performing lander operations on such a large vessel. Completing our deployment and recovery operations was a success and learning how to use the ships A-frame, winch, and quick release devices was extremely useful in both planning and confidence levels for future deployments. Additionally, we determined the best location for our team to complete lander set up inside the ship next to the galley and became familiar with the ship’s layout and how at-sea procedures function. The entire crew was extremely welcoming and encouraging, I loved learning about their research operations and getting the opportunity to share with them about our research as well as teach them how the lander operates.

![Figure 4-39: R/V Fulmar Port Test Operations (Photos courtesy of NOAA Crew)](image)

4.2.3.2.1.2 R/V SHEARWATER - AUGUST

Even though we were unable to go to sea with NOAA in July on the R/V Fulmar, Lindsey suggested we reach out to the R/V Shearwater (a 62-foot vessel with nearly identical layout and equipment as the Fulmar) crew since she knew they would be in the central coast in August. While the crew was very willing to accommodate us, we learned this trip was being funded by a research group from Stanford who were performing research in the area. Because of this we were told we would need their permission to join, so I was connected to Dr. Marilla Lippert who was the Principal Investigator (PI) of this trip. After talking with Marilla, it was very fun to learn that
she had actually worked in Dr. White’s lab when she was an undergraduate student at Cal Poly, so she was thrilled to find a way to incorporate us into their cruise. Because their research was primarily close to shore dive operations, they would not be making any trips out to the WEA but said they were still happy to include us on one of their day trips to get practice doing a real deployment/recovery off one of NOAA’s ships. It was decided we would be joining them on their day from Morro Bay to the Harmony Headlands dive sites. There we would stop near their second dive location to drop the lander, then proceed to the first dive location, wait for them to complete their dive, and return to the second dive site where they would do their second dive before we go to recover the lander.

![Figure 4-40: NOAA's R/V Shearwater Ship [34]](image)

The next step in the planning process was to begin official paperwork and planning for our cruise. As a part of this I learned how to use NOAA’s Vessel Project Manager (VPM) system which is an online portal where I can create project proposals, float plans, cruise plans, and more, such that NOAA can track what equipment and people will be on their vessels on any given day. For this process I worked with Danny Lucas, the vessel operation coordinator for the Shearwater. It began with a quick email summary of our project and explanation of our goals for the cruise, then was elaborated in a Zoom call where I answered his questions more in depth and learned how the vessel operates more fully. Thanks to my previous planning with Jean on the Fulmar, it was very easy to explain our new deployment and recovery operations to Danny in order for him to relay it all to the crew. Additionally, Danny explained to me what my role as PI of our project would be. I
was responsible for completing all VPM documentation, relaying safety guidelines to my team, and ensuring all were followed. Additionally, during the time we were completing our operations on the ship, I was responsible for managing my team’s time and interfacing with the crew for all ship operations. With all documentation and planning complete, we were ready to go to sea. All documentation for this cruise can be found in Appendix H.

We joined the crew on the R/V Shearwater on the afternoon of August 22nd in Morro Bay. After introductions and loading both projects supplies aboard, we left port and headed to the Harmony Headlands. We deployed the lander at 35.455379, -121.008636 (west of Harmony 1 Dive site) at a depth of approximately 60ft. On our way to the drop site, Danika, Maya, and I completed the entire set up on a moving ship with 4-5ft swells which made maneuvering parts a bit challenging. Regardless, we worked together like a well-oiled machine, effectively setting up the lander with no delays.

With the lander set-up complete, it was time for deployment operations. First, the lander recovery bale was attached to a quick-release mechanism. The quick-release was attached to the end of a line which was passed through a pulley on the ship’s A-frame and whose length is controlled by a mechanical winch system. Additionally, two guidelines were looped through the side body of the lander. The ship’s crew manned the A-Frame and winch controls, slowly moving the lander up and away from the ship before lowering it into the water such that the orange side floats were at the water’s surface. While the lander moved, Maya and Danika manned the guidelines, ensuring the lander remains stable and did not swing wildly to injure anyone. I manned the quick release wire, giving instructions about lander placement and position to the crew and releasing the lander once properly located on the surface. The entire process went very smoothly.
After deploying, we left the area to go to Harmony 2 for Marilla’s team’s first dive operation. Once all divers were back on board, we went back to Harmony 1 and our team watched for the lander to surface while the divers were in the water for the second time. One of the NOAA crew was the first to spot it on the surface since the lander was very far away on the horizon. Once spotted, our team then continued to keep an eye on it while we waited for divers to finish and return. While Maya and Danika kept an eye on the lander, I began setting up for recovery. We attached the recovery clip to the end of the line looped through the A-frame pulley and driven by mechanical winch system, just like we had done with the quick release mechanism for deployment, but with extra slack. The recovery clip/line was then attached to the end of the recovery pole. Once the dive team was back, we sailed towards the lander, approaching from down swell to allow the lander to gently come to us. I then used the recovery device to reach overboard and clip onto the lander’s recovery bale. While I was doing this, Maya was responsible for spotting me to ensure I did not fall overboard due to unexpected swell while leaning over the edge of the ship. Once clipped, I removed the recovery pole and passed it to Danika. The Shearwater crew then used the A-frame and winch to reel in the lander. I stood on deck ready to catch the lander to prevent it
from swinging wildly and helped guide it back on deck. Once all was back on deck, we returned the safety wires across the aft deck and began to clean up. The excess bait was disposed overboard, and the bait arm was tied back in an up-right position. The lander and all equipment that came into contact with salt water was then washed off with fresh water to prevent salt build up on our equipment. With the day a success for both projects and a fantastic learning experience, we returned to port.

Once back on shore, we returned the lander to the shop, stopping to acquire the SD card from the camera. The deployment was shallow enough that there was still good atmospheric light, so we couldn’t get a great read as to whether the red light was sufficient in lighting the species seen on camera for deep water deployments, but unlike our blue light test at the pier, its brightness did not inhibit our ability to identify species seen on the video. From our recordings we saw a total of five different species of fish, three sea pens (one of which was seen recoiling its comb on camera), but most exciting was one fish species that came to visit SeaStang – a wolf eel!

Figure 4-42: Wolf Eel visits DOV Seastang at Harmony Headlands
It was extremely rewarding, being able to share our results with the Shearwater crew and Marilla’s team but was even more rewarding as a mentor to hear all the compliments from both the NOAA and Stanford teams about how impressed they were with our team and their excitement to work with us again in the future.

4.2.3.2.1.3 R/V SHEARWATER - NOVEMBER

In November, we had the opportunity to do just that by joining Dr. Lindsey Peavey and her team of scientists on the R/V Shearwater for the Central Coast Collaborative Passive Acoustic Monitoring research cruise. For this cruise my team was scheduled to go out on the ship for two days, the first on November 7th to do a 90-meter deployment at the location of NOAA’s MB05 buoy in the Monterey Bay National Marine Sanctuary and the second on November 8th to do a 1 kilometer deployment in the Wind Energy Area (WEA) off the coast of Morro Bay.

Set-up for these deployments began on November 6th, where my team completed lander preparations and purchased additional supplies necessary for our deployments. We were then informed that due to poor weather conditions predicted the next day, both our deployments would be pushed back by a day. The next day, while it wasn’t safe to go to sea, we were able to meet the NOAA crew to load the ship. Additionally, after loading the ship, we were invited to join them all for a group barbeque to bond and get to know everyone aboard the ship. This was a phenomenal experience and I really enjoyed getting to bond with the crew more and learn all about their different research projects. After dinner, we went home to rest before returning to the ship to depart at sunrise.

On the way to the ship, we realized we forgot to buy bait the night before, so Maya and Danika ran to a nearby bait shop which was scheduled to be open according to their website. However, this turned out not to be true. Thankfully though, the crew had some extra squid bait in the freezer we were able to use instead. Once everyone was on board, due to colder waters this time of year, everyone on board needed to be trained on how to put on a full-body immersion suit (an oversized wetsuit to keep you warm and floating if immersed in the water) in case of an
emergency like the ship going down. We each had 2.5 minutes to take out the suit and fully put it on as part of our training, which we all completed successfully!

![Image: Full-Body Immersion Suit Test]

Once this training was completed, the ship left port and began its transit to MB05. My team worked to set up the lander during the hour and a half transit. This proved to be challenging since not only were we going over consistent 4–5-foot swells but had occasional 8 foot swells as well, which led to both Maya and Danika struggling with sea sickness. Thankfully though, we were able to get everything together before we arrived, so only had to attach the weight and bait before deploying. We deployed the lander at 35.765991, -121.430313 which had a depth of 90 meters, and was programmed for a 60-minute bottom time. For the deployment operations, I manned quick release while Danika and Emma Beretta (fellow Cal Poly student and NOAA intern filling in for Maya who was too sea-sick to assist) manned the tag lines to steady the lander while in the air and the NOAA crew-controlled the A-frame/winch.

While the lander was underwater, the NOAA team recovered their MB05 buoy and completed their buoy turnaround. We then returned to the lander drop point where we had all hands-on deck on lookout for the lander. Captain Zac spotted it behind the ship where it had drifted 500 feet from
where we originally dropped it. The crew then repositioned the ship to approach from down swell where I then used the Shearwater's carabiner boat hook to latch onto the lander's recovery bale while Danika spotted me to make sure I didn't fall overboard. Once the lander was back on deck, we washed it off with fresh water to prevent saltwater build up on its components.

![Figure 4-44: DOV Seastang Recovery at MB05](image)

After NOAA redeployed their MB05 buoy, we transited back to port. While in transit, we disassembled the lander's spheres and began recharging its batteries since they take several hours to charge. Once in port, while we waited for the batteries to finish charging, I soldered on new burn wires while Maya and Danika acquired mackerel bait for the next day's WEA deployment. Before leaving the ship, I took out the SD card in order to take it home and get a preliminary look at the videos from that day's deployments. At home, I skimmed through the videos where I saw: lots of flat fish (sand dabs/flounders), a shark, 2 octopi, lots of crabs, and several other fish species as well. It took 2 hours for each video to upload, so before going to bed with another long day to come, I only had time to upload the first two videos to the drive that night. I planned to upload the rest along with the WEA deployment videos in the coming days after the cruise.
The next day, on November 9th, Maya unfortunately woke up sick and was unable to join us at sea that day. Danika, myself, and the rest of the NOAA crew departed once more at first light and began our transit to the WEA. While in transit, we once again prepared the lander while traversing 4-5ft swells with occasional 8ft waves. Unfortunately, today was my turn to battle some sea sickness in the process. We ended up deploying the lander just outside the WEA at 35.311600, -121.585457 which had a 900-meter depth. After calculating ascent and descent times for the lander, the entire deployment was scheduled as follows: (1) 33 minutes to descend, (2) 60 minutes of bottom time, (3) 20 minutes for burn wires to burn, and (4) 36 minutes for the lander to ascend. This meant that when the lander went in the water at 9:04 AM, its burn-wire timers were set to go off at 10:36 AM, and the lander should surface around 11:32 am.
The ship then transited to a location 400m away to the NRS-13 drop sight for NOAA’s operations. During their deployment operations, we heard a massive explosion but couldn’t figure out what it was. It sounded like it came from the sky and further out to sea rather than shore and our best guess based on the sounds was a rocket or missile explosion. After a pause to assess the situation and ensure the ships safety, NOAA was able to complete their NRS-13 deployment.

After this was completed, we return to the lander drop point to keep a look out for its return. At 11:15 AM, we began having all hands-on deck keep a look out. At 11:30 AM, I started checking the SPOT Trace app, but it only showed the location of the lander from when we dropped it with last signal at 8:51 AM. At 11:45 AM, I began to worry some but thought maybe there had been low salinity and burn wires taking longer to burn as this had happened in a past deployment off the Cal Poly pier during senior project. At 12:00 PM, we returned to collect NRS-13 while those not doing ops continue keeping an eye out for Seastang and I continue to check SPOT Trace. Figures depicting the drop point of the lander as recorded by the SPOT Trace and the Shearwater’s navigation system can be seen below.

During these operations, my worry-filled brain began trying to think of explanations for the lander’s late arrival. I wondered if my ascent/descent calculations were off. I had based them off
the times recorded on video of the 200ft deployment from my senior project, and while I had originally remembered it being 100ft, my team all confirmed to me it was 200ft, so I used their number. If I had been correct though and it was only 100ft it could double the time it took the lander to ascend/descend. I additionally began to wonder if I forgot something during deployment set up, but no – Danika and I were thorough and checked each other at every step. We made sure not to plug in burn wire batteries until after timers were set to prevent prematurely draining the batteries. The only thing I noticed was a slight residue of salt build up on the burn wire electrode from the MB05 deployment which I had thought about cleaning off but don’t remember if I did. Even if I didn’t clean it though, while it might slow down burn times, it would not stop it from corroding entirely. Next, I wondered if the explosion sound during the NRS-13 deployment was related to lander imploding or landing on an old military mine/bomb since after doing the math in my head I realized it occurred right as the lander was supposed to hit the bottom. The NOAA crew, however, all confirm this couldn’t be the case due to where we heard the explosion come from and attested that even if it did implode, we could not have heard it from that depth. The explosion sound didn’t come from underwater; it was definitely in air.

At 1:30 PM, there was still no sign of Seastang and NRS-13 operations were completed, so after discussing with the crew we began to conduct a final area visual search to look for Seastang with all hands-on deck. The search pattern followed can be seen in the images below. At 2:00 PM, there was still no sign of DOV Seastang, and I was left to make the call to return to shore. On our way back, I confirmed with the crew through their sensors that the sea floor at the drop location was extremely soft/silty, meaning there is a chance the lander could have gotten stuck in the mud from its momentum upon touch down.
I officially deemed the lander lost at sea, and then began the process of notifying everyone involved in the project. I began of course with a message to Dr. White and Maya, followed by the rest of my committee, Kevin Hardy at Global Ocean Design, and the new interdisciplinary senior project team Maya and Danika were mentoring. I let them all know where things stood and our best guesses for what may have happened. In his response, Kevin mentioned that the lander could also have gotten stuck on some jetsam, like a ghost net or abandoned fishing line, and to wait for a local fisherman to find it and contact us in the next week. One of the NOAA crew told me about how in college her teams frequently had burn wires fail in past with them taking hours, days, or even months to burn. I also recounted one of Kevin’s stories of a lost lander showing up 4-5 years after it was dropped. On this deployment, the lander in question didn’t have it’s burn wire timers set so they had to wait for them to naturally corrode. It was deployed off the coast of San Diego and washed up on Catalina where a tourist found it and called the recovery phone.
number on its “If Found Please Recover” sticker. I was also told about some equipment NOAA lost just washing up this year in Japan 10-12 years after they went missing.

Overall, the NOAA team was very sweet about the whole situation, sharing horror stories of all the expensive high-tech equipment they had lost at sea. They said it happens to everyone in this field at least once, and while they were sorry it happened to me so early in my career, they welcomed me to the club - saying I’m officially one of them.

![Figure 4-49: NOAA Crew + Visiting Scientists Group Photo (Courtesy of Lindsey Peavey)](image)

### 4.2.3.2.2 CAL POLY TL RICHARDS DEPLOYMENTS

While we had wanted to complete another deployment off the Cal Poly boat over the summer, each attempt we made at scheduling it was unfortunately met with either scheduling conflicts or weather delays. Because of this, we began exploring other options including using a third-party boat rental. When we had been talking with Lindsey, she mentioned meeting a ship captain in Morro Bay who did work in the WEA and would be interested in helping with scientific research. Lindsey then gave me the contact information for Captain Shawn Stamback, who I called to discuss our options with. While Shawn was incredibly willing to take us out to the WEA and assist
in our lander deployments, unfortunately the cost to operate his vessel daily was more than we could fit into our budget at the time. The quote provided by Shawn was for one day and one deployment in the WEA at a price of $3,000 as can be seen in Appendix I. This combined with concerns about Cal Poly allowing students to use a third-party vessel for liability reasons, led to us unfortunately having to deem this option a dead end.

4.2.4 LOST LANDER ANALYSIS

Once back on land, I began analyzing what may have happened to the lander during the WEA NOAA deployment and putting together recovery plans for it.

4.2.4.1 THEORIES ON WHAT HAPPENED

As alluded to in the NOAA Boat Deployment’s section, I have many theories as to what might have happened to the lander. One theory, first posed by the NOAA crew, was the idea of the lander having gotten stuck in the mud. The crew confirmed that the location we dropped the lander contained extremely soft sediment, so much so that it was actually softer than the soil they look for when taking sediment samples. From this we have a few theories as to what might have happened to the lander. The first is if the lander sunk far enough into the sediment, there is a possibility that the mud could have covered the burn wires. This may be enough to prevent the electrolysis that is required to drop the weights from corroding the burn wires properly, effectively trapping the lander on the sea floor. Next, I recalled from our senior project boat deployment that when the lander first reached the floor, the momentum of the lander body continues to travel downward after the anchor for a little bit before floating back up to its resting position. From this I wondered if this momentum would be enough to wedge the lander body into the mud itself, not just the weights. Without knowing more specifics about the soil density in the area, it’s hard to tell for certain. Lastly, we wondered if the bait arm might have sunk into the mud and wedged itself such that even if the weights dropped, it could have kept the rest of the lander on the sea floor with it. The more these theories were analyzed by Dr. White, Danika, and I, the less we thought these were the actual cause, however.
Dr. White asked what human errors could have led to the lander failing to return and if there was any chance they could have occurred. I began by explaining the possible errors that could have occurred while setting up the burn wires: (1) setting/starting the timers with the batteries plugged in, (2) hitting a button on the timers after the batteries were connected, or (3) improperly sealing the burn-wire sphere. While I had been battling sea-sickness during set up, Danika and I were checking and keeping tabs on each other the entire time. We are both highly confident that all steps of lander set-up went according to plan, and whatever happened was not due to human error. To use one of Kevin’s favorite phrases: sometimes in ocean exploration you can do everything right, but Davy Jones will still covet what he keeps!

Next, we questioned whether one of the lander’s spheres could have failed. We know both pressure sphere housings were rated to 2km below sea level and this deployment was only 45% of that depth. Additionally, as we saw from Kevin’s sphere testing in Chapter 2, the shallowest failing sphere from his tests failed at a depth of 2,905 meters. This deployment was only 31% of that depth and should only have faced an external pressure of 1,322 psi. For both these reasons, we believe the pressure spheres would have remained intact. Next, we looked at the side-floats of the lander. These buoyancy spheres were rated to a depth of 1.2km below sea level, meaning this deployment was at 75% their maximum depth. Additionally, similar to the pressure spheres for the lander, Kevin also tested these side floats and found that they failed at 1,960 meters in testing (Appendix K-3). With these numbers, this deployment was only at 46% its failure depth. These numbers all indicate that all four spheres (the two pressure sphere housings and the two buoyancy side-floats) should have been well below failure at these depths. This means that unless there was some major manufacturing flaw that we were unable to detect visually, the lander should still be fully intact at this depth.

This leaves our final and currently most likely theory – that the lander got stuck on some unknown fowling. Whether this takes the form of some unknown terrain, a ghost net, discarded fishing line, or some other obstacle, our best guess at what happened to the lander was it getting entangled in something either on the sea floor or in the water collum which prevented it from surfacing.
Regardless of what actually happened however, we are left at best with speculation and theory because, as Kevin said, it's hard to do an autopsy without a body.

4.2.4.2 RECOVERY PLANNING

While we can theorize all day, the only way to know for sure what happened to Seastang is to wait until she is recovered and do a thorough investigation then. So, in addition to having plans for continuing research with the lander, we began to make plans for recovering the lander. Unfortunately, at this depth, there is no easy way to recover the lander as it is far too deep for human divers and all capable equipment would be far more expensive than simply building a new lander, so we are left with building a series of fail-safe plans.

The first of these was hoping for the lander to surface on its own and signal us via our SPOT Trace GPS. After researching battery lengths, we found that with our current settings, the SPOT Trace could last up-to 1.3 months depending on how much it moves. This is because more movement triggers the device to try to send more GPS signals, using up the battery faster. However, we believe the lander is most likely stationary and since we have it set to “Dock-Mode” its movement alerts are only set to trigger if it moves more than 200 m, we are hopeful that it will be at the high end of this number range. See Appendix V for SPOT Trace Battery Life Data.

In hopes this does happen, as at the time of publishing this paper we are still within the possible recovery window, we looked at what our ship options were for getting out to the lander’s deployment location. We talked to Tom Moylan and Jason Felton, the Cal Poly Marine Operations staff and inquired about the possibility of using Cal Poly’s boat, the TL Richards, as a recovery vessel. Unfortunately, but understandably, they made the decision that at this time, due to the distance and possible range of conditions to be expected in the WEA, the TL Richards is not properly equipped to support operations beyond a 10-mile range offshore working out of local harbors. For this reason, if the lander does surface, we will need to find an outside contractor to take us out for a recovery mission. While we had planned to use our remaining Baker-Koob funds
to purchase lander consumables for future work, paying for this recovery operation would take a
new priority.

Additionally, if for some reason the SPOT Trace does not trigger or the lander surfaces after it
has died, the top of the lander has a large “If Found Please Recover” sticker on it. Below this
sticker contains my contact information (phone number and email). So, if a fisherman or other
vessel finds it at sea, or anyone else finds it washed ashore, they will be able to contact me, and I
can organize a way to recover it. The only possible flaw is that my email on the lander is my Cal
Poly email which expires 6 months after graduation. Thankfully after talking to Cal Poly ITS
though, I learned that if we need to extend this, Crow will be able to submit a service request to
ITS to do so. The only limitation is that such requests must be submitted by faculty and not
students. So, if in 5 months from now the lander has still not surfaced, Crow will file for this
extension.
5 CONCLUSION

5.1 RESULTS SUMMARY

5.1.1 EXISTING PRESSURE SPHERE ANALYSIS

I was able to explore the limitations of the existing pressure spheres and explore alternative designs and materials that could enable the lander to go deeper than is currently possible. Utilizing the existing pressure sphere material properties for the 30% Fiber Glass 70% Nylon injection-molded isotropic composite, I was able to simulate sphere failure and compare it to real-life test data collected by Global Ocean Design. On average, the existing spheres failed at a depth of 3,047 meters below sea level in lab testing which was well below the manufacturer rated maximum depth of 4,500 meters. Because of this, Global Ocean Design assigned these spheres a depth rating of 2 km below sea level, giving a 1.52 factor of safety for this design. I then developed a Finite Element Analysis (FEA) model to simulate the pressure sphere. The first model I made was a simplified axi-symmetric model, which consisted of 2 hemispheres, neither of which contained O-ring grooves or electrical ports. After completing a mesh convergence study, I found this model predicted sphere failure at 3,954 psi or 2,690 meters ocean-depth. This is 215 meters shallower than the earliest failing sphere from Global Ocean Design’s experiments but is still 690 meters deeper than what the pressure spheres are rated too. This is only a 7.38% error compared to the real minimum failure depth, so was thus determined to be a valid model.

Because the addition of O-ring grooves and electrical ports were expected to cause increased stress and thus earlier sphere failure, I then created an axisymmetric O-ring groove model and a quarter model containing an electrical port to see their effects. I found that while the O-ring groove does have an impact on the sphere’s contact pressure and opening results, it is not significant enough to concern us for future changes since the sphere does not open at all, and thus it is safe to neglect the O-ring groove in most future models. After analyzing the quarter model with the electrical port, I found that the contact opening and pressure results are nearly unchanged from the axisymmetric model, but the minimum principal stress is nearly double those
shown the axisymmetric model. This was not surprising as this increased stress all appeared around the electrical port hole which of course introduced a significant stress concentration. That said, our simple sphere axisymmetric model was found to be highly accurate, and conservative compared to real life test results for the pressure spheres, so I decided that all future stress failure analysis may safely be completed using only the axisymmetric model.

5.1.2 ALTERNATIVE PRESSURE SPHERE DESIGNS

While wanting to find ways to enable the lander to go deeper than is currently possible, I modeled several different pressure sphere designs to determine their viability. First, I modeled what would happen if the existing pressure spheres were filled with an incompressible fluid. This model predicted failure at an external pressure of 12,670 psi or 8,621 meters of ocean depth - over three times the maximum depth of the exact same sphere under air filled conditions. While this is a great option in theory, there are many details including the need for the camera lens to be viewing through air rather than an inert fluid and concerns about internal sphere pressures damaging pressure-sensitive electronics that led us to determine this was not a great option for our application. Next, using the existing pressure sphere materials, I varied the sphere thickness to determine how that impacted its depth rating. Because the internal components of the spheres would not allow for a smaller internal diameter, we modeled spheres with increasing external diameters. I found that while the increased thickness does provide an increase in depth rating, we get diminishing returns as we make the sphere thicker. Due to the significantly larger spheres requiring an entirely new lander frame to be additionally built, it was decided this method is not optimal for our purposes.

To keep the pressure spheres the same size and thus use the existing lander frame, we would need to look at alternate materials. Specifically, we were interested in looking at laminated composites. For these composites to be used in application however, we would need to use an equatorial ring on the sphere from a different material that the O-ring grooves could be installed in, since the laminate would be difficult to machine cleanly and would likely result in fraying
composite fibers. Before modeling these materials, we wanted to verify a sphere design using an
equatorial ring would be a viable option as well. We began by looking at a simple cylindrical
equatorial ring which would be inserted in between the existing lander hemispheres. Using the
existing material for both the hemispheres and ring, we found the model failed at 2,351 psi or just
under 1,600 meters of ocean depth. This is 1,090 meters shallower than the sphere without the
ring. Since most of the stress in this model was seen by the center ring, we decided to model it
using both aluminum and stainless-steel rings, but kept the existing hemispheres made from the
existing 30% Glass 70% Nylon composite. The aluminum ring predicted failure at 2,882 psi or
1,961 meters below sea level, however the stainless-steel ring out lasted the composite spheres.
The model containing the stainless-steel ring failed at 3,017 psi or a depth of 2,053 meters below
sea level. While this is still 637 meters shallower than the sphere without the ring, it is the first
model with the ring to reach the rated depth for the existing pressure spheres of 2 km below sea
level. For this reason, stainless-steel was decided to be the best equatorial ring material to
consider for woven fiber spheres.

Lastly, we decided to try an alternate ring design where the ring took the form of a cut out within
the existing pressure sphere. For this design, the modified hemispheres were cut shorter than
before with the end surface still being in the radial direction from the center of the sphere. The
equatorial ring was then designed with angled faces and a spherical shape to fit between the two
hemispheres to create a perfect sphere once combined. The results from the stainless-steel ring
in this model were actually extremely close to the original two part sphere model, with a
maximum external pressure of 3,915 psi or a depth of 2,664 meters – only 26 meters less than
the original, an 8.3% difference. Because of its successful performance and near identical results
to the original axisymmetric model, a stainless-steel spherical equatorial ring was chosen as the
best option for laminated composite sphere sealing.
5.1.3 ALTERNATIVE PRESSURE SPHERE MATERIALS

I then decided to analyze three different kinds of laminated composites to consider making new pressure spheres out of: two kinds of carbon fiber and one fiber glass. Each laminate was designed to be quasi-isotropic and as close to 0.8" thick as possible to keep it as similar to the original sphere design. Each was modeled using the same simple sphere design as the original lander apart from it being a quarter model, rather than axi-symmetric in order for Abaqus to apply composite properties. The first sphere analyzed was made of 584 Carbon Fiber and had a lay-up of: $[-45/45/0/90]_6$. After analyzing the internal stress as well as Tsai-Hill and Tsai-Wu failure criterion, it was found that the 584 Carbon Fiber composite sphere predicted failure at an external pressure of 10,000 psi or 6,804 meters below sea level, more than 2.5 times that of the original sphere. Next, I analyzed a model made of 282 Carbon Fiber with lay-up orientation of: $[-45/45/0/90]_11$. The 282 Carbon Fiber composite was predicted to fail at an external pressure of 9,242 psi or 6,289 meters below sea level. A little less than 584 Carbon, but still more than 2.3 times as deep as the original pressure spheres. Lastly, I modeled a sphere of 7781 Fiber Glass with a lay-up orientation of: $[-45/45/0/90]_{11}$. This composite model predicted failure at an external pressure of 6,630 psi or 4,511 meters below sea level. About two-thirds the depth of the 584 Carbon Fiber composite, but more than 1.6 times the depth of the original sphere model failure. While real life applications of these materials would include design modifications and manufacturing imperfections which would cause the stress experienced by the material to be higher than shown in these ideal models, therefore lowering its maximum depth rating, these results are highly encouraging and show that all three materials could be viable options for future production.

5.1.4 LANDER MODIFICATIONS

Many modifications were made to the existing lander which enabled it to successfully be implemented in numerous deployments for scientific research. The bait containment was modified with the addition of a PVC mesh bait bag to prevent all the bait from being stolen by a single
predator during deployment. Light color filters were added to the system through the addition of light filter caps which allow for easily interchangeable light colors. The existing GPS tracking device was activated and tested, confirming its great accuracy in order to guarantee we would be able to relocate the lander in case it gets lost at sea. Lastly, a large vessel recovery device was created for the lander in order to safely recover it from NOAA’s ships.

5.1.5 LANDER APPLICATIONS

All of this allowed us to conduct a total of 5 pier deployments and 3 boat deployments over the course of 6 months. Most of these pier deployments acted as training exercises for the two undergraduate students I was mentoring – Danika Cornejo (Marine Science, 2024) and Maya Netto (Biology, 2025). As a part of their training, they received their basic safety certifications from the Mechanical Engineering Machine Shops and learned numerous engineering and manufacturing skills. Most of all they learned everything required for lander operation and upkeep in order to continue work with the lander after I graduate. The rest of these pier deployments were completed to collect footage for one of Dr. Crow White’s other undergraduate students, Sierra Bentti (Marine Science, 2024), who was developing science lesson plans for high school curriculum using lander footage.

The most exciting application however was getting to complete boat deployments at sea with NOAA on their R/V Fulmar and R/V Shearwater vessels. While our deployments off the R/V Fulmar were cancelled in July due to poor weather conditions, many preparations were accomplished in its lead up including permitting and deployment/recovery operation planning. Our team also completed a practice deployment/recovery exercise while the R/V Fulmar was in port in Morro Bay. Next, we went to sea on the R/V Shearwater in August where we completed a deployment at 35.455379, -121.008636 (off the coast of the Harmony Headlands) at a depth of approximately 60ft. From this deployment’s video recordings, we saw a total of five different species of fish, three sea pens (one of which was seen recoiling its comb on camera), but most exciting was one fish species that came to visit Seastang – a wolf eel!
Finally in November, we had the opportunity to go to sea on the R/V Shearwater once more, this time we conducted two boat deployments. The first took place in the Monterey Bay National Marine Sanctuary at the location of NOAA’s MB05 buoy (35.765991, -121.430313) which had a depth of 90 meters and was programmed for a 60-minute bottom time. From these recordings we saw lots of flat fish (sand dabs/flounders), a shark, 2 octopi, lots of crabs, and several other fish species as well. The next day, we went out to the Wind Energy Area (WEA) where we dropped the lander in 900 meters of water (35.311600, -121.585457). Unfortunately, the lander did not surface on time and after additional search procedures were followed it was ultimately deemed lost at sea.

5.1.6 LOST LANDER ANALYSIS

After the lander went missing, we considered many possibilities as to what might have happened to it. Theories we considered but do not believe are the cause include: the lander getting stuck in the mud, human errors, and sphere failure(s). Our current most likely theory is that the lander got stuck on some unknown fowling. While we can theorize all day about what might have happened to the lander, ultimately the only way to know for sure what happened to Seastang is to wait until she is recovered and do a thorough investigation then.

So, we began to make plans for recovering the lander. Unfortunately, at this depth, there is no easy way to recover the lander as it is far too deep for human divers and all capable equipment would be far more expensive than simply building a new lander, so we are left with building a series of fail-safe plans. The first of these was hoping for the lander to surface on its own and signal us via our SPOT Trace GPS. After researching battery lengths, we found that with our current settings, the SPOT Trace could last up to 1.3 months. In hopes this does happen, as at the time of publishing this paper we are still within the possible recovery window, we looked at what our ship options were for getting out to the lander’s deployment location. Cal Poly’s boat, the TL Richards, was unfortunately, but understandably, deemed improperly equipped to support operations beyond a 10-mile range offshore working out of local harbors. For this reason, if the
lander does surface, we will need to find an outside contractor to take us out for a recovery mission. While we had planned to use our remaining Baker-Koob funds to purchase lander consumables for future work, paying for this recovery operation would take a new priority.

Additionally, if for some reason the SPOT Trace does not trigger or the lander surfaces after it has died, the top of the lander has a large “If Found Please Recover” sticker on it. Below this sticker contains my contact information (phone number and email). So, if a fisherman or other vessel finds it at sea, or anyone else finds it washed ashore, they will be able to contact me, and I can organize a way to recover it.

5.2 PROJECT REFLECTION

5.2.1 WHAT I LEARNED

I learned and have grown a lot as a part of this project. I have also gained invaluable experiences I would not have had the opportunity to accomplish in a classroom setting. This applies for both engineering skills and wider career skillsets as well. While I had gotten some base knowledge on Finite Element Analysis and modeling as well as analysis of composite materials from elective classes I took at Cal Poly, I got the phenomenal experience of combining these two areas of study as a part of my alternative pressure sphere analysis. I learned so much about modeling composites in Abaqus as well as lots of methods to compute basic models more efficiently in the program. Before this project, I would say I had a decent knowledge of FEA modeling and mild familiarity with the Abaqus program, but now can confidently say I am very comfortable with the program. Additionally, since no one I knew had modeled laminated composites in Abaqus before, learning to do this myself taught me a lot about the Abaqus program, its modeling requirements and possible outputs. All this has led to me confidently be able to tackle new and unique problems in Abaqus that I may not have attempted before.

Outside of engineering specific skills, I have grown a lot of skills I know will be critical to my future career. My project management skills have grown fantastically over this project as I have learned
to navigate setting my own deadlines as well as coordinating with not only other individuals, but other organizations as well. Mentoring Maya and Danika while working with Dr. White has given me great opportunity to improve my interdisciplinary communication skills – especially between marine science and engineering disciplines which I know will be critical to my future career in ocean engineering. While I had expected to get some more basic experience with at sea deployments as a part of this project, I could not have predicted just how much of an opportunity I would get in working with NOAA to go on multiple cruises throughout the year. Learning the ins and outs of how to execute deployments through cruise planning, permitting applications, float plans, and ship crew coordination was truly the epitome of Learn by Doing for me. Most of all, going to sea and spending time on the ship as the Principal Investigator (PI) during lander deployments was thrilling and a great learning experience. I learned so much from everyone I got to interact with as a part of these experiences (scientists, engineers, ship crew, and office staff alike) and I am incredibly grateful for their patience and taking time out of their busy schedules to share their knowledge and experiences with me.

Lastly, while the end to this project did not go according to plan with DOV Seastang being deemed lost-at-sea, it has taught me a lot about how to handle unexpected obstacles. This has served as a good reminder of the unpredictability of the ocean and the risks associated with deep sea exploration and why you must always remain vigilant when dealing with these extreme environments. While I put my heart and soul into everything I do and I am devastated at the loss of our lander, the important thing I keep reminding myself is that at the end of the day, it was just a piece of equipment, and no one was hurt. While I loved Seastang, I have learned a lot about the field of deep-sea research through these experiences and am looking forward to future opportunities to implement the lessons I learned from all of this.

5.2.2 WHAT I WOULD DO DIFFERENTLY

I am proud to say that overall, I’m very happy with how I have handled this project and all of the elements it includes. That said, no one is perfect, and I know I am no different. The primary parts
I would want to do differently would have to do with my mentorship of Danika and Maya. While I feel we quickly got a close bond while working together, I wish I had made more of an effort during the school year to organize group activities that didn’t focus on the project. This would have allowed our group’s friendship to grow quicker, and I think led to more comfortability on all sides when working together early on and teaching them about the lander. Additionally, when it comes to growing their confidence in using the lander on their own, I wish I had taken smaller steps in letting them build up to putting it in the water by first having them complete a dry land solo deployment with me observing prior to doing one at the pier. This was something suggested to me by them as part of their reflection on their solo deployment experience and one that makes perfect sense in hindsight. They were already nervous about operating the lander on their own so minimizing the risks as their confidence grows would help with this anxiety. For future projects, I will be sure to look for smaller intermediary steps that can be taken as practice when building confidence in someone’s ability to execute new operations.

5.3 NEXT STEPS

5.3.1 ALTERNATIVE PRESSURE SPHERES

While the analysis completed as a part of this thesis shows great promise for the use of laminated composites in deep-sea pressure vessels, there is still much analysis and testing that would need to be completed before putting them into application. As discussed before, the real-world application of the composite pressure spheres analyzed in Chapter 3 would include the use of an equatorial ring as well as the inclusion of electrical port holes and possible view ports. The addition of each of these features would introduce stress concentrations which would increase stress experienced by the material and therefore decrease its maximum depth rating. Because of this, more models would need to be run in FEA including these elements to get an idea of how drastically these features would impact its capabilities and whether the materials analyzed would still prove to be viable for our application.
Additionally, the models created for the analysis in this report do not account for any imperfections in the layup including the creation of voids or porosity during manufacturing, both of which would further decrease its pressure capabilities. For this reason, additional testing on manufactured spheres would need to be completed. The production of pressure spheres which were still found to be viable after further FEA testing would need to be well manufactured and be done in a way which is consistent and repeatable. These test specimens would then be tested in the same way the existing pressure spheres were tested for Global Ocean Design in Chapter 2: each sphere would be sealed and placed inside a pressure chamber which would then gradually increase the external pressure until failure. These failure pressures could then be recorded and compared to FEA models to determine the modeling accuracy.

Even with these tests completed, there are still additional factors that should be tested for laminated composite pressure spheres. This includes the analysis of fatigue life cycles and the effects of moisture absorption on the material strengths. Composite materials are known to have different behavior to that of traditional pressure vessel materials like their ability to absorb moisture into their epoxy matrix. The absorption of moisture can drastically reduce the materials strength and must therefore be tested given that the working environment for these pressure spheres will be submerged at the bottom of the ocean. Additionally, the act of pressurizing and depressurizing a sphere can incrementally damage its structural integrity over time. Because of this, a study should be completed on these spheres to determine how many life cycles or deployment operations they can safely endure before needing to be replaced.

Lastly, once all analysis is complete and these pressure spheres have been given a final depth rating, a cost comparison analysis would need to be completed. This would analyze how much it costs to produce these new spheres compared to the existing designs by Global Ocean Design. Once final costs (which account for not only materials but manufacturing costs of the technician time and tooling) are completed, these spheres can then be compared to the existing options to determine if the cost of making them is worth the trade-off of how deep they would now allow the vehicle to go.
5.3.2 FUTURE APPLICATIONS

More than just the technical engineering, there is still much more that the future holds for this project. This begins with Dr. White’s research: the Before and After Controlled Impact (BACI) study on the proposed windfarm off the coast of Morro Bay. The deployments completed as a part of this thesis stand as a proof of concept to show that using a deep-sea lander is a viable survey method for his research. The data and footage collected here can now be used in grant applications in order to gain funding for both more boat deployments and even additional landers. This research project will continue with more marine science and biology students each being trained by the last generation and is expected to last 10-20 years. Right now, Danika Cornejo is using this project as her senior project in marine science and Maya Netto will have the option to do so as well. The current hope is that these grants will be able to provide enough funding for the lab to purchase a new lander that can be used until DOV Seastang resurfaces.

Additionally, at my suggestion, Danika and Maya are now mentoring a new College of Engineering Interdisciplinary Senior Project team advised by Karla Carichner (my former senior project advisor). The original plan for this senior project was to continue to improve the functionality of the lander for Dr. White’s research, however their focus now will be designing a new weight-release system to hopefully prevent future landers from having the same fate. This new team consists of undergraduate students: Eric Meseck (Computer Engineering), Evan Hall (Mechanical Engineering), Erin Malone (Mechanical Engineering), and Andrew Gaskell (Industrial Engineering). If more funds are attained to purchase a new lander, the focus of this project would shift to outfitting the new lander with its own camera/lights and bait systems.

Furthermore, Sierra Bentti (Marine Science, undergraduate) was also using the lander in her senior project to develop science lesson plans for high school curriculum. She planned on using footage from the lander in both day and night deployments off the Cal Poly pier to have students compare species abundance and behavior differences between the two different time frames. Now I believe the plan is to use existing lander footage for her lesson plans instead. She also
plans on developing a small-scale lander experiment made of household materials that the students will be able to build and test in class to get a feel for how the lander works. Since I have experience with these types of projects and great familiarity with the lander, I have offered to help her with this as well.

Lastly, after the completion of my thesis defense, my committee discussed their desire to have the project continue and are now looking into sponsoring a new Mechanical Engineering Senior Project starting next quarter (Winter 2024). This project would look at continuing my research into laminated composite pressure sphere design and hopefully complete design, manufacturing, and testing of such spheres!

While I obviously wish there was something I could do to prevent the lander from going missing, I can truthfully say that I still believe this project is far from over. I know where there is a will, there is a way, and my heart is warmed to see how much drive there still is in the rest of the team to continue this project. No one is going to throw in the towel this easily, so I am truly thrilled to see what the future holds for them all. I can’t wait to see what amazing things happen next!
WORKS CITED


mary.html.


APPENDICES

APPENDIX A: Meeting Notes

APRIL 10, 2023

ATTENDEES: Nikki Arm, Drew Davol

NOTES:

- Meeting with Crow & students
  - Meeting planned for 4/12/23
- How to purchase things
  - Contact Amanda (covering for Brenda)
- NOAA Trip
  - July and November
- Comp Heat Transfer Lab Final Project
  - Can talk to Shollenberger about options
- Discuss redistributing thesis component scope
  - Focus more on project management and engineering communication
  - Still include composite design in “modifications/improvements section”

TO-DO:

- Contact Amanda in ME office about purchasing process
- Look into composite manufacturers for spheres
- Talk to Shollenberger

APRIL 12, 2023

ATTENDEES: Nikki Arm, Crow White, Danika Cornejo, Maya Netto

NOTES:
• NOAA Fulmar
• July trip not ideal but possibly in WEA
• Lindsey Peavey, was a grad student when crow was post doc
• Sea sickness is bad on Fulmar - catamaran
• July deployment - objective for Summer
• Set up TD sensor
• Bait - PVC Tube w/ holes so ideally both ends removable. Sun resistant weather resistant pipe, make sure it's better with the elements. Sardines as bait (discard from fishing boat)
• Deployments - try to prep the lander to do a second deployment (need additional batteries, different battery securements, additional burn wire set ups)
• Deployment practice, practice turn arounds
• Length of time we'll be in the deployment area in July (minimum 90-120min)
• Prioritize a full deployment over practicing redeployments
• Timelapse photos are not ideal
• Rather compromise deployment time than do photos, do full video - do some tests to see how long the recording can be
• 2 hours of video ideal - worries about battery and memory, high res video ideal
• Need external hard drive
• Test battery length for lights as well
• Worries about presenting timers and camera present times due to tune
• Blue filter the lights
• Tests
  o Battery time (camera and lights)
  o Memory (camera, video quality?)

TO-DO:

Ranked by order of importance.
1. Order additional burn wire attachments and supplies (consumables needed for each deployment, weights & additional lifesavers needed)
2. Create new bait cage (PVC pipe covered in holes with two removable end caps)
3. Preform battery drain timed tests (both camera and lights, in cold temperatures, in vacuum spheres, etc)
4. Practice Deployments with Maya and Danika (dry land test, then pier tests, and hopefully at least one CP boat test before NOAA Fulmar test)
5. Set up SPOT trace and test how it works
6. Time deployment turnaround times and lander set up times after setting timers and turning on camera (plug in batteries, seal spheres, etc)
7. Add blue light filters to lander
8. Order additional batteries for everything (camera, lights, burn wires)
9. Set Up TD (temperature/depth) sensor

APRIL 19, 2023

ATTENDEES: Nikki Arm, Danika Cornejo, Maya Netto

NOTES:

- What do we want out of these meetings:
  - Feeling competent using the lander
  - Make modifications and updates
  - Do test deployments (with/without Nikki)
  - They want to get more hands-on and comfortable with the tools and machines – I’m gonna help them schedule getting their red tags.
- Before next week
  - Nikki
    - Find actual items to order
    - Create a budget sheet
• Maya - find things to order for bait cage

   • To do in next week’s meeting
     • Make a timeline!
     • Place orders
     • Schedule red tags

TO-DO:

• Find actual items to order
• Create a budget sheet

APRIL 24, 2023

ATTENDEES: Nikki Arm, Drew Davol

NOTES:

• Okay moving focus, sphere will still be part
• Adjust table of contents, make spheres a part of a “updates to lander” section, discuss fuses and other additions/modifications
• Discuss lander prep, NOAA deployments
• Appendix with meeting notes

TO-DO:

• Make a format you like and stick with it
• Check grad office formatting requirements for paper and templates

APRIL 26, 2023

ATTENDEES: Nikki Arm, Danika Cornejo, Maya Netto

NOTES:
• Created group calendar
• Began making a timeline for NOAA Deployments
• Attempted to schedule Red-Tags, unable to fit their class schedule next week
• Showed them our budget sheet and where order tracking goes
• Team Bonding

TO-DO:

• Find actual items to order

MAY 1, 2023

ATTENDEES: Nikki Arm, Drew Davol

NOTES:

• MSCI girls meeting updates
• Getting them their red tags
• Project - lander V2
• All updates to lander improvements
• Have technical slice - spheres
• Dig into scope of spheres, budgeting and manufacturing of spheres
• Standard stuff to buy and verify our modeling

TO-DO:

• Carbon spheres off the shelf purchasing?
• Send an email to schedule a group coffee meeting with everyone (Drew, Jim, crow, Maya and Danika)

MAY 3, 2023 (MORNING)

ATTENDEES: Nikki Arm, Danika Cornejo, Maya Netto
NOTES:

- Run purchasing plans past the girls
- Place orders via Baker-Koob grant to Amazon and McMaster-Carr
- Collect lander dimensions for Lindsey Peavey (NOAA)

  ![Lander Dimensions](image)

  Metric
  - Height: 141cm (with visibility flag attached) or 113cm (without - flag only needs to be attached just before deployment)
  - Width: 79cm (with side buoys attached) or 41cm (without - easiest if they remain attached, but can be removed if needed for transit)
  - Depth: 51cm

  Imperial
  - Height: 55.5” (with visibility flag attached) or 44.5” (without - flag only needs to be attached just before deployment)
  - Width: 31” (with side buoys attached) or 16” (without - easiest if they remain attached, but can be removed if needed for transit)
  - Depth: 20”

- Schedule red tags for May 10th

TO-DO:
• Look into finding scale for weighing lander
• Girls complete red tag Canvas course

MAY 3, 2023 (AFTERNOON)

ATTENDEES:  Nikki Arm, Danika Cornejo, Maya Netto, Drew Davol, Crow White, Jim Widmann

NOTES:

• All-Team Meet Up
• Official introductions
• Discussions of MSCI and ME sides of the project
• Discussing expectations from all committee members
• General “get to know each other” meeting to have everyone be able to put faces to names

MAY 10, 2023 (MORNING)

ATTENDEES:  Nikki Arm, Danika Cornejo

NOTES:

• Collected McMaster-Carr Package from Mustang ’60
• Showed Danika the hangar (where to meet at the red tag)
• Located Scale in the Hangar
  o Too big to carry to M’60
  o Will need to drive the lander up to the hangar to weigh it

TO-DO:

• Weigh the lander
MAY 10, 2023 (AFTERNOON)

ATTENDEES: Nikki Arm, Danika Cornejo, Maya Netto

NOTES:

- Maya and Danika received their Red Tag certifications
- Nikki administered the tag

MAY 15, 2023

ATTENDEES: Nikki Arm, Drew Davol

NOTES:

- All team meeting went well
- Packages have started to be delivered
- Girls got their red tags
- Analyze existing spheres?

TO-DO:

- Reach out to Kevin about make-up of current spheres and any testing data/analysis. Can he share and we can compare results? (Also check on cost for Crow)
- Meet in Bonderson Next week
- Continue to look into off the shelf composite spheres

MAY 17, 2023

ATTENDEES: Nikki Arm, Danika Cornejo, Maya Netto

NOTES:

- Crow's goal for summer
• After NOAA, what's next?
• Types of animals to focus on?
• Need a completed experiment?
• Likely more a proof of concept, and a plan for the long-term study
• Inaccessibility of the deep sea
• Need to show frost they're working
• How to analyze the results
• Statistical model data incorporation
• Light filter - blue light filter, adhesive filter? Marine grade?
• Adhesive types

TO-DO:

• Research light filters and marine grade adhesives to put on the lights
• Weigh the lander

MAY 22, 2023

ATTENDEES: Nikki Arm, Drew Davol

NOTES:

• Model sphere
  o Axisymmetric modeling
  o 2d cross section of 1/2 circle, 2 parts with contact surface between them
  o Material properties needed
  o Internal vacuum model
  o Then external pressure added
  o Where is failure?
  o Boundary condition at seal?
• Abaqus - axisymmetric type, it'll give an axis, no o-ring groove yet, just contact
  o Only boundary condition need is vertical limit at one point at the bottom
  o Negative internal pressure step
  o Then external pressure step
  o Convergence study

• Heat transfer
  o Axisymmetric
  o Nothing varies with theta
  o Boundary conditions
  o 2D model

TO-DO:

• Discuss heat transfer model with Dr. Shollenberger

MAY 26, 2023

ATTENDEES:  Nikki Arm, Danika Cornejo, Maya Netto

NOTES:

• Figured out how to fit the lander in Mayas car
• Determined the scale in the hangar is broken and cannot weigh things anymore
• Decided on using mesh bags for bait

TO-DO:

• Find bags to order
• Find light filters to order
• Talk to crow about finding a scale to weigh the lander
JUNE 2, 2023

ATTENDEES:  Nikki Arm, Danika Cornejo, Maya Netto

NOTES:

• Found and ordered light filters and bait bags
• Discussed red vs blue light filters - bought both to maybe try
• Wrote Lindsey

TO-DO:

• Weigh lander
• Decide on location for deployments
• Update lander spec sheet and deployment/recovery protocol

JUNE 5, 2023

ATTENDEES:  Nikki Arm, Drew Davol

NOTES:

• Update on purchasing
• Discussion of wind turbine research funding
• Will connect with Paul over summer
• Comparing to published data
• Need to be able to repeat every detail of model to compare - is it enough to do your own model?
• Axisymmetric model - use isotropic aluminum at the start then can build complexity
• Check for graduation in December

TO-DO:
• Write Kevin about getting existing data from his spheres

JUNE 9, 2023

ATTENDEES: Nikki Arm, Danika Cornejo, Maya Netto

NOTES:

• Weighed lander (75lbs without drop weight and chain)
• Introduced Maya and Danika to Bri & Kyle (from senior project team) via zoom

JUNE 26, 2023 (MORNING)

ATTENDEES: Nikki Arm, Drew Davol

NOTES:

• Discussion on OceanGate Titan tragedy and impact on thesis research
  o Agreed studies will be part of my literature review
  o Discussed Kevin being a part of Marine Technology Society’s Manned Vessels Committee and co-authoring letter to OceanGate 2 years ago
  o Mentioned my own ideas for new safety features for vessels based on search and rescue techniques
    ▪ Neon Orange vehicle color (easy to spot on the surface from a plane/helicopter)
    ▪ Door release from inside the vehicle for at/near the surface
    ▪ Satellite buoy/float attached to the outside of the sub that has a release mechanism that will send it to the surface to ping a location even if you’re stuck at depth (tethered depending on depth, not an exact location cause of drift due to currents but it’s a heck of a lot closer than other considerations)
    ▪ System to draw in air from outside if at surface and hatch is stuck
• Internal navigation systems (not reliant on external communication to know where you are)
• Manual powered mechanical overrides to critical electrical systems (In case of battery or engine failure)

• Abaqus Modeling Drew started
  o 2D Axisymmetric model abaqus - read up on variable meanings as results don’t totally make sense
  o Create composite layups within abacus
  o Abaqus copen user manual
  o 2 step model, 1-vacuum, 2-external pressure

• Discussed NOAA deployments 2 weeks out
  o Drew and Michelle might join on test deployment off the pier

TO-DO:

• Talk to girls about NOAA deployments and test deployments
• Research OceanGate further
• Research Abaqus modeling and begin building model

JUNE 26, 2023 (AFTERNOON)

ATTENDEES: Nikki Arm, Danika Cornejo, Maya Netto

NOTES:

• Developed Timeline for NOAA Prep
  o Pier deployment Friday
  o Light filter night test on land (Tuesday)
    ▪ Meet at 4 to drive to Avila to look at piers and decide which to test from (Cal Poly or Port San Luis)
    ▪ Pick up parts for weights at hardware store
- Get group dinner
- Get bait and put in crow's freezer
- 8:30pm meeting Tuesday for light test

- Discussed Sea sickness antinausea patch
  - Nikki will see campus dr Tuesday to see about prescription
  - If works Maya and Danika might get one as well

- Need to set up spot connect/spot trace

- Went to Crow's lab to show pier key location and determine freezer space for bait

- Decide on light filter attachment
  - Got clear acrylic from laser cutter scrap bins which will work for our application
  - Will build external covers rather than need to dismantle lights each time

**TO-DO:**

- Email Lindsey about timing for deployment times
- Write Tom/Drew about pier deployment
- Look into Spot trace
- Acquire bait
- Get antinausea patch
- Need to build light filter adapters
- Get GoPro and CamDo running
- Charge batteries

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**JUNE 27, 2023**

**ATTENDEES:** Nikki Arm, Danika Cornejo, Maya Netto

**NOTES:**

- Confirmed San Luis Port Pier Location for Friday deployment
• Picked up batteries and welded rings for weights from Miners
• Had team bonding dinner
• Attempted to acquire bait but turned out the store only had canned sardines (not fresh or frozen)
• Taught the girls how to operate the camera and cam do
• Did light test with the camera testing red vs blue light filters
• By human eye we could see more with blue light but the camera actually picked up red light better
• Decided to use red light filters for our deployments

TO-DO:

• Measure and cut chains
• Complete building weights system
• Solder on new burn wire
• Recharge batteries used in yesterday’s tests

JUNE 29, 2023 (AFTERNOON)

ATTENDEES:  Nikki Arm, Danika Cornejo, Maya Netto

NOTES:

• Scheduled Zoom meeting with Crow – he accidentally put it on Friday on his calendar
• Received email from Lindsey saying NOAA just realized we do need deployment for our 30 min test deployment on the 10th due to it being in the Monterey Bay National Marine Sanctuary
  o Get in app ASAP and they will attempt to expedite it in time
• Nikki filled out application with Crow as “co-applicant”
• Lindsey will assist answering questions since Crow is traveling
TO-DO:

- Finish App
- Get Crow to Sign
- Submit app (See copies of submitted application and completed permit in Appendix)

**JUNE 29, 2023 (EVENING)**

**ATTENDEES:** Nikki Arm, Danika Cornejo, Maya Netto

**NOTES:**

- Finished Application
- Took photos and sent to Jean
- Measured and cut chain for weight system
- Built weight system
- Attached mesh bait bag to plate
- Recharged used batteries
- Sanded down flagpole to make it fit again
- Applied marine grade electrical coating to slight tear in wiring
- When working on soldering on a new burn wire we discovered an old solder had its marine grade heat shrink come loose and ad began corroding
- Had to cut off a lot of corroded wire
- Needed to clean existing wire on connector cable before soldering on new burnwire
  - Used vinegar soak at the suggestion of eric
  - It worked but took time
  - Found vinegar reacted with solder to create black substance
  - Out of time for day

**TO-DO:**
• Finish cleaning wire
• Solder on new burn wire
• Acquire bait

JUNE 30, 2023 (MORNING)

ATTENDEES:  Nikki Arm, Danika Cornejo, Maya Netto, Crow White

NOTES:

• Permit discussion – respond to Sophie to answer additional question
• Deployment dates reminder for crow, explain full timeline
  o Crow will be out of service starting on the 6th so between then and the deployments he’ll be in the dark and we won’t be able to contact him
• Discussion of funding and reimbursement for Frost Fellowship money
• OceanGate/Titan discussion
• Post NOAA ecology study (R code) discussion
• Talk of WHOI interview process

TO-DO:

• Upload photos of deployments onto Google Drive Folder Crow requested
• Zoom meeting on the 5th to touch base before he goes dark

JUNE 30, 2023 (AFTERNOON)

ATTENDEES:  Nikki Arm, Danika Cornejo, Maya Netto

NOTES:

• Finished cleaning wire using scotch brite pad
• Soldered burn wire to connecting cable and taught girls how to use heat shrink
• Had them set camera time and walked them through necessary cable attachments in camera sphere
• Worked with them to clean then seal camera sphere
• Attached camera sphere onto lander
• Taught them to set burn wire timers
• When pulling seal on burn wire sphere discovered the vacuum port was leaking
  o Discovered it was the plastic internal component
    ▪ Had a crack in the plastic and found a metal chip imbedded in an o-ring
  o Replaced it with one from 1km sphere we had on the shelf
  o Want to get more spares to have with us on NOAA
• Reset timers and sealed burn wire sphere
• Loaded up the car with supplies and went to the pier
• Attached all cables
• Taught girls how to do a buoyancy test prior to deployment
• Tied rope to weights
• Attached weights to lander
• Completed successful 90-120 min deployment off the San Luis Port Pier
• Cleaned lander and returned everything to project room
TO-DO:

- Download videos off camera and upload to drive
- Recharge batteries
- N – design light caps
- M&D – research how using SPOT Trace works and how to sign up for subscription

JULY 3, 2023

ATTENDEES: Nikki Arm, Danika Cornejo

NOTES:

- Nikki shows light cap design
- Shopping for supplies for lander recovery device as advised by Kevin
  - Purchased fiberglass extending rod (8-24’), large carabiner hooks (110lb rating), strong recovery line, and masking tape
  - Assembled and tested recovery device on land
  - Created and set up SPOT Trace Account
  - Did initial testing of SPOT Trace locator – fickle success – need further testing
TO-DO:

- Build light filter caps
- Test SPOT Trace

**JULY 4, 2023**

**ATTENDEES:** Nikki Arm, Danika Cornejo, Maya Netto

**NOTES:**

- Taught the girls how to use the laser cutter
- Cut all parts for light filter caps
- Assemble and glue light filter caps
- Discover need for more burn wires of both are used on NOAA Deployments
- Played “hide and seek” with the SPOT Trace for testing
  - Once functional, Maya took the spot trace and was given 5 minutes to go hide on campus
  - Danika and Nikki then used the tracking capabilities to find her
  - Tracking was extremely accurate with updates every 2.5 min
  - Found it is critical you keep the device far enough away from other GPS devices (like cell phones) otherwise it’s signal gets interfered and turns off
  - Green satellite light blinks to signal it has connection, but flashes consistently for 30 seconds every time it sends its location (every 2.5 min)
  - Location pin pointing was great
  - Found using the web browser is much more accurate for tracking than the phone app (even when on a cell phone)

TO-DO:

- Attach light filter caps (with filters) onto lander
• Build more burn wires

**JULY 5, 2023 (MORNING)**

**ATTENDEES:** Nikki Arm, Danika Cornejo, Maya Netto, Crow White

**NOTES:**

• Discussion of deployment last week
• Visibility at the pier
• Use of bait plate to measure fish
• Use of mackerel vs sardines
• Purchase reimbursement discussion
• Made group text chain

**TO-DO:**

• Keep him updated on everything
• **TAKE PICTURES**

**JULY 5, 2023 (AFTERNOON)**

**ATTENDEES:** Nikki Arm, Danika Cornejo, Maya Netto

**NOTES:**

• Cut light filters to fit caps
• Packing list and deployment checklist update and printing (See Appendix)
• Cut chains & assemble weights
• FROST Fellowship Ice Cream Social
• NOAA Permit Q&A emails

**TO-DO:**
• Make more burn wires
• Girls do solo test deployment

JULY 6, 2023

ATTENDEES: Nikki Arm, Danika Cornejo, Maya Netto

NOTES:

• Received back up vacuum ports in mail from Kevin
• Shopping for more marine grade wire for burn wires
  o Home Depot and Ace do not carry any
  o Marine Stores only did boat repair and no sales online and didn’t answer phone call
  o Radio Shack employees extremely helpful but did not have what we needed
  o Decided to make what we could and discuss with Kevin where to get more information
• Purchasing charging cables and back up batteries for timers/SPOT Trace
• Taught the girls how to build more burn wires
• Burn wires left drying
• Received email about possible deployment delays/cancellation due to weather – will keep updated but still on to meet Saturday the 8th for deployment recovery test ops

TO-DO:

• Email Kevin about Burn Wire marine grade wire & payment for vacuum ports

JULY 7, 2023 (MORNING)

ATTENDEES: Nikki Arm, Drew Davol

NOTES:
• Updated him on EVERYTHING from the last 2 weeks
• Discussed documentation and reports
• Discussed WHOI interview process

TO-DO:
• Keep him updated
• Ask about Baker Koob reimbursement policy & if could be used for health center visit

JUNE 29, 2023 (MORNING)

ATTENDEES: Nikki Arm, Jean de Margiac

NOTES:
• Answered questions regarding lander functions
• Discussed deployment/recovery operations for larger vessel
  o Use rope tied to cleat or railing on one end, looped through lander rope and slowly lowered into the water, once in, free end of rope can be released and will slide through the loop
  o Discussed using a boat hook off the back diving platforms but warned those locations may not be safe for crew depending on weather conditions
  o Need to look at making a quick release hook with line?
• Recommended I talk with someone who has experience with these types of deployments
• Discussed coming on board after they get back to port the 8th or 9th to do a test run while docked to make sure our plan works

TO-DO:
• Talk to Kevin about deployment strategies (see Appendix for decided operations)
• Email Lindsey about scheduling docked deployment recovery ops
- Send photos of lander to Jean

**JULY 7, 2023 (AFTERNOON)**

**ATTENDEES:** Nikki Arm, Danika Cornejo, Maya Netto

**NOTES:**

- Received email from NOAA – no longer going to ship tomorrow as FULMAR is stuck in port in Monterey due to weather
  - Might get delayed by a few days
  - More info to come
  - Stand-by

- Girls Solo Deployment!!!
  - Overall Success!
  - Success’s
    - Burn wire’s went off and lander came back on 1st burn
    - Girls did nearly everything by themselves
  - Not According to Plan
    - Camera/lights did not turn on or record
    - The girls did not document what time they set the burn-wire timers for and got mixed up such that it came up half an hour earlier than they expected (but was the time I thought I had remembered them initially discussing)
  - Take Aways
    - Girls now feel a lot more confident in how to operate the lander
    - Wish we had done a “dry deployment” test run on campus first
    - Discovered if you unplug the CamDo after setting camera times it will reset the device and you will need to resynch it and start that step over
TO-DO:

- Offload any video recordings (there were none)
- Recharge batteries
- Replaced used burn wire
- Organize and set up for NOAA deployment

**JULY 8, 2023**

**ATTENDEES:** Nikki Arm, Danika Cornejo, Maya Netto

**NOTES:**

- Dismantled spheres and took out camera
- Discovered no videos were recorded
- Decided to do a dry land test on the camera and lights now that we have the new light caps
  - It all worked
  - Found there is a small bit of white light that escapes around the edges of the light through the side of the clear caps
  - Maya and Danika do not believe this is a problem for the fish
  - For future improvements, Nikki wants to paint the outside of the caps black to prevent this light leakage
- Attached new burn wire to cable on the lander
• Charged batteries
• Checked new burn wires from the 6th, found while looking good, some were very thin so did second coat of electrical coating to be safe
• Organized and cleaned out tool box in prep for NOAA

TO-DO:

• Finish extra burn wires – heat shrink needs to be shrunk after they finish drying
• Be ready for Lindsey/NOAA whenever they need us to go (last told to “standby”)

JULY 10, 2023

ATTENDEES: Nikki Arm, Danika Cornejo, Maya Netto

NOTES:

• Finished building existing burn wires
• Laser cut and assembled back up set of light filter caps
• Taped and spray painted the outside of existing light caps black to prevent light leakage of white light around the filter
• Cut additional light filter inserts

TO-DO:

• Reassemble lander in prep for NOAA deployments
• Prep all additional supplies to load car for deployments on FULMAR

JULY 12, 2023

ATTENDEES: Nikki Arm, Danika Cornejo, Maya Netto

NOTES:

• Prep for going out with NOAA
• Assemble spheres and reattached to lander
• Organize toolbox
• Have everything ready to load the car and go to Morro

TO-DO:

• Load the Car
• Test deployment/recovery ops

JULY 13, 2023

ATTENDEES: Nikki Arm, Danika Cornejo, Maya Netto, Lindsey Peavey & NOAA Fulmar scientists/crew

NOTES:

• Loaded car and drove to Morro
• Met Lindsey and everyone else on the Fulmar
• Taught them how the lander works and talked with them about our research
• Learned how ship operations work
• Completed test deployment/recovery ops
  o Learned about a new recovery device that does what the one we designed does but better
  o https://www.hookandmoor.com/
• Toured the ship
• Bonded with everyone on board
• Determined workspace near Galley would be best for set up of lander prior to deployment (good counter and floor space)
• Discussed possibly going out to sea in August on Shearwater or November on Fulmar

TO-DO:

• Thank everyone we met and connect with them on Linked in
• Set up for pier deployment tomorrow

JULY 14, 2023

ATTENDEES: Nikki Arm, Danika Cornejo, Maya Netto

NOTES:

• Danikas car broke down so she had to take it to the shop while Maya and I set up
• Time Set Up for NOAA
  o 35 min to set spheres and assemble in lab
  o 20 min after parking were ready to go in the water
  o Tell NOAA we need 1 hr 15 min from the time we need to start set up to the time it needs to go in the water
• Found the bolt for the flag went missing – need to order more
  o Nylon Bolt
  o 11mm or 7/16in head
  o 1/4-20 threads
• Lander deployment success, met Danika at pier
• Used blue light filters for girls to compare to white light in shallow water
• Team dinner
  o Girls feel well prepared to do deployments without me if necessary
  o MUCH more comfortable with it all than before
  o I feel proud of them
TO-DO:

- Look at doing boat deployment with CP boat
- Order more nylon bolts
- Order Happy Hook

AUGUST 2, 2023 (MORNING)

ATTENDEES: Nikki Arm, Drew Davol

NOTES:

- Update Drew about all the boat deployment possibilities with Lindsey emails
  - Possible NOAA on Shearwater at end of August
    - Meeting with Stanford PI later today to discuss viability
  - SIO deployment in September? Will connect me with PI to discuss
  - Deployment in November with Lindsey on Fulmar
  - If needed can connect with local ship captains they met in Morro willing to help science projects to take us out to WEA
- Plan for Friday
  - Early morning, 1000ft deployment off TL Richards
  - Back up day is Wed 9th if weather goes poorly
- Job advice

TO-DO:

- Add light filter caps to paper

AUGUST 2, 2023 (AFTERNOON)

ATTENDEES: Nikki Arm, Danika Cornejo, Maya Netto, Marilla Lippert

NOTES:
Day one loading
Day 2 going north - could work out for their trip
22nd would be the best day
Can do one deployment for sure
Can bring our own lunch and then do dinner off the ship
90 min deployment would be great, 2 sites are close by
She needs to confirm with the project PI in charge of funding and a few other higher ups but sees no reason why we couldn’t tag along on the 22nd!

TO-DO:

Answer any questions from Marilla, her team, or NOAA crew for deployments

AUGUST 2, 2023 (EVENING)

ATTENDEES: Nikki Arm, Danika Cornejo, Maya Netto

NOTES:

Charged batteries
Soldered burn-wire
Changed light filters
Found & placed order request for Reflective Tape & Happy Hooker
Took SD card to offload videos and upload to drive
Suspended SPOT Trace Subscription
  Can reactivate easily before NOAA Shearwater Deployment

TO-DO:

Upload videos from last pier deployment
Confirm with Marilla about NOAA on the 22nd
AUGUST 3, 2023

ATTENDEES: Nikki Arm, Danny Lucas

NOTES:

- Discuss project
- Discuss deployment recovery ops - forward info from fulmar to them
- VPM - vessel project manager
  - Project proposal in VPM
  - After accepted, input cruise plan
    - Need emergency contact and phone number for all of them
- Should be good on permits – hell check and confirm
- Asked about funding Incase Marilla wants to split the costs (let her do it)
- GPS tracker on it is important
- Will send me info packets for PI’s and ship rules

TO-DO:

- Send lander documentation (specs sheet, ops sheet, deployment/recovery docs)
- Fill out VPM info and read over cruise info
- Sign and return PI expectations

AUGUST 4, 2023

ATTENDEES: Nikki Arm, Paul Kuhl

NOTES:

- Explained project
- Discussed analysis tools
  - Abaqus
• Pressure vessel Calc

• Equatorial ring

• Share existing models with him as SW drawings (PDF – doesn’t have SW)

• Consider - Inter laminar tension or strain

• Modeling existing designs
  o Model comparison good

• Big challenges with composites
  o Resin systems considering - very structural - epoxy resins systems good
  o Wide array of carbon fiber options
  o Mix right epoxy and carbon fiber

• Composite pressure vessels
  o Liquid natural gas - fiber winding, metallic liner with composite wound around it
  o Fiber winding can still work for sphere cause the cylinders have hemispherical ends - one of the challenges
  o Challenging to make material comparable with forming process- filament winding goes over a mandrel- how to do a sphere?
  o Thin metallic liner could be the base

• Carbon Fiber vs Fiber Glass
  o Signals going through can’t happen with carbon fiber - not RF transparent
  o Fiber glass could be an option - more RF transparent than carbon but less than glass or plastic
  o Fiber glass more strain tolerant
  o Fatigue could be better with fiber glass as well
  o Coefficient thermal expansion of graphite very different than steel - need to be accounted
  o Fiber glass much higher than graphite - closer to steel, less of a challenge
• Account for combination of moisture with resin, it absorbs moisture at a molecular level - strength drops
• Challenge data for composites is all geared around aerospace - high temps and max saturation
• Major impact - how well consolidated and minimal void - massive impact on inter laminar strength
• Resin is there to stabilize the fiber in compression - so it doesn’t buckle - key for external pressure
• Strain capability of laminate dependent on resin
• Very deliberate on manufacturing process - very good consolidation and minimizing void content is key
• Fiber winding for pressure very different for internal pressure
  o Filament winding manufacturing methods are wet winding - crude process of draping dry bundle of fiber through a resin bath and wrapping onto mandrel - not great control - fine for internal pressure vessels - not so much for external
• Composite designer need to know how it'll be made
• Reverse process of filament winding, put fibers into female tool - external wall would be tooled surface for better conditions
• Consolidation pressure during cure - Autoclave for pressure curing
• Dr E’s daughter works for Paul
• Pre-preg material
• Challenge designing form for spherical tool and minimart wrinkles and fiber distortion
  o Orange peel slices - butted together to (cut on bias?)
  o Want a lot of hoop strength
  o Quasi-isotropic most likely
• Need to look at fiberglass and carbon-epoxy and how it integrates with other features like view ports and electrical ports
• Asked about Titan
• Set of standards - calculate pressures
• Material suppliers could connect with them to inquire about unpublished data to better suit my environment
  o Write down gaps of understanding and data and he can send messages to try to pull together more data
• Will wait to hear from me but feel free to email and send papers or designs and questions at any time for him to look over - this is all at my pace

TO-DO:

• Send him drawings of existing spheres
• Begin research/design

AUGUST 11, 2023

ATTENDEES: Nikki Arm, Danika Cornejo, Maya Netto

NOTES:

• Discuss possibilities of partnering with senior project again
  o Agree it would be good
• What projects new engineers could do
  o If funding allows
    • Out fit an entire second lander
  o If funding is tight
    • Integrate TD sensor onto current lander
    • Implement parallel laser device for measuring fish

TO-DO:

• Email Crow
• Email Kevin

AUGUST 14, 2023

ATTENDEES: Nikki Arm, Drew Davol

NOTES:

• Show Abaqus simple file with just vacuum
• Non linear monitor job runs
• COPEN (gap) and CPRESS (pressure at contact)
• Aluminum make sure things make sense
• Make more regular mesh
• Understand interface and variables
• Do stresses make sense
• Apply external pressure
• Composite tool
• Fix units in material properties and pressures to inches

TO-DO:

• Fix Mesh
• Check values of material props and pressures to account for sphere drawn in inches
• Check stresses make sense for aluminum with vacuum
• Figure out meaning of COPEN and CPRESS
• Add external pressure
• Check again
• Begin figuring out how to input composite lay ups into abaqus

AUGUST 21, 2023

ATTENDEES: Nikki Arm, Danika Cornejo, Maya Netto
NOTES:

- Charged batteries for all lander components
- Sealed spheres and assembled
- Loaded car for NOAA deployment tomorrow
- Determine meeting times for tomorrow

TO-DO:

- Activate SPOT Trace
- On Shearwater
  - Set timers and camera
  - Reseal spheres
  - Deploy
  - Recover

AUGUST 22, 2023

ATTENDEES: Nikki Arm, Danika Cornejo, Maya Netto, Marilla Lippert & Team, NOAA Crew

NOTES:

- At sea with NOAA on the RV Shearwater!
- Left from Morro Bay
- Deployed lander at 35.455379, -121.008636 (west of Harmony 1 Dive site)
- Did entire set up on moving ship with 4-5ft swells
- Saw whales while parked at Harmony 2 for Marilla’s divers
- Used A-frame and quick release on stern of ship for deployment
- After deploying left the area to go to Harmony 2 for Stanford Dive
- Came back to Harmony 1 and our team watched for the lander to surface while the divers were in the water
One of the NOAA crew was the first to spot it as it was very far away on the horizon
Our team then continued to keep an eye on it while we waited for divers to finish and return
Once dive team was back we sailed towards the lander
Approaching from down swell was great to allow the lander to gently come to us
I recovered the lander using their carabiner boat/rope hook
We then used the A frame pulley/winch system to bring it back onto the vessel
Cleaned up and returned to port

TO-DO:

- Off-load videos
- Solder on 2 new burn wires
- Connect with Stef for video of deployment

AUGUST 23, 2023

ATTENDEES: Nikki Arm, Danika Cornejo, Maya Netto

NOTES:

- Disassembled lander
- Offloaded videos
- Soldered new burn wires
- Learned Friday deployment on the Richards is canceled, maybe reschedule next week.
- Thanked Shearwater team for yesterday
- Asked about deployment depth
- Emailed Lindsey about local ship captains and SIO cruise
  - Sounds like SIO will be too full but she’s gonna double check
Said to reach out to Captain Shawn (captains the RHIB) and say she sent us “to explore local research support”

TO-DO:

- Charge batteries
- Contact Captain Shawn

AUGUST 25, 2023 (MORNING)

ATTENDEES: Nikki Arm, Captain Shawn Stamback

NOTES:

- Texted him mentioning Lindsey suggested him and explained our project
- He called to talk more about it
- Sounds promising as an option – he’s happy to help
- Asked for a few specifics so he can get us a quote for how much it’ll cost for him to take us out to the WEA.
  - Specifics on drop location
  - Number of passengers
  - Weight and dimensions of lander
  - Required ship equipment

TO-DO:

- Find out specifics of location from Crow, Maya, and Danika
- Email Sawn info above + specs & ops sheets

AUGUST 25, 2023 (AFTERNOON)

ATTENDEES: Nikki Arm, Crow White
NOTES:

- Agreed to aim for same spot discussed with NOAA
- Asked me to ask Shawn about if he has liability insurance and the details on it if so. He said Cal Poly might require it and might not like the idea of us going with a charter vessel anyways so could be critical to it.
- He said once we know what he has it would be best for one or both of Maya and Danika to talk to Katy Doctor (BIO dept finances) in person to ask about going on his ship. He said an in person conversation would be better than me emailing her

TO-DO:

- Email Shawn asking about liability insurance

AUGUST 29, 2023

ATTENDEES: Nikki Arm, Kevin Hardy

NOTES:

- Acquired USB with...
  - Existing material properties
  - Test data
  - Photos of testing and failed parts
- Asked Kevin About
  - Black burn wire wires, marine grade coating, where to purchase - Subcon Aniexter (see photo)
How to purchase more of the vacuum ports - custom product made for Kevin

Lander quote – said he will get it to Crow “soon”

- Looked at Failed Spheres in Person
  - Sphere failed at 4400psi
- Unmixed Materials and Void found in Electronic Port Hole

- Crack in O-Ring Groove caused by Void in Sphere Near Surface

- Jig to Determine if Sphere is “Out of Round”
• Looked at Sphere with equatorial ring for O-rings

  o Ports through equatorial ring
    ▪ Less stress in spheres
    ▪ Easier access to parts when mounted to ring and spheres come off

• Recommended Adhesive

  o Discussed use of composites
    ▪ Composite fibers in tension instead of compression
- Fiberglass parts in tension used for body of lander
- Landers for Crow
  - Parts for 3
  - Lights and camera for 2
- New battery system for longer life with 2 big batteries and voltage regulator
- Working on external battery charger
- New 6 month timers can be set from outside
- Learned CamDo plug in battery - **INSTEAD** of Battery in Camera

**TO-DO:**
- Begin implementing existing materials into model to compare to test data

*SEPTEMBER 1, 2023*

**ATTENDEES:** Nikki Arm, Drew Davol

**NOTES:**
- Write up - does it make sense make sense
- Pictures of model then paragraph analyzing it
- Nylon/Glass
  - Hydrophilic material - absorbs water
  - Use conditioned properties
  - Cold temp might affect nylon water absorption
- Run it at 3000m to compare to implosion
- Fix node not face
- How to do Axisymmetric modeling with composites? Does it look the same at all slices
  - Wound sphere, could assume fibers all run in and out of the page
- Chapters
  - Existing sphere testing
  - FEA of existing spheres
  - Redesign
  - Alternate designs and alternate materials
- Keep analytical to keep scope of work reasonable

TO-DO:

- Convergence study on current model
  - Max & Min principle stress want to report (mainly min cause compression)
  - Copen and C Pressure
- Lay out a plan (everything Axisymmetric)
  - Next add O-Ring groove
- Quarter model?
  - Penetrations can be modeled that way
  - Start with a hole
  - Then add a stainless steel sleeve
• Add equatorial ring - make same material as rest of sphere

SEPTEMBER 6, 2023

ATTENDEES: Nikki Arm, Drew Davol

NOTES:

• Showed Drew progress I’ve made on my report
  o Outlining sections through use of headings
  o 13 pages written of intro and lander modification + application section

• Talked about SPOT Trace functions and use similar to a Sat Phone GPS

• Agreed to keep working on documentation of everything I’ve done up to this point before moving forward with more modeling
  o Said most people wouldn’t have anything written yet so this is great
  o Definitely best to write it while it’s fresh

TO-DO:

• Add sections for GPS Tracking and large vessel recovery device
• Add notes in appendix for large vessel recovery

SEPTEMBER 16, 2023

ATTENDEES: Nikki Arm, Danika Cornejo, Maya Netto

NOTES:

• Helped prioritize goals for senior project group
• Taught them about what I learned from Kevin about using the camera back-up battery (NO BATTERY IN CAMERA)

• Helped them develop the senior project summary description for Karla
  o Ocean Lander Vehicle Enhancements (depth sensor, species sizing)
A Deep Ocean Vehicle (DOV), specifically a lander, has been donated for use in our class as a part of this senior project. It has been tested to a 200 ft depth. The existing lander has a scientific payload (lights/camera and bait systems) to film the seafloor around the lander developed by a previous senior project. An area off the coast of Morro Bay is being considered for a wind farm (2000+ ft depth), and the goal is for this lander to be used in visually assessing the area in a before-and-after controlled impact (BACI) study on the wind farm’s construction.

With the current project funding and supplies, the primary goal would be incorporating an existing pressure-depth sensor onto the lander (purchased by the last senior project with excess funds); followed by replaceable battery modules to swap out dead batteries with freshly charged ones for back-to-back deployments with one lander without needing to wait for charge times. There is also potential for creating a parallel laser system for measuring the size of animals caught on film if time allows. If more funds are attained to purchase a second lander, focus of this project would shift to outfitting this new lander with its own camera/lights and bait systems. The final goal is to use the completed lander(s) on future deployments from the Cal Poly boat (we'll need $ to support fuel and captain costs) and off NOAA research vessels.

**SEPTEMBER 19, 2023**

**ATTENDEES:** Nikki Arm, Danika Cornejo, Maya Netto, and Crow White

**NOTES:**

- Plan for Fall
  - Deployment
  - Inter-D SP
  - Estimate on second lander
• Crow talked to Tom yesterday
  o Sorry, wants to make it happen
  o Scheduling difficulty
    ▪ Danika has no class on Friday
    ▪ Maya has one class on Friday (1 hr lecture, could skip if need be)
    ▪ Thursday next best for Danika, Maya could skip as well for a one day thing
    ▪ Tuesday next best day for both
  o Crow really wants to do it on the CP boat
  o Difficulty with travel
• Western Society of Naturalists overlaps with NOAA
• Danika and Maya presentations went great
  o Wrote about light filter testing
    ▪ Blue vs red, full on self study
    ▪ Would be great but not feasible
    ▪ Rely on existing studies
  o Danika and Crow look at mapping code modifications
    ▪ Maya will join
• Invoice from Kevin for Landers
  o Crow put in drive to all see
  o Almost $40k
  o Out of the question right now, need larger grant
• Karla’s class
  o Discuss goals for the team
    ▪ Depth sensor integration
    ▪ Module batteries
    ▪ Parallel laser measuring system
  o Go to SP to present project (9/26 at 1 pm)
• All three will be there to present

• Discuss sensor info

TO-DO:

• Check in with Lindsey about November cruise
• Email Eric and get him to extend Maya and Danika’s access to project room + will have new senior project
• Kevin email about battery info
• Email Tom on Friday
  o Priority: Friday, Thursday, Tuesday
  o Check with Maya and Danika about Midterms
  o Mention NOAA dates
• Check into Driving options to get to SLO
  o Baker-Koob funds reimbursement for last minute plane tickets

SEPTEMBER 20, 2023

ATTENDEES: Nikki Arm, Drew Davol

NOTES:

• Talk with new senior project
• Baker-Koob travel reimbursement
  o Big complaint now, a lot of trouble
  o Not sure if continuing enrollment counts to make me a current student
• Call ITS about email address
• Talk to Amanda in ME office about finances for travel
• Timing for thesis completion
  o A few weeks for committee to review paper before defense
  o Defense itself usually has a few edits after too
• Find post date for this quarter

• Appendix is mainly for me

• In Wisconsin 3-10 of Oct

• Lay out Analysis plan

TO-DO:

• Call ITS about email address
  o Account extension request submitted by Drew if need email past this quarter

• Email Amanda about travel

• Email grad office about submission deadline
  o December 15, 2023 Deadline
  o NOAA Nov 5-13, aim to have all other analysis and documentation done by then

• Check baker koob expiration date
  o January 15, 2024

SEPTEMBER 27, 2023

ATTENDEES:  Nikki Arm, Drew Davol

NOTES:

• Update about life chaos and bit delay in thesis stuff
  o Lift device get people off the floor with very little effort

• Travel planning – sent him account info for form

• Deadline planning
  o Defense before NOAA?
  o Schedule defense after NOAA (Nov 7-10th)
  o Next weekday plan defense
    ▪ Figure out Jims time zone difference (morning for us)
o Get them paper before defense
o Advertise defense – talk to Shollenberger

TO-DO:

- Add disclaimer page
- Email committee

OCTOBER 2, 2023

ATTENDEES: Nikki Arm, Drew Davol

NOTES:

- Mesh convergence
- Find a sphere eqn it will be slightly different
- % difference
- Element size on x axis not mesh number
- Compare run times too
- Roarks formulas for stress and strain

TO-DO:

- Redo hand calc
- Finish mesh convergence

OCTOBER 6, 2023

ATTENDEES: Nikki Arm, Danika Cornejo, Maya Netto, Senior Project Team (Eric Meseck, Evan Hall, Erin Malone, Andrew Gaskell)

NOTES:

- Senior Project Team
Discuss how they want communication and the project run
• Possible meeting times - Class 12-3 TR, Friday mornings great as well
• Next meeting is showing everyone the lander
• Make group chat text for everyone
• Scope of Work Convo
  o Depth Temperature Sensor
  o Battery System
  o Laser Scale
• Discuss reflective tape questions
• Temperature range research
• Possibly connect them to RBR contact
• Baker Koob Application deadline

TO-DO:

• Send Danika WhenIsGood link
• Temperature range research

OCTOBER 11, 2023

ATTENDEES: Nikki Arm, Drew Davol

NOTES:

• Got past his trick question on Mohr’s Circle – no shear stresses on calc is correct
  o Shear would need mohrs to find principal
• Look at opening got o ring groove - both external pressure and just internal vacuum
• Get rid of o ring groove quarter
• Mesh quarter with
  o Hex
  o Quadratic tets if needed
• Incompressible fluid filled - fix inside surface for 100% fill
  o Axisymmetric with o ring groove
• 90% fill with 10% vacuum

TO-DO:

• Re run o-ring groove
• Remove oring from quarter model and re run
• Try other designs and materials

OCTOBER 17, 2023

ATTENDEES: Nikki Arm, Drew Davol

NOTES:

• Travel form
• Schedule defense room reservation with Me front desk?
  o 124B
  o Call them
• Quarter model
  o Make 2D circle plate instead of cylinder
  o Tie it to inside edge
  o Apply pressure
  o Adjust limits on stress value to view effects
- Incompressible fluid model
  - Looks good
  - Doesn’t open
- New materials
  - Quasi isotropic weave layup pattern
  - Symmetric, 0 45, -45
  - Composite tool in Abaqus
    - Axisymmetric? Or apply to solid
- Suggested thickness for different depths?
- Thicker version of existing?
  - Go in vs out, internal vs external limitations (inside electronics size vs external lander size.

TO-DO:

- Call ME Front Desk to reserve room for defense
- Add plate to quarter model
- Write up incomp fluid model
- Research composite tool in abaqus
- Determine quasi-isotropic layup order
- Test thicker versions of sphere

OCTOBER 20, 2023

ATTENDEES: Nikki Arm, Drew Davol

NOTES:

- Quarter model try display group to turn off some elements
- Make equatorial ring spherical
• Think about presentation
  o Half and half ME and application
  o Run it by the undergrads to make sure it makes sense to everyone
  o 40 min
  o Remember your audience - don’t get too technical and explain what things mean

TO-DO:

• Add COPEN and CPRESS for quarter model
• Make spherical equatorial ring

OCTOBER 23, 2023

ATTENDEES: Nikki Arm, Danika Cornejo, Maya Netto, Crow White, Sierra Bentti

NOTES:

• Sierra - 4th year MSCI
• Lesson plan made for middle school
• Doing more in depth for high school
• Lander model
• Show Sierra the lander
• Pier access for the team
• Ability to lift?
• Reach out to Kyle?
• Aim for one Saturday afternoon
• NOAA and defense planning
• Send video folder
• They discuss lesson plan options
• Ask Maya about metrics measured by BRUVs
• Join Maya Danika and Crow for incoming student event Friday at 1pm

TO-DO:

• Send email
• Saturday pier deployment

OCTOBER 24, 2023

ATTENDEES: Nikki Arm, Drew Davol

NOTES:

• Model looks great
• Is min principal what we’re looking for?
  o Stresses given are in the fiber direction so need to look in the fiber direction
  o Report S11 - stress in fiber direction
  o Tsai-Wu or Tsai-Hill? Direction matter
  o Great news - no shear!
• Look at holes - stress concentrations can be more pronounced in composites
• Don’t worry about equatorial ring model
• With words address how holes effect differences and equatorial ring
• Talk to Thorncroft about lessons and lander models
• ME Dept might do unofficial graduation Saturday after finals so keep eye out for that
• Presentation slides - keep it super simple
  o Want people listening not reading
  o Bullet points pop up in Groups animation
  o Lots of pictures

TO-DO:
• Run simple sphere models
• Write discussion of results
• Research Tsai-Wu/Tsai-Hill – do we need to do any analysis with it?
• Write conclusion

OCTOBER 27, 2023 (AFTERNOON)

ATTENDEES: Nikki Arm, Danika Cornejo, Maya Netto, Crow White, Sierra Bentti

NOTES:

• Group participated in Cal Poly’s United by Excellence program
  o “United by Excellence is a one-day event hosted by the Office of Admissions. It is designed to provide access to educational resources, equitable learning experiences, and higher education preparation to underrepresented and historically underserved student scholars interested in pursuing higher education. This session is tied into Admissions’ Latinx/e heritage event.”
• Presented to 8 groups of 4 high school students from underrepresented communities and explained to them about our research
• Showed them the lander in person and played highlight real of footage for them
• Represented the Bio dept and took turns presenting and interacting with students
• Also met Sierra for the first time and got to show her the lander for the first time
OCTOBER 27, 2023 (EVENING)

ATTENDEES: Nikki Arm, Danika Cornejo, Maya Netto

NOTES:

- Prepared the lander for deployment after open house
  - Set up camera and timers
  - Used new battery set up suggested by Kevin with back up battery
- Loaded car with everything needed for open house and deployment
- Dropped everything off at the pier and coordinated with Tom and Jason for the next day

OCTOBER 28, 2023 (MORNING)

ATTENDEES: Nikki Arm, Danika Cornejo, Maya Netto

NOTES:

- Presented at the Cal Poly Pier Open house
- Showed the lander and highlights reel along with explaining our research and answering community questions
- I was interviewed by Mustang News for it
- Overall had a great time and everything went off without a hitch
  - My favorite interaction was with one little girl who, upon finding out what our project was got the widest eyes and biggest smile – literally shaking with excitement – and said “I LOVE THE DEEP-SEA!” she loved hearing about the lander and I don’t think could have moved faster when I directed her to our videos she could watch!
OCTOBER 28, 2023 (AFTERNOON)

ATTENDEES:  Nikki Arm, Danika Cornejo, Maya Netto, Sierra Bentti, Kyle Walsh, Jake Roth

NOTES:

- After cleaning up for open house, we met up with Sierra, Kyle, and Jake to help us with a deployment
- Kyle and Jake helped spot Maya and Danika in lifting and lowering the lander into the water since my shoulders would not allow me to help
- Things went great overall
- We are unsure why but the lights turned on at the time of deployment, but then immediately turned off – not sure what caused this but will investigate further when preparing for NOAA
- Determined Maya and Danika can deploy the lander, but at least 3 people able to lift the lander are required to do a deployment off the pier safely (for both people and lander safety)
- Determined for future pier deployments
  - Do NOT use the visibility flag – don’t need to risk breaking it on underside of pier
  - Do NOT have rod for lifting bale in place for same reason
- Just tie rope directly to bail, bail doesn’t need to be held up since we aren’t recovering with boat hook
- Locked up pier after we were done as we were the last group out there
- Returned everything to campus and had a celebratory dinner with those available to do so 😊

**NOVEMBER 6, 2023**

**ATTENDEES:** Nikki Arm, Danika Cornejo, Maya Netto

**NOTES:**

- Completed Lander Preparations for NOAA
  - Fixed broken light filter cap
  - Soldered on new burn wire
  - Prepped new weights and chains
  - Prepped burn wires and tools to bring on ship for following day deployment
  - Charged batteries
  - Assembled lander
  - Swapped light filters to red
  - Packed tool box and vacuum pump
• Investigated light/camera from pier deployment
  o Camera recorded for just a few seconds
  o Looks like battery died
  o Not sure why but believe back up battery died on us so made decision to use GoPro build in battery for future deployments

• Purchased additional supplies
  o Purchased 3 small travel sized silicon grease tubes
  o Purchased 7-gallon plastic crate to transport soldering tools now (water safe) but can use for weights/chains, rope, and other supplies for the future

• NOAA canceled for tomorrow but are aiming for MB05 Wednesday and WEA Thursday

TO-DO:

• Order
  o Silicone grease
  o Chain connectors
  o Welded rings
  o Weights
  o Reflective tape

• Submit purchase reimbursement forms

NOVEMBER 7, 2023

ATTENDEES:  Nikki Arm, Danika Cornejo, Maya Netto, NOAA Crew

NOTES:

• Loaded the ship with lander and all our supplies

• Joined NOAA team for a walk on the beach at sunset, learning about each other’s projects and getting to know each other

• Attended BBQ with crew at the house they were staying at in Morro
Befriended the rescue cat they found that morning

TO-DO:

- Rest Up for Tomorrow!

NOVEMBER 8, 2023

ATTENDEES: Nikki Arm, Danika Cornejo, Maya Netto, NOAA Crew

NOTES:

- Realized we forgot to buy bait
  - Shop we stopped at that said they were open online was not
  - Crew had squid they offered for us to use instead
- Depart at first light
- Transit to MB05
  - Set up lander in last hour of transit
  - Maya and Danika struggling with sea-sickness
  - 4-5ft swells whole way with occasional 8ft swells
- Deploy lander
  - 35.765991, -121.430313
  - 90 m depth
  - 60-min bottom time
  - I manned quick release
  - Danika manned one of the tag lines to steady it while it was in air
  - Emma Beretta (cal poly student/NOAA intern) manned the other
  - NOAA crew controlled A-frame/winch
- While lander was under
  - NOAA team recovered MB05 buoy
  - Completed buoy turnaround
• Returned to lander drop point
  o All hands on deck lookout
  o Zac spotted it behind the ship (it had drifted 500 ft from where we dropped it)
  o Repositioned ship to approach on downswell
  o I used SW’s carabiner boat hook to latch onto bail
  o Danika spotted me to make sure I didn’t fall overboard
  o Washed off lander with fresh water

• Redeployed NOAA’s MB05 buoy

• Transited back to port
  o Disassembled spheres to begin charging batteries

• In port
  o Soldered on new burn wires
  o Waited for batteries to finish charging
  o Maya and Danika acquired Mackerel bait for tomorrow’s WEA deployment
  o Took out SD card to take a quick peak at the videos

• Sightings
  o Lots of sea lions and otters
  o Lots of gulls and sea birds
  o 3 baby and 1 young adult Mola Mola

• Home
  o Skimmed through the videos
    ▪ Lots of flat fish
    ▪ A shark
    ▪ 2 octopi
    ▪ Lots of crab
    ▪ More fish
  o Uploaded first two videos (each took 2 hours to upload) but needed to call it a night with another long day to come
Will upload the rest after tomorrow’s deployment

**TO-DO:**

- Rest up for tomorrow

**NOVEMBER 9, 2023**

**ATTENDEES:** Nikki Arm, Danika Cornejo, NOAA Crew

**NOTES:**

- Maya woke up sick – unable to join
- Depart at first light
- Transit to WEA
  - Prep lander 1 hour out
  - 4-5 ft swells with occasional 8ft
- Deploy lander just outside WEA
  - 900 m depth
  - 35.311600, -121.585457
  - 33 min descent, 60 min bottom time, 20 min burn wires, 36 min ascent
  - Went in the water at 9:04 AM
  - Timers set to go off at 10:36am
- Transit 400 m to NRS-13 drop sight
  - Hear MASSIVE explosion in the sky but couldn’t find what it was
    - Sounded like it came from the sky and further out to sea
    - Like a rocket or missile explosion
  - NOAA deploys NRS-13
- Return to lander drop point to keep an eye out for it
  - 11:15 all hands on look out
11:30 I start checking SPOT Trace app, only shows location when dropped with last signal at 8:51am

11:45 worry begins, think maybe low salinity and burn wires taking a long time

Wonder if ascent/descent calculations were off

- Based off 200ft deployment from senior project
- I originally thought it was 100ft but team told me 200ft so I used their number but if it was 100ft it could be double the time

Worry brain begins to wonder if I forgot something in set up

- No, Danika and I were thorough and checked every step
- Made sure not to plug in burn wire batteries until after timers were set
- Only thing I noticed was a slight residue on the burn wire electrode which I had thought about cleaning off but don’t remember if I did
  - Even if I didn’t, this might slow down burn times, but not stop it entirely

Wonder if explosion sound was related to lander imploding or landing on an old military mine/bomb as it occurred right as it was supposed to hit the bottom

- NOAA crew all confirm this couldn’t be the case
- Even if it did implode we could not have heard it
- The explosion didn’t sound like one from under water, was definitely in air

12:00 we return to collect NRS-13 while those not doing ops continue keeping an eye out for Seastang and I continue to check SPOT Trace

1:30 no sign of Seastang and NRS-13 ops done, complete final area visual search pattern to look for it with all hands on deck

2:00 no sign of it, have to make the call to return to shore

Confirmed sea floor at drop location was extremely soft/silty meaning there is a chance it could have gotten stuck in the mud from its momentum on touch down

- Lander is officially deemed lost at sea
Begin notification process of informing everyone involved on the project of where things stand and our best guesses for what may have happened

Kevin mentions it could also have gotten stuck on some jetsam (ghost net, abandoned fishing line, etc) and to wait for a local fisherman to find it and contact us in the next week

Told about burn wires sometimes failing in past with them taking, hours, days, or even months to burn

Remember Kevin’s story of a lost lander showing up 4-5 years after deployment
  * No burn wires activated (weren’t set) so had to wait for them to naturally corrode
  * Washed up on Catalina

Kourtney tells me about some equipment NOAA lost just washing up in Japan 10-12 years later

  * NOAA team is very sweet, sharing horror stories of all the expensive high tech equipment they have lost at sea
    * It happens to everyone in this field at least once
    * Sorry it happened to you so early but welcome to the club!
    * “We have snacks!”

  * All of those on board want to tune in for my defense next week

Sightings
  * Sea lions and otters
  * Lots of gulls and sea birds
  * Harbor porpoises
  * Humpback whales
  * Baird’s beaked whales which came right up to our ship

TO-DO:

  * Finish sending emails and notifications of lander status
- Research battery life for SPOT
- Figure out how to extend cal poly email as it was one of my contact options on the lander
- See if there is a database to enter equipment lost at sea
- Reimbursement forms for spot trace, home depot, and travel

**NOVEMBER 11, 2023**

**ATTENDEES:** Nikki Arm, Drew Davol

**NOTES:**

- Take picture of consumables together (burn wire, weight + chains, life saver)
- Add sections theorizing what happened to lander
- If the images look the same just keep one and make a table with numbers
- In body shorter synopsis of each deployment
- First person narrative for everything (intro)
- Suggestions on reordering things
- Make design section and deployment section
- Discuss acoustics controls
- Weed out slides and put them at the end Incase of questions
- One short video
- Keep it technical as possible
- Concentrate of design changes
- Sphere analysis
- Shockwave caused by small failure

**TO-DO:**

- Changes listed above
NOVEMBER 13, 2023

ATTENDEES: Nikki Arm, Cal Poly ITS

NOTES:

- Professor submit service request to extend account
- Still listed as a student, so should be 6 months after registrar marks as “recent student”
- Still marked as “current student in the system”

TO-DO:

- Talk to Crow

NOVEMBER 15, 2023 (MORNING)

ATTENDEES: Nikki Arm, Danika Cornejo, Crow White

NOTES:

- Sucks but not the end of the world
- Not an obvious mistake
- SPOT
- Amount of positively buoyant force would need more at deeper depth? - or not cause solid pressure spheres not changing volume? - nope not a concern
- Back up nature degrade system? Takes a week to degrade?
- Redundancy in buoyancy such that one sphere fails would still float
- HAVE A SECOND MEMORY CARD
- Chain longer but bait arm out of view? Already
- Email Crow + Mare to connect them with all contact info on the lander
- Try to find second hand landers - SIO, Stony Brook? Navy?
- Second Follow up meeting: BACI papers at WSN
TO-DO:

- Update Maya
- Send Emails
- Look into current lander locations (unused?)

NOVEMBER 15, 2023 (AFTERNOON)

ATTENDEES:  Nikki Arm, Danika Cornejo, Senior Project Team (Eric Meseck, Evan Hall, Erin Malone, Andrew Gaskell)

NOTES:

- Karla suggests focus on newer or revised release system
- Lots of Q & A
- Default is release, mechanical hold the weight attached
- Answered their questions and helped brainstorm new focus

TO-DO:

- Send paper once finished
NOVEMBER 15, 2023 (EVENING)

ATTENDEES:  Nikki Arm, Drew Davol

NOTES:

• Up to me if I want them to hold questions
• Ask to hold questions to the end
• Jim Crow and Drew probably won’t ask questions till after everyone leaves
• Then ask Jim and Crow for questions after everyone is kicked out
• Then I’m dismissed and they discuss
• Comment to Jim and Crow about rearranging I talked about with Drew
• If anybody asks - we looked at the hole in the sphere, we understand it’s not the reality cause it doesn’t include the plug with threads and everything
• Metals should be showing von mises to yield strength
• Presentation stuck with min principal for comparing apples to apples

TO-DO:

• Add notes to slides
• Get a good nights sleep!

NOVEMBER 16, 2023

ATTENDEES:  Nikki Arm, Committee, Audience

NOTES:

• THESIS DEFENSE!
• Presentation went well
• Notes from committee suggestions:
  o Incompressible sphere
- Make sure boundary conditions are mentioned in paper
- Mention kuler Mohr(?) failure Theory
- Brittle - min princ
  - Cantilever beam on side floats, buoyancy of float pulling it up

TO-DO:

- TAKE A BREAK
- Make changes to paper
APPENDIX B: NOAA Documentation – Operations and Specifications Sheets

Below are the Specifications and Operations Sheets Updated on 6/15/23 and provided to Lindsey Peavey at NOAA in preparation for July 10th and 11th cruise deployments.

APPENDIX B-1: Specifications Sheet

### DOV SEASTANG
**Picolander Specifications Sheet**

#### Quick Guide

<table>
<thead>
<tr>
<th>Specification</th>
<th>Metric</th>
<th>English</th>
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<tbody>
<tr>
<td>Height (with Visibility Flag)</td>
<td>141 cm</td>
<td>55.5 in</td>
</tr>
<tr>
<td>(without Flag)</td>
<td>113 cm</td>
<td>45.5 in</td>
</tr>
<tr>
<td>Width</td>
<td>79 cm</td>
<td>31 in</td>
</tr>
<tr>
<td>Depth</td>
<td>51 cm</td>
<td>20 in</td>
</tr>
<tr>
<td>Weight (with Drop Weights)</td>
<td>43 kg</td>
<td>95 lb</td>
</tr>
<tr>
<td>(without Drop Weights)</td>
<td>34 kg</td>
<td>75 lb</td>
</tr>
<tr>
<td>Depth Rating</td>
<td>1.5 km</td>
<td>3281 ft</td>
</tr>
<tr>
<td>Maximum Deployment Time</td>
<td>4 days</td>
<td>4 days</td>
</tr>
</tbody>
</table>

#### Capabilities

- **Burn-Wire Weight Release System**
  - Operates on a Timer set Prior to Deployment
  - Takes ~15 Minutes to Burn after Timer Goes Off
  - 20 lb Cast Iron Drop Weight left on Sea Floor

- **Camera & Lights System**
  - GoPro Hero 4 Camera within Pressure Sphere
  - CamDo Controller
    - Operates Camera Photo/Video Recording at Predetermined Intervals
    - Automatically Activates Lights when Recording
  - Custom Made Pressure-Safe Lights
    - Filled with Mineral Oil

- **Bait Arm**
  - Bait Stored in Mesh Bag on Bait Plate
  - Candy Melt Release System
    - LifeSavers Candy Ring Dissolves in Water
  - Place Bait in View of Camera
  - Arm Swings below Lander for Ascent

![High Quality Render of SolidWorks Model of Lander](image.jpg)
APPENDIX B-2: Operations Sheet

DOV Seastang – Picolander: Product Guide for User

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

1. **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 (Battery Management System)
      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.
         i. 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!
         i. 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 of deployment.

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 LiPo 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 connection cap as done in step (a).

   i. Secure cap onto valve.

   j. Repeat for both spheres.
2. 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 mesh bait bag to the bait plate.
   b. Be sure to cut off excess zip tie lengths.
   c. Fill bag with your desired amount of chosen bait.

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 in its “upright” position.

4. Attach Weights
   a. Be sure to use Zinc-Oxide between any threaded metal attachments.
      i. 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.

5. **Drop Overboard**
   a. Once ship is in desired drop location, two people will lift the lander and attached weights over the side of the boat.
   b. Once clear of the ship side, the lander is lowered gently into the water – careful not to tangle chain or wires before releasing it overboard.

3. **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. Release mesh bag seal.
   b. Throw any remaining bait overboard.
4. **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.

5. **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 or made 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.
APPENDIX C: NOAA Permitting Documentation

APPENDIX C-1: Application


Refer to “Instructions for Submitting Applications for National Marine Sanctuary Permits and Authorizations” for guidance on how to properly complete this application. Applicants are responsible for reviewing the instructions in their entirety to ensure the application meets all requirements.

Note: for certain activities, completion of this application may not be required. Consult the Office of National Marine Sanctuaries (ONMS) permitting webpage or contact the local permit coordinator (under “Where to Apply” on the webpage) prior to completing and submitting this application. Review the list of sanctuary prohibitions to see if your proposed project involves an otherwise prohibited activity for a sanctuary, and would therefore require a permit.

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<td>Flower Garden Banks</td>
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Select one of the following:

- New application
- Amendment or modification to previously issued permit, including request for permit time extension (Note: expired permits cannot be amended or modified)

Enter any previously issued ONMS permit number(s) relevant to this project or issued to the applicant: N/A

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Section B – Applicant Information

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<th>Nichole</th>
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</tr>
<tr>
<td>Department (if applicable)</td>
<td>Biological Sciences</td>
</tr>
<tr>
<td>Organization address:</td>
<td></td>
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<tr>
<td>Address Line 1</td>
<td>1 Grand Ave</td>
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<tr>
<td>Address Line 2</td>
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<tr>
<td>City</td>
<td>San Luis Obispo</td>
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<td>State</td>
<td>CA</td>
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<tr>
<td>Zip Code</td>
<td>93407</td>
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<td>Phone</td>
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<tr>
<td>Email</td>
<td><a href="mailto:cwhite31@calpoly.edu">cwhite31@calpoly.edu</a></td>
</tr>
</tbody>
</table>

Page 1 of 6
<table>
<thead>
<tr>
<th>Section C – Project Information</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Project title and summary (maximum 300 characters):</strong></td>
</tr>
<tr>
<td>Cal Poly Lander BRUV BACI Experiment at WEA: Study to be conducted in the wind energy area off the California coast to determine wind farm construction impact on benthic species.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Project dates (mm/dd/yyyy format):</th>
</tr>
</thead>
<tbody>
<tr>
<td>Requested permit start date: 07/10/2023</td>
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<tr>
<td>Requested permit end date: 07/10/2024</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Project abstract (maximum 3000 characters – field will expand as needed):</th>
</tr>
</thead>
<tbody>
<tr>
<td>The area this experiment will primarily be conducted does not require permitting as it is in the Morro Bay Wind Energy Area, however as a part of NOAA’s July R/V Fulmar cruise, a test deployment needs to be conducted in the MBNMS in collaboration with other cruise participants. This deployment will be a one time data collection.</td>
</tr>
</tbody>
</table>

The full experiment will collect 2 hour video recordings of benthic fauna through the use of a baited deep-sea lander capable of deployments up to 1.5km depths. This data will be collected before and after the construction of the wind farm off the coast of Morro Bay and will be used to determine it’s impact on local species.

<table>
<thead>
<tr>
<th>Methods and protocols proposed to be employed (maximum 10000 characters – field will expand as needed). For field experiments or monitoring, provide details on what will occur, how, when, where, and for how long. If equipment is required, fully describe and attach supporting diagrams, as applicable. For collections, provide sampling season and frequency and justification for sample numbers. For all projects (including lab component) provide experimental design and statistical analysis methods:</th>
</tr>
</thead>
<tbody>
<tr>
<td>The deployment to be completed on 07/10/2023 will consist of a 30 minute study where the lander will be deployed within the MB05 area of the MBNMS. The lander operates on timer systems for both the camera/light subsystems and the burn-wire weight release systems. The bait arm is operated using a candy melt release system where a LifeSaver candy ring will dissolve in the water releasing the bait arm which will subsequently drop the arm into view of the lander’s camera. Full details of lander specifications and operations can be found in the attached documents (DOV Seastang Spec Sheet and DOV Seastang User Guide &amp; Operations Sheet).</td>
</tr>
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</table>
### Section C — Project Information (Continued)

Proposed location of activities:
Will this activity occur within any special management zone (such as marine reserves, no-take areas, research areas, sanctuary preservation areas, or state preserves?)

- **No**

Yes — List zone names in box to right and provide justification in Section E

Describe specific location(s) within the sanctuary or sanctuaries where activities are proposed to be conducted. Provide a map showing GPS coordinates in decimal degrees for individual points, point with radius, or polygon(s) with bounding coordinates. List any special management zone(s) by name.

This deployment will be taking place next to NOAA's regular and permitted survey location at MB05. It is within SESA 15, La Crus Canyon (https://nmsmontereybay.blob.core.windows.net/montereybay-prod/media/research/techreports/sesaquicklook/ sesa15quicklook_2016.pdf).

### Section D — Collections Data

Complete this section when requesting collections as part of this activity. Collections include biological, geological and hydrological samples. Describe the type, quantity, and size of sample to be collected. Also, describe the intended sampling location. Provide scientific nomenclature where possible. Complete/attach additional pages if necessary. Leave blank if project does not include collections.

<table>
<thead>
<tr>
<th>Type of Collection (e.g., species name, sediment type, or water sample)</th>
<th>Quantity: Identify number of samples per year or per permit period (if less than one year)</th>
<th>Sample Limits: Identify maximum or minimum size, or other relevant parameters</th>
<th>Location: Identify GPS coordinates in decimal degrees, site name, and note if in special management zone</th>
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<tbody>
<tr>
<td>N/A</td>
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</table>
### Section E – Environmental Effects
Answer the following questions as accurately as possible. Maximum 1000 characters per question.

Describe any direct effects on sanctuary resources or qualities that would occur at the same time and place as a result of this activity (e.g., if equipment is used, describe level and scope of disturbance to species, habitats, or maritime heritage resources. If samples are proposed, explain resulting effects to individuals or populations):  
This project consists of deploying a 75lb baited lander with 20lb drop weights onto the sea floor where it will record video of local fauna lured by the contained bait. After the deployment duration, the weights are left on the sea floor and the rest of the lander floats back to the surface for recovery.

Describe any indirect effects on sanctuary resources or qualities that would be caused by the action that are later in time or farther removed in distance, or incidental to other species or habitats as result of the activity, but still reasonably foreseeable (e.g., If equipment is used, does it have the potential to move and cause unintended effects to species, habitats, or maritime heritage resources? Will field experiments alter the behavior of non-target species?):  
The 20lb cast iron weight will be left on the sea floor which will eventually corrode over time. We do not expect this to effect the enviroment or species found in the area.

---

### Section F – Rationale
Answer the following questions as accurately as possible. Maximum 1000 characters per question.

1. Describe how the proposed activity would be conducted in a manner compatible with the National Marine Sanctuaries Act’s primary objective to protect sanctuary resources and qualities.  
This deployment does not involve the collection or removal of any flora or fauna from the MBNMS and only serves to provide a visual documentation of benthic species through the use of a BRUV with camera and light systems.

2. Describe why this activity needs to be conducted within the sanctuary or sanctuaries to achieve its purpose.  
This research is being conducted as a part of NOAA’s July Cruise on the R/V FULMAR so the location of this test deployment must be completed in this location as it is where one of the cruises collaborative research groups will be conducting research at the time the test is planned for.

3. Describe any benefits this activity would have for the national marine sanctuary or national marine sanctuary system.  
This deployment would provide video recordings of benthic fauna found within the marine sanctuary which can then be used as a part of research and conservation awareness.
<table>
<thead>
<tr>
<th>Section F – Rationale (Continued)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4. If this activity is proposed to occur in any special management zone (e.g., marine reserves, no-take areas, research areas, sanctuary preservation areas, NOAA regulated overflight zones, state preserves), explain why this is necessary and how it would further the understanding of the zone.</td>
</tr>
<tr>
<td>N/A</td>
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<tr>
<td>5. Describe how the proposed methods and procedures are appropriate to achieve the proposed activity’s stated purpose and would avoid, minimize, or mitigate adverse effects on sanctuary resources and qualities as much as possible. The lander is designed for minimal enviromental impact such that it takes up only a very small footprint on the sea floor (2ft x 5ft area) and all material is removed from the area after deployment with the exception of only the 20lb cast iron drop weight and connector chain.</td>
</tr>
<tr>
<td>6. Describe how the proposed duration, seasonality and frequency of the activity requested are appropriate for this activity and are no greater than necessary to achieve the activity’s stated purpose. This permit is requested for one day as a part of a one time deployment with no plan for further activity in the area.</td>
</tr>
<tr>
<td>7. Describe how the expected end value of the proposed activity furthers sanctuary goals and purposes and outweighs any potential adverse effects on sanctuary resources and qualities. This deployment will provide data and visual media of species within the MBNMS as well as provides confirmation of study techniques wich will be used as part of a larger BACI study in the Wind Energy Area off the coast of Morro Bay.</td>
</tr>
<tr>
<td>8. Provide a statement explaining why the applicant and all personnel involved are professionally qualified to conduct and complete the proposed activity. This study is being conducted by Dr. Crow White, Associate Professor in Marine Science from Cal Poly SLO and his students (Nichole Arm - Mechanical Engineering Graduate, Danika Cornejo - Marine Science Undergraduate, and Maya Netto - Biology Undergraduate) in partnership with NOAA on their July 2023 R/V Fulmar cruise.</td>
</tr>
<tr>
<td>9. Provide information to demonstrate that the applicant has adequate financial resources available to conduct and complete the proposed activity and meet the terms and conditions of the permit. This projected is primarily funded by the Cal Poly Baker-Koob Endowments which have funded this project 2 years in a row for the maximum award amount of $5,000 each year. All supplies necessary for this proposed deployment has already been purchased and is ready to go.</td>
</tr>
<tr>
<td>10. Provide information relevant to any other sanctuary-specific permit review criteria, as applicable. Enter N/A if not applicable. N/A</td>
</tr>
</tbody>
</table>
### Section G - Other Information

Identify any other permits, authorizations, or approvals obtained or required to conduct the proposed activity including, in the case of applications for authorizations, a copy of the application for a valid lease, permit, license, approval or other authorization from any federal, state, or local authority of competent jurisdiction.  

Check here if no other federal, state, or local permits are required.  

Check the boxes as appropriate if other permits or authorizations are required. Identify the status of the application(s) as not yet submitted, in progress, or received. Provide permit number(s) and copies of any permit(s) already received.  

<table>
<thead>
<tr>
<th>Permit number if applicable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Marine Mammal Protection Act (MMPA) permit or authorization</td>
</tr>
<tr>
<td>Endangered Species Act (ESA) permit or authorization</td>
</tr>
<tr>
<td>U.S. Army Corps of Engineers permit</td>
</tr>
<tr>
<td>Other federal, state, or local permit(s) or authorization(s)</td>
</tr>
</tbody>
</table>

Check the boxes as appropriate. If consultations are required. Identify the status of the consultation(s) as not yet submitted, in progress, or completed. Provide copies of any final assessments or analyses.  

| N/A | Endangered Species Act (ESA) Section 7 |
| N/A | Coastal Zone Management Act (CZMA) Federal Consistency Determination or Negative Determination |
| N/A | Magnuson-Stevens Fishery Conservation Act – Essential Fish Habitat (EFH) |
| N/A | National Historic Preservation Act (NHPA) Section 106 |
| N/A | Executive Order 13175 – Consultation and Coordination with Indian Tribal Governments |
| N/A | Other tribal, federal, state, or local consultation(s) |

Check the boxes as appropriate. If, to your knowledge, any of the following environmental analyses are required. Provide title of the analysis and any associated decision document. Provide the name of agency responsible for the analysis. Identify the status of the environmental review as not initiated, in progress, or completed.  

- Federal environmental impact statement, environmental assessment, or categorical exclusion memorandum prepared pursuant to the National Environmental Policy Act (NEPA). Include the associated Record of Decision or Finding of No Significant Impact, if the NEPA review has concluded.  
- State or local environmental impact statement, analysis, or review.

### Section H - Certification

I certify that this application is accurate and complete. I understand that incomplete applications will not be acted upon until any required additional information is provided. I further understand that applications not received within the timelines outlined in the instructions may not be processed in time for my activity to begin as planned. I authorize the ONMS to seek peer reviews of my proposal, if deemed necessary.

<table>
<thead>
<tr>
<th>Signature of applicant: Nicholas White</th>
<th>Date: 06/29/23</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signature of co-applicant, if applicable:</td>
<td>Date: 6/29/2023</td>
</tr>
</tbody>
</table>

(Options for authenticating this document: Provide digital signature; provide signed and scanned last page; or provide acknowledgement using the paragraph above by email.)

**Paperwork Reduction Act Statement:** Notwithstanding any other provision of the law, no person is required to respond to, nor shall any person be subject to a penalty for failure to comply with, a collection of information subject to the requirements of the Paperwork Reduction Act, unless that collection of information displays a currently valid OMB Control Number. Public reporting for this collection of information is estimated to average 1.5 hours per response for most activities, including the time for reviewing instructions, gathering and maintaining data, and completing and reviewing this application. See the instructions for details regarding this burden estimate.

**Privacy Information:** We will only use personally identifiable information submitted in this application for the purpose of considering the permit application. We do not collect or use information for commercial marketing. We may share the information you give us with another government agency if your inquiry relates to that agency. Please refer to the permit instructions for the Privacy Act Statement. To view the full privacy policy, please visit [https://www.oscar.doc.gov/opog/privacy/NOAA-pins.html](https://www.oscar.doc.gov/opog/privacy/NOAA-pins.html)
Subject: Questions for permit application to test Cal Poly lander in MBNMS

From: Sophie De Beukelaer

To: Nikki Arm, Crow White, Lindsey Peavey

Hello,

Hope you are doing well. I am trying to rush your permit application through the permit process and have a few questions based on my initial review.

- What is the Lat/long of the planned deployment location?
- Can you confirm the planned location is outside of Piedras Blancas SMCA?
- Would you like to build a time buffer for weather rather than permitting it for only one day?
- What do you use as bait (is it local?) and how much bait is used?
- Can you confirm you do not deploy an associated buoy with the lander? How will you avoid placing it on sensitive habitat or structure forming organisms?

Thank you! Sophie

From: Nikki Arm

To: Sophie De Beukelaer, Crow White, Lindsey Peavey
Hi Sophie,

I'll defer to Lindsey regarding deployment location questions.

I believe I filled out the form to be for a full year at the suggestion of Lindsey as there is a chance we may be going on future cruises and she wanted us to have the option for those as well.

We use sardines as bait which we source locally. We will use approximately 0.5 lb of sardines per deployment.

No, we do not deploy any buoys as a part of lander deployments. Thanks! Nikki

---

From: Lindsey Peavey

To: Sophie De Beukelaer, Nikki Arm, Crow White

Hi Sophie,

Thank you for working on this!

Most of the BRUV deployments will be outside sanctuary boundaries in the Morro Bay WEA, for example on the 11th we'll deploying at 35.4598 N, 121.5420 W, inside the 1000m contour.

MB05 is located at 35.7677 N, 121.4336 W at ~96 m. On the 10th we will deploy the BRUV nearby this site and it will soak for 30 mins as we service MB05, and then we'll recover the BRUV.

I suggested Nikki request a permit for 1 year in case they decide to revisit the MB05 site again, for example in Nov when we will back there with the Shearwater.

Thanks again! Lindsey
From: Nikki Arm

To: Sophie De Beukelaer, Crow White, Lindsey Peavey

Hi Sophie and Lindsey,

I realized we hadn’t answered your last question. Crow recommended using the fathometer to determine a relatively flat terrain which we expect to be sandy bottom to make sure to avoid rocky bottoms or other sensitive habitats when deploying the lander.

Please let me know if you have any other questions. Thanks so much! Nikki

From: Sophie De Beukelaer

To: Nikki Arm, Crow White, Lindsey Peavey

Thank you Nikki. Your permit application is complete and you will hear from us shortly. In drafting the environmental compliance document I did map the location and known hard substrate is within the EFH Conservation Area to the west of the MB05 site so it would be best if the test deployment of the lander was conducted to the east of MB05 but the hard substrate data is quite coarse so using the fathometer would be a good additional mitigation strategy.

Take care, Sophie

From: Sophie De Beukelaer

To: Nikki Arm, Crow White, Lindsey Peavey

Hello,
One more question arose during the review process. I know you only plan to do one deployment next week. How many do you plan to conduct in November? Since you will be abandoning the weights, we'd like to know how many deployments total you'd like to conduct under the permit.

Thank you, Sophie

From: Lindsey Peavey

To: Sophie De Beukelaer, Nikki Arm, Crow White

Hi Sophie,

Jumping in for Nikki here. At the moment, none in MBNMS. Only additional surveys in the WEA, not MB. We asked for a year in case a need arises for additional surveys around MB05.

Thanks! Lindsey

From: Sophie De Beukelaer

To: Nikki Arm, Crow White, Lindsey Peavey

Thank you Lindsey. Since we would like to indicate the number of deployments in the permit, it would be best to just permit for what is planned in MBNMS next week and if need arises for additional surveys around MB05 in November, a new permit can be applied for by September.

Thank you, Sophie

From: Lindsey Peavey
To: Sophie De Beukelaer, Nikki Arm, Crow White

Ok, that’s fine and makes sense. We (Jean, crew & I) are chatting about cruise weather at noon today, so maybe standby so I can give you an accurate window for the MB05 station ops. Thanks! Lindsey

From: Lindsey Peavey

To: Sophie De Beukelaer, Nikki Arm, Crow White

Hi Sophie,

Our cruise is a-go for next week, however we still need to play the CalPoly deployment by ear. Since there is a chance they might get pushed to our Nov Shearwater cruise, can we make the permit window until the end of Nov 2023?

Thanks! Lindsey

From: Sophie De Beukelaer

To: Nikki Arm, Crow White, Lindsey Peavey

Hello Lindsey,

Yes, that sounds good to me.

Thank you, Sophie
July 5, 2023

Nichole Arm
AND
Crow White, Ph.D.
Cal Poly San Luis Obispo
1 Grand Avenue
San Luis Obispo, CA 93407

Dear Ms. Arm and Dr. White:

The National Oceanic and Atmospheric Administration Office of National Marine Sanctuaries (ONMS) has approved the issuance of permit number MBNMS-2023-022 to conduct activities within Monterey Bay National Marine Sanctuary (sanctuary) for research purposes. Activities are to be conducted in accordance with the permit application and all supporting materials submitted to sanctuary managers, and the terms and conditions of permit number MBNMS-2023-022 (enclosed).

This permit is not valid until signed and returned to ONMS. Retain one signed copy and carry it with you while conducting the permitted activities. Additional copies must be signed and returned, by either mail or email, to the following individual within 30 days of issuance and before commencing any activity authorized by this permit:

Sophie De Beukelaer
Permit Coordinator
Monterey Bay National Marine Sanctuary
99 Pacific Street, Building 455A
Monterey, California 93940
Sophie.DeBeukelaer@noaa.gov

Your permit contains specific terms, conditions and reporting requirements. Review them closely and fully comply with them while undertaking permitted activities. If you have any questions, please contact Sophie De Beukelaer at Sophie.DeBeukelaer@noaa.gov. Thank you for your continued cooperation with ONMS.

Sincerely,

[Signature]

for
Lisa Wooninck, Ph.D.
Superintendent

Enclosure
MONTEREY BAY NATIONAL MARINE SANCTUARY
RESEARCH PERMIT

Permittees:
Nichole Arm
AND
Crow White, Ph.D.
Cal Poly San Luis Obispo
1 Grand Avenue
San Luis Obispo, CA 93407

Permit Number: MBNMS-2023-022
Effective Date: July 10, 2023
Expiration Date: November 30, 2023

Project Title: Test deployment of the Cal Poly lander

This permit is issued for activities in accordance with the National Marine Sanctuaries Act (NMSA), 16 USC §§ 1431 et seq., and regulations thereunder (15 CFR Part 922). All activities must be conducted in accordance with those regulations and law. No activity prohibited in 15 CFR Part 922 is allowed except as specified in the activity description below.

Subject to the terms and conditions of this permit, the National Oceanic and Atmospheric Administration (NOAA) Office of National Marine Sanctuaries (ONMS) hereby authorizes the permittees listed above to conduct research activities within Monterey Bay National Marine Sanctuary (MBNMS or sanctuary). All activities are to be conducted in accordance with this permit and the permit application received June 29, 2023 and all subsequently provided information. The permit application is incorporated into this permit and made a part hereof; provided, however, if there are any conflicts between the permit application and the terms and conditions of this permit, the terms and conditions of this permit shall be controlling.

Permitted Activity Description:
The following activities are authorized by this permit:

- Temporary placement of the Cal Poly lander on the submerged lands of the sanctuary for one (1) deployment;
- Discharge of approximately 0.5 pounds of locally caught bait; and
- Abandonment of one 20-pound cast iron weight and connector chain.

No further activities prohibited by sanctuary regulations are allowed.

Permitted Activity Location:
The permitted activity is allowed only in the following location:

at approximately 35.77 N, 121.43 W within approximately 96-meters of water near La Cruz Canyon in MBNMS.
Special Terms and Conditions:

1. All authorized activities may be conducted from July 10, 2023 through November 30, 2023. All equipment shall be removed no later than the expiration date of this permit. The permittees may request an amendment from the MBNMS Superintendent at least 60 days in advance of the expiration date, to extend the effective date of this permit.

2. The lander shall not be placed on sensitive habitat, structure forming organisms or gorgonian corals.

3. The permittees will ensure the bait, landers and the associated components do not harbor any introduced species, to prevent introduced species from being released within or into the sanctuaries.

4. The equipment authorized by this permit shall be used in accordance with techniques and intentions identified in the permit application and subsequent information provided to MBNMS, special terms and conditions, and the general terms and conditions. Disturbance of any other sanctuary resources is prohibited.

5. No activity authorized by this permit shall disturb or impact any historical or marine archaeological resources of the sanctuary. The lander shall not be placed on or near sensitive cultural or historic resources. If historical or marine archaeological resources are encountered at any time, the permittees shall cease all further activities under this permit and immediately contact the MBNMS Permit Coordinator.

6. All equipment authorized for installation under this permit shall be removed when such equipment is no longer in use, or sooner as directed by the MBNMS Superintendent if such equipment is causing or may cause unacceptable harm to sanctuary resources or qualities. Intentional abandonment of equipment or any item (except for bait and weight) is prohibited. In the event the lander equipment is damaged or dislocated due to weather or any other cause, the permittees shall use all available means to locate and recover the affected item(s). The location and description of any equipment abandoned or lost in the sanctuary for any reason shall be noted in the summary report (see special term and condition #15) with an explanation why the equipment was not recovered.

7. At no time may batteries be exposed to the sea or discarded within the sanctuary.

8. This permit does not allow disturbance of marine mammals or seabirds protected under provisions of the Endangered Species Act (ESA), Marine Mammal Protection Act, or Migratory Bird Treaty Act. Disturbing or taking any marine mammal, sea turtle or bird within or above the sanctuary is prohibited except as permitted by valid National Marine Fisheries Service (NMFS) or United States Fish and Wildlife Service (USFWS) permits.

9. During vessel operations, constant vigilance shall be kept for the presence of marine mammals and ESA listed species.

10. When piloting vessels, vessel operators shall alter course to remain at least 100 m from whales, and at least 50 m from other marine mammals and sea turtles.
11. Reduce vessel speed to 10 knots or less when piloting vessels in the proximity of marine mammals, and 5 knots or less in the vicinity of turtles or known/suspected turtle activity. If approached by a marine mammal or sea turtle, put the engine in neutral and allow the animal to pass.

12. This activity may also require permission from other agencies. The enclosed permit is not valid until all other necessary permits and/or authorizations are obtained. Any direct or incidental harassment of marine mammals requires a permit from NMFS (contact PR.ITP.applications@noaa.gov) and/or USFWS (contact the Ventura USFWS office at 805-644-1766). Direct or incidental harassment of seabirds requires a permit from the USFWS. Deployment of mooring or surface buoys may require authorization from the U.S. Coast Guard. Research conducted within California state waters or California state marine protected areas (MPA) may require permission from California Department of Fish and Wildlife (contact Lara Slatoff at Lara.Slatoff@wildlife.ca.gov). The use and/or occupation of state-owned lands within the sanctuary may require a lease or other authorization from the California State Lands Commission (contact Drew Simpkin at Drew.Simpkin@slc.ca.gov).

13. The permittees may be required to pay any or all expenses associated with the locating of and/or removal by NOAA or its designee of any equipment not recovered by the permittee including possible whale entanglement issues requiring a federal response.

14. In the event of any entanglement, injury or death to any ESA-listed species, resulting from interactions with the permitted equipment, the permittees shall immediately contact the NMFS Western Region stranding coordinator, Justin Viezbicke at (562) 980-3230, in addition to ONMS staff identified in general term and condition # 1 below.

15. The permittees shall submit a final permit report of all activities conducted under this permit to the MBNMS Permit Coordinator no later than December 31, 2023. The report should include information regarding daily activities such as the locations (site description, latitude/longitude, and depth) where the lander was deployed, discovery or disturbance of historical artifacts, reporting of any disturbances to marine mammals or seabirds, problems encountered, equipment lost, etc.

**General Terms and Conditions:**

1. Within 30 (thirty) days of the date of issuance, the permittees must sign and date this permit for it to be considered valid. Once signed, the permittees must send copies, via mail or email, to the following individual:

   Sophie De Beukelaer  
   Permit Coordinator  
   Monterey Bay National Marine Sanctuary  
   99 Pacific Street, Building 455A  
   Monterey, California 93940  
   Sophie.DeBeukelaer@noaa.gov
2. It is a violation of this permit to conduct any activity authorized by this permit prior to ONMS having received a copy signed by the permittees.

3. This permit may only be amended by ONMS. The permittees may not change or amend any part of this permit at any time. The terms of the permit must be accepted in full, without revision; otherwise, the permittees must return the permit to the sanctuary office unsigned with a written explanation for its rejection. Amendments to this permit must be requested in the same manner the original request was made.

4. All persons participating in the permitted activity must be under the supervision of the permittees, and the permittees are responsible for any violation of this permit, the NMSA, and sanctuary regulations for activities conducted under, or in conjunction with, this permit. The permittees must assure all persons performing activities under this permit are fully aware of the conditions herein.

5. This permit is non-transferable and must be carried by the permittees at all times while engaging in any activity authorized by this permit.

6. This permit may be suspended, revoked, or modified for violation of the terms and conditions of this permit, the regulations at 15 CFR Part 922, the NMSA, or for other good cause. Such action will be communicated in writing to the applicants or permittees, and will set forth the reason(s) for the action taken.

7. This permit may be suspended, revoked or modified if requirements from previous ONMS permits or authorizations issued to the permittees are not fulfilled by their due date.

8. Permit applications for any future activities in the sanctuary or any other sanctuary in the system by the permittees might not be considered until all requirements from this permit are fulfilled.

9. This permit does not authorize the conduct of any activity prohibited by 15 CFR Part 922, other than those specifically described in the “Permitted Activity Description” section of this permit. If the permittees or any person acting under the permittees’ supervision conducts, or causes to be conducted, any activity in the sanctuary not in accordance with the terms and conditions set forth in this permit, or who otherwise violates such terms and conditions, the permittees may be subject to civil penalties, forfeiture, costs, and all other remedies under the NMSA and its implementing regulations at 15 CFR Part 922.

10. Any publications and/or reports resulting from activities conducted under the authority of this permit must include the notation the activity was conducted under National Marine Sanctuary Permit MBNMS-2023-022 and be sent to the ONMS official listed in general condition number 1.

11. This permit does not relieve the permittees of responsibility to comply with all other federal, state and local laws and regulations, and this permit is not valid until all other necessary permits, authorizations, and approvals are obtained. Particularly, this permit does not allow disturbance of marine mammals or seabirds protected under provisions of
the Endangered Species Act, Marine Mammal Protection Act, or Migratory Bird Treaty Act. Authorization for incidental or direct harassment of species protected by these acts must be secured from the U.S. Fish and Wildlife Service and/or NOAA Fisheries, depending upon the species affected.

12. The permittees shall indemnify and hold harmless the Office of National Marine Sanctuaries, NOAA, the Department of Commerce and the United States for and against any claims arising from the conduct of any permitted activities.

13. Any question of interpretation of any term or condition of this permit will be resolved by NOAA.

Your signatures below, as permittees, indicate you accept and agree to comply with all terms and conditions of this permit. This permit becomes valid when you, the permittees, countersign and date below. Please note the expiration date on this permit is already set and will not be extended by a delay in your signing.

[Signature]

Nichole Arm
Graduate Student
Cal Poly San Luis Obispo

7/5/23

Crow White
Ph.D.
Associate Professor
Cal Poly San Luis Obispo

7/5/23

[Signature]

Lisa Wooninck, Ph.D.
Superintendent
Monterey Bay National Marine Sanctuary

7/05/2023
APPENDIX D: Packing List & Deployment/Recovery Checklist (7/5/2023)

APPENDIX D-1: Packing List

- Lander
  - Mesh Bait Bag
  - Light Filters and Caps
  - Bait
  - Flag
  - Weights
  - Chain
  - Camera SD Cards

- Toolbox
  - LifeSavers
  - Zinc Oxide
  - Silicone Grease
  - Soldering Iron
  - Solder
  - Wire Stripper
  - Wire Snips
  - Heat Shrink (Marine Grade and Normal)
  - Zip Ties
  - Wrenches
○ Pliers
○ Screw Drivers (Flat and Phillips heads, small Electrical size and Normal)
○ Masking Tape
○ Work Gloves
○ Burn-Wire Charging Cable
○ Silicone Spray
○ Alcohol
○ KimTech Wipes
○ Lighter
○ Vacuum Pump
○ Recovery Device
   ○ Large Carabiner Hook
   ○ Recovery Line
   ○ Extendable Fiberglass Rod
○ Snacks
○ Water

APPENDIX D-2: Deployment/Recovery Checklist

○ Set-Up (On Land!)
   ○ Charge Batteries
   ○ Two burn-wire batteries
   ○ Large LiPo battery for lights
○ Be sure to charge through the BMS (Battery Management System)

○ Back-Up battery for GoPro/CamDo

○ GoPro internal battery

○ Set-Up (On Boat!)

○ Set Timers

  ▪ Keep in mind the burn wires will take 10-25 minutes to burn through.
  ▪ It is important the timers are set PIROR 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.

○ Set CamDo Time Settings

  ▪ Plug CamDo into the GoPro Hero 4.
  ▪ Use the CamDo remote to activate the WIFI.
  ▪ Connect to the CamDo WIFI.
  ▪ Enter 192.168.1.1 into a web browser on a phone or computer.
  ▪ Select the day and time of deployment.
  ▪ Select the mode and interval to capture footage.
  ▪ Hit “Save” and “Sync Camera Time” to program the CamDo.

○ Plug in Internal Cables

  ▪ Plug in each burn-wire battery.
  ▪ Plug in the light LiPo battery/BMS.
  ▪ Plug in the CamDo into the GoPro.
  ▪ Plug in the 1.5mm AUX plug into the CamDo.
  ▪ Plug in the extra battery pack to the CamDo.
 Seal Spheres
- Clean each O-ring, O-ring groove, and sealing surface with alcohol and KimTech wipes. Repeat cleaning process until wipes come back clean.
- Cover O-ring with silicone grease.
- Place O-ring inside groove.
- Place half-sphere with flat surface on top of O-ring.
- Attach vacuum pump to sphere.
- Pull a vacuum of -0.5 to -0.6 Bar.
- Detach vacuum hose.
- Clean O-ring, groove, and surface for connection cap as done in step (a).
- Secure cap onto valve.
- Repeat for both spheres.

 Deployment (On Boat)

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

 Attach External Cables
- Burn wires mounted at base of lander frame.
- For all external plugs, use silicone spray on rubber port to ensure watertight seal.
- Plug burn-wires into electrode cable.
- Plug electrode cable into burn-wire control sphere.
- Plug lights into cables.
- Plug light cables into light/camera sphere.
- Coil excess cable lengths around internal beams/structures of the lander to ensure they do not risk them snagging on anything during deployment.

 Attach Bait
Attach LifeSaver Ring

- Tie one loop of rope through the LifeSaver and one of the upper holes on the lander side plate.
- Tie another loop of rope through the LifeSaver.
- Use a bolt on the side of the bait arm to secure the loose rope loop to the arm and hold it aloft in its “upright” position.

Attach Weights

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

Drop Overboard

- Once ship is in desired drop location, two people will lift the lander and attached weights over the side of the boat.
- Once clear of the ship side, the lander is lowered gently into the water – careful not to tangle chain or wires before releasing it overboard.

Recovery (On Boat)

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

- Navigate the boat to come alongside the lander.
  - Be careful – it is better to overshoot and need to come back around several times rather than accidentally run into the lander.
- Use a boat hook to catch the upper rope loop of the lander.
  - Pull the lander to the side of the boat.
- Carefully haul the lander back on board.
- Use at least two crew to do this – be careful to watch your footing and center of gravity to ensure no one falls overboard.

- Dispose of excess Bait
  - Release mesh bag seal.
  - Throw any remaining bait overboard.

- Clean-Up/Analysis (On Land)
- Wash off the Lander and Gear with Fresh Water
- Detach External Cables
  - Remove any cable from the outside of the lander before transit.
- Release Seals On Spheres
  - Unplug any batteries.
  - Turn off timers.
  - Remove camera + CamDo.
- Recover Footage from GoPro
  - Remove the SD Card.
  - Plug into computer.
  - Download videos
APPENDIX F: Large Vessel Deployment/Recovery Operations

After discussions with Kevin Hardy (Founder of Global Ocean Design and my mentor/former boss) and Jean de Marignac (Vessel Operations Coordinator for NOAA), I began to develop a plan for how best to deploy/recover Seastang from the R/V FULMAR as it was a significantly larger vessel than I had used in previous deployments. After developing a rough idea of a plan with Jean, I took his advice and reached out to Kevin as he had experience taking landers to sea on these types of vessels. Below are the suggestions I received from him.

APPENDIX F-1: Previous Method Concerns

- For both deployment and recovery, Jean was concerned about our existing methods due to the size of the vessel (minimum 4ft drop to the water from the edge of the deck) so needed to develop a method safe for this type of vessel
- For the recovery method, Jean was concerned about the use of a boat hook since the platform that is best to stand on for that operation isn’t always safe for crew depending on weather conditions.

APPENDIX F-2: Deployment Suggestions

- “Simplest way is to lower the lander with a 2-leg tagline. One end tied to the railing, pass through the lifting bale, the other end handled by hand.” (Kevin Hardy, 6/29/2023)
- This is the same method Jean and I discussed with the only difference being the end of the line getting tied to a cleat instead of a railing.
APPENDIX F-3: Recovery Suggestions

- “A quick-attach hook with a line is held to the end of a long, say 10-ft, lightweight, telescoping pole, like fiberglass or aluminum. Reach out with the pole and hook the Kevlar recovery bale on the lander. Pull the pole to release the quick attach hook, and now you have a recovery line attached to the top of the lander. The lightweight pole is passed to a shipmate to set on deck out of the way.” (Kevin Hardy, 6/29/2023)

- “The goal is to reach out and attach a line to the lander recovery bale (ted line on top). We do that using a line terminated with an aluminum snap hook. One end of the line ties to the snap hook. The other end of the line ties to the ship somewhere convenient. The reach is made using a fiberglass telescoping pole like the one pictured below. It’s length
can be adjusted from 8-ft to 24-ft. (Awesome!). The snap hook is taped with masking tape to the far end. The tape holds the hook, but can be torn once the hook is attached to the DOV lifting bale.” (Kevin Hardy, 7/3/2023)

• “Recall... that the corrosion of the burnwire is not precise as it affected by water temperature, the width of the exposed wire, battery voltage, and other factors. The sum of all the variables requires some patience on the surface. Keep a sharp eye in the direction of the deployment epicenter. The lander goes down and up pretty straight. It will be off a little depending on currents and maybe some unbalanced drag on the vehicle. Burn time plus rise time is a ballpark number. It might also come up on the back-up timer, which offsets it further.” (Kevin Hardy, 7/3/2023)

  o Burn wires are expected to take **10-15 minutes to burn**, but as discussed above, this is variable dependent on ocean conditions.
  o I calculated an approximation for DOV Seastang’s ascent time from a 1km depth based on our 200ft deployment from last year where it took 2.2 min to ascend and calculated it should take about **36 minutes for it to ascend from 1km**.
    ▪ Our video was recording the whole time the lander ascended, so I know that 2.2 minutes is a fairly accurate number from the time the burn wire snapped.
    ▪ I know this is an over-approximation as the lander would spend more time at terminal velocity for the 1km ascent compared to the 200ft deployment but would rather account for more time than less.

• Photographs/Shopping List of Parts for recovery device
  o Fiberglass Telescoping Pole
    ▪ “The recovery pole is easy to make from hardware store parts. They have Fiberglas and aluminum telescoping poles for tree trimming, painting, and other tasks that need a long reach.” (Kevin Hardy, 6/30/2023)
- Aluminum Snap Hook
- Line
- “Choose something comfortable to handle.”
- Assembly Instructions all quotes from Kevin Hardy 7/3/2023
  - “Using masking tape, tape the hook onto the far end of the telescoping pole.”
  - “Tape the line to the pole in a few places so the weight of the line isn’t all hanging on the hook.”
o "There are others ways to attach the hook, which I’ll illustrate later, but this will work."

o "You can get a long reach with this recovery pole. Be thoughtful of the guys behind you with this thing extended."

o "Once the aluminum snap hook is attached, the goal is to tear the masking tape holding the line to the pole, leaving just the snap hook and line attached to the lander. Hand the pole to a colleague to telescope down and walk out of the way. Haul in on the line to recovery the lander."
APPENDIX F-4: Additional Advice

- “I learned a number of years ago to approach the lander on the surface from down swell. The opposing forces of the swell coming at you and the thrust of the ship’s propulsion makes control better. It’s easy to fall off if something doesn’t look right. Coming in from up swell often leads to running over the lander. Never good.” (Kevin Hardy, 6/30/2023)
- “Don’t let the bos’n throw a grappling hook!” (Kevin Hardy, 7/3/2023)
• “Remind the captain to approach from down swell to prevent running over the little lander.” (Kevin Hardy, 7/3/2023)

• Confidence and Leadership
  
  o “You know your machine better than anyone else aboard. For the moment that all eyes are on the lander ops, you are the Chief Scientist. Stand tall. The ship is taking direction from you. Brief the bridge before the op so they know what to expect. Drawings help. Explain the variables. Explain what you need the crew to do, like all eyes on deck during recovery. The lander can float off pretty quickly once on the surface. Start the look-out early. Accepting the risks, establish a cut-off time after which you can say to the captain it’s time to say the lander could be lost.”
  
  o “Chief Scientist is a pretty cool role. Act with confidence.”
  
  o “Sometimes Davy Jones keeps what he covets. The job comes with some risk. With an unmanned lander, no one cries except the accountants. The challenge to beat the odds is addictive. Testing and care in preparation increase the odds of success.”
  
  o “The possibility of loss makes the thrill of recovery even sweeter.”
  
  o “One of my favorite quotes is from Nietzsche, ‘When you stare into the abyss, the abyss stares into you.’”
  
  o “The ocean challenges you to know it.”
  
  o “It’s not that easy, but it’s not that hard either.”

**APPENDIX F-5: Final Deployment / Recovery Operations**

• DEPLOYMENT
  
  o Set-Up
    
    • Lander recovery bale is attached to quick release mechanism.
Quick release is attached at end of line which goes through a pulley on the ship’s A-frame and whose length is controlled by a mechanical winch system.

2 guidelines are looped through the side body of the lander.

Deployment

Ship crew mans the A-Frame and Winch controls, slowly moving the lander up and away from the ship before lowing it into the water such that the orange side floats are at the water’s surface.

While the lander moves, 2 people man the guidelines, ensuring the lander remains stable and does not swing wildly to injure anyone.

PI mans the quick release wire, giving instructions about lander placement and position, releasing the lander once properly located on the surface.

RECOVERY

Locating Lander

All hands on deck watch for lander surfacing, vocalizing its location when spotted.

At least one crew member keeps eyes on the vessel at all times until recovery is complete.

Approach from down swell to prevent running over the lander.

In case ship is not in area during lander surfacing, SPOT Trace GPS may additionally be used to track it down.

Recovery

Recovery clip/line is attached to A-frame pulley and mechanical winch system used for deployment with extra slack.

Recovery clip/line is attached at end of recovery pole.

PI uses recovery device to reach overboard and clip onto the lander’s recovery bale.
▪ One crew member spots the PI to ensure they do not fall overboard due to unexpected swell while leaning over the edge of the ship.

▪ Once clipped, the recovery pole is removed and passed to nearby crew member and ship crew use the A-frame and winch to reel in the lander.

▪ PI stands on deck ready to catch the lander to prevent it from swinging wildly and helps guide it back on deck.

  o Clean-Up

  ▪ Excess bait is disposed overboard (unless otherwise specified by marine sanctuary regulations).

  ▪ Bait arm is tied back in up-right position.

  ▪ Lander and all equipment that came in contact with salt water is washed off with fresh water.
Channel Islands National Marine Sanctuary

NOAA RV Shearwater Crane and Winch Info:

Science Winch:
Markey Compact Hydraulic CTD Winch (S/N 18487)
850lbs SWL approx 1000 meters of data (EM) cable

Wire Diameter: 0.322"

Speed: 126'/min or 38m/min (can increase to 197'/min or 60m/min after 2,500')

A-Frame:
1,300 lbs max working load

156" to bottom of block from deck

163.5" to bottom of cross-arm from deck

124" between vertical arms

96" clearance of cross-arm from back deck when fully extended over water

Crane (knuckle boom):
Morgan Model 300 Marine Crane with Rotzler
4,510 lbs safe working load (SWL)
1,320 lbs SWL at full extension (14')
Hydraulic Winch (Winch S/N 355662)
2,850 lbs max working load for winch
APPENDIX H-2: CINMS Request for Proposal Memo

MEMORANDUM FOR: Applicants requesting time aboard Channel Islands National Marine Sanctuary Research Vessels Shearwater and Shark Cat

FROM: Lieutenant Nicolas DeProspero, NOAA Vessel Operations Coordinator, CINMS

SUBJECT: Request for Proposal (RFP) and Vessel Allocation Process Calendar Year 2023

Channel Islands National Marine Sanctuary (CINMS) is accepting proposals for ship time aboard the 62ft Research Vessel (R/V) Shearwater and the new 29ft Radon workboat, R/V Minke for calendar year 2023. The R/V Shearwater is anticipated to be available late-February, through December 2023. The R/V Minke will be available in the late winter to early spring through December of 2023. Project proposals must be submitted using the online Vessel Project Manager (VPM) system by January 20, 2023; submissions for work occurring before January 20, will be accepted and reviewed at any time following this request for proposals. Vessel characteristics and capabilities are attached.

All projects must support a NOAA or other federal mission. Because we anticipate receiving more requests than we can accommodate, we will assign priority to those projects that most closely address CINMS needs and priorities as determined by staff. Points of contact are below if you have questions:

- Research and monitoring: Chris Caldwell, Research Coordinator
- Education and Outreach: Julie Bursek, Team Lead for Education and Outreach
- Cultural and Maritime Heritage: Bob Schwenmer, Maritime Heritage Coordinator
- Resource Protection / Permits: Sean Hastings, Resource Protection Coordinator
- Media/Outreach: Shauna Fry, Outreach Coordinator
- Uncrewed Systems (UxS): Todd Jacobs, Deputy Superintendent for Operations

Budget constraints will limit the number of projects that CINMS can fund outright. The selection of collaborative projects and allocation of vessel time will therefore also consider the applicant’s ability to help offset operational costs at the following rates. These cost-sharing rates are subject to change prior to allocation awards:

- **R/V Shearwater**
  - 2-crew: $4,200/day (10 hour day round trip to/from Santa Barbara).
  - 3-crew: $5,000/day (up to 12 hour operations or day trips that require use of the skiff)
  - Mobilization/weather flex day (standby days) reservation costs are $1,000/day.

- **R/V Minke**
  - $2,000/day (10 hour day)
  - $2,500/day if 3rd crew member is required (10 hour day)
  - Mobilization/weather flex day (standby days) reservation costs are $1,000/day
- Cancellations require at least 15 days' notice or are otherwise subject to a fee not less than mobilization costs ($1,000/day).
- Note that the total cost of scheduling, operating and conducting long-term maintenance on both vessels far exceeds the cost-sharing rates indicated above.
- Depending on your projects requirements, the cost of days at sea aboard our vessels may fall outside of the specified day rates during CY2023. As a result, your day at sea cost may be greater than the specified day rates seen above.

If your project has funding available to help cover costs please indicate that full or partial funding is available, where asked, within the project proposal.

During normal years, we strive to stay involved with NOAA’s Teacher at Sea (TAS) Program by inviting Kindergarten through 12th grade teachers and college/university instructors aboard as often as possible. We also support high school STEM mentoring programs aboard our research vessels when appropriate. Your willingness to allow teachers and or students to participate directly in your project may be factored into our allocation decisions.

If your proposal is approved by CINMS, you will be required to use the VPM system for managing the creation and submission of cruise plans as well as completing post cruise reports. Visit http://sanctuarysimon.org/vpm/ and follow the link for first time users to create a login and begin using the system. Proposals submitted in previous years using the VPM¹ may be copied, updated online, and resubmitted for consideration.

Our intent is to make initial allocation decisions by late January and notify applicants shortly thereafter. However, we cannot be certain of the timing of passage of the final FY23 federal budget and the subsequent allocation of vessel operating funds to CINMS. We appreciate how uncertainty can affect planning and logistics for all involved. Therefore, we will strive to make vessel allocation decisions as quickly as possible, and will provide all applicants with regular email updates regarding the decision process and timeline. Additional requests submitted any time after the due date will be considered as time and resources permit. Historically, the months of June through October have been the most requested. Please let us know if you can work earlier or later in the year.

Those who are awarded vessel time are required to provide the sanctuary copies of any products created upon project completion (outreach materials, reports, publications, etc.), to complete an online post cruise summary report through the VPM, and submission of a project description to the sanctuary's SIMoN website (post-completion). For returning parties, past compliance with both safety and reporting requirements will be factored into our allocation decisions. Please note that in addition to VPM submission, research and education activities in the Sanctuary may also require a sanctuary permit (in addition to State and/or other Federal permits). Timely submission of permit requests is required, and all required permits must be provided to us one month in advance of your cruise date. If you have not already started this process, please begin 60 days prior to your sail date as it takes time.

Thank you for your interest in CINMS vessel operations. If you have any questions, please feel free to communicate with your CINMS point of contact, or LT Nicolas DeProspero (voc.cinms@noaa.gov, 805-450-1504).

Attachments: R/V Shearwater and R/V Minke Specifications, VPM User Guide

¹ Note that the account used to create each proposal is also used to submit subsequent cruise plans, float plans, and post cruise summaries.
APPENDIX H-3: Vessel Project Manager – Project Proposal

*** PROJECT PROPOSAL ***

Project: Cal Poly Deep-Sea Lander Deployment - DOV Seastang
Year: 2023
Vessel: R/V Shearwater
Submitted by: Nichole Arm

Overview

Project purpose:
Practice at sea deployment/recovery operations for future deployments off R/V Fulmar for November 2023.

Principal Investigators (PIs):
- Nichole "Nikki" Arm

Collaborators:
- Danika Cornejo
- Maya Netto

Resources available to offset vessel operation costs, if any (technical, financial):
Can discuss if necessary, project funded by Cal Poly Baker-Koob Endowments and Frost Summer Research Fellowship

Operational risks associated with this project:
20-lb cast iron weight and small amount of chain left on sea floor at deployment sight.

Describe how the project addresses Office of National Marine Sanctuaries missions and/or benefits program areas (i.e. research, education, outreach, resource protection, maritime heritage, etc.):
This deployment will allow our team to finalize survey strategies for our overarching research project - to preform a before-and-after impact study in the Wind Energy Area (WEA) off the coast of Morro Bay to determine the wind farm constructions impact on local fauna.

Requirements

Explain why the R/V Shearwater meets your operational requirements:
It has a similar hull and crane/rear frame to the Fulmar which we will be doing future deployments from and will be local to us at the end of August.

Does this project require multiple cruises per year?
- No

Does this project span multiple years?
- No

How many 8-hour days at sea are required?
- 1

How many 10-hour days at sea are required?
- 0

How many days at sea with overnights at anchor are required?
- 0

How many 24-hour days at sea are required?
- 0

Total number of days requested for this project (including mobilization and demobilization)?
- 1

Does this project require SCUBA diving operations?
- No

Permits

Does this project have a permit from the Office of National Marine Sanctuaries?
- Yes

Permit number:
- MBNMS-2023-022

If you have any other local, state, or federal permits, please provide permit numbers, dates, and a short description describing the scope of the permitted activities:
Allows for one deployment in the MBNMS with weight drop near MB05. Received in preparation for Fulmar Cruise.

**Data Collection**

*Describe the procedures and methods to be used on this project:*

---

*Describe the post-cruise analysis timeline for this project:*

---

*Describe the expected products from data collected on this project:*

---

*Provide any additional comments regarding this project:*

---

**Personnel**

*How many personnel including all scientists, observers, and educators, (excluding the vessel crew) will be aboard for the project?*

---

*Describe external ONMS staff provided for this project:*

---

*Describe ONMS staff requested for this project:*

---

**Equipment**

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<th>Size</th>
<th>Weight</th>
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<td>0.51 x</td>
<td>0.79 x</td>
<td>75 lbs, Batteries will be charged off board, but vacuum pump to seal pressure spheres requires plug into 120v/60Hz power supply (standard wall plug).</td>
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Notes: Will have additional 20lb cast iron drop weight and accompany tool box, vacuum pump, recovery device.

**Locations**

No locations have been entered for this project proposal.

**Documents**

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**Dates**

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APPENDIX H-4: Vessel Project Manager – Float Plan

FLOAT PLAN

Cruise Date: 2023-08-22

VESSEL DESCRIPTION

Vessel Name: R/V Shearwater
Hull Type: Aluminum catamaran
Length: 62
Hull ID: R6201
Other: Engine type/manufacturer: Two Detroit Diesel series 60; Manufacturer: All American Marine; Owner: CINMS/NOAA; Width: 24ft; Draft: 6ft; Max POB: 14 research cruise, 32 EdU cruise; Fuel Capacity 1200 gallons of Diesel; Range 300NM at 18kts
Alternate Shore Contact: Sean Hastings

COMMUNICATIONS

Boat Cell Phone: [ ]
Boat Sat Phone: [ ]
Radio Channels: [ ]

Other: MMSI (AIS Equipped); EPIRB # [ ]
Radio call sign [ ]
Primary Sat Phone dial [ ]
NPS Radio call sign [ ]
Radio Callign: [ ]
(back-up Sat phone on board)

CREW

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EMBARKED PERSONNEL

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<td>Arm, Nichole</td>
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<td>2</td>
<td>Corneg, Danika</td>
<td>[ ]</td>
<td>[ ]</td>
</tr>
<tr>
<td>3</td>
<td>Netto, Maya</td>
<td>[ ]</td>
<td>[ ]</td>
</tr>
</tbody>
</table>

MISSION DESCRIPTION

Project Title: Cal Poly Deep-Sea Lander Deployment - DOV Seastang

Itinerary: One (1) lander deployment will be fit in between dive operations for Marilla Lippert’s team. Will be deployed while heading north between sites and picked up 90-min later for recovery on the way back south to another dive site.

- **Avila** -- Point
  Possible disembarking location.

- **Morro Bay** -- Point
  Team boarding location.

Equipment: - DOV Seastang

EMERGENCY/SHORE SIDE CONTACT

<table>
<thead>
<tr>
<th>Shoreside Contact</th>
<th>Primary Phone</th>
<th>Secondary Phone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daniel Lucas</td>
<td>(c)</td>
<td>(p)(c)</td>
</tr>
</tbody>
</table>

Prepared By: Nikki Arm  Date: 2023-08-21  Approved By:  Date:
APPENDIX H-5: Vessel Project Manager – Cruise Plan

Cruise Plan: Cal Poly Deep-Sea Lander Deployment - DOV Seastang

Vessel: R/V Shearwater

Project: Cal Poly Deep-Sea Lander Deployment - DOV Seastang

Details

<table>
<thead>
<tr>
<th>Planned number of vessel use days (incl. mobilization and demobilization):</th>
<th>Planned Dive Operations:</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>No</td>
</tr>
</tbody>
</table>

Cruise purpose:
Practice one (1) at sea deployment off the Shearwater in preparation for deployments off the Fulmar in November in the WEA.

Notes:
Cal Poly team is joining PI Marilla Lippert and her team from Stanford on their research cruise and will be fitting in a deployment between their dive schedule.

Day 1: 2023-08-22

Itinerary

One (1) lander deployment will be fit in between dive operations for Marilla Lippert’s team. Will be deployed while heading north between sites and picked up 90-min later for recovery on the way back south to another dive site.

Detailed procedures to be performed

75-minutes (1-hr and 15-min) Prior to Deployment: Team is alerted and begins set up. This includes setting timers, plugging in internal cables, and sealing spheres.

30-minutes Prior to Deployment: Team finalizes lander preparations, plugging in external cables, adding bait, attaching drop weights, etc.

Deployment Time: Attach lander top rope to quick release and rope over a pulley on the A-Frame lift on the stern of the ship. Lander is lifted out and away from the vessel and partially into the water before releasing.

90-minutes Later: Burn-wires activate. Exact burn time is dependent on many environmental factors including salinity and temperature, but usually take 10- to 15-minutes to burn.

Burn-Wires Snap: Lander drops weights and begins ascent. Ascends at a rate of approximately 90-ft per minute.

Once on Surface: All-hands on deck watching for lander to surface, once spotted ship will navigate near the lander. Recovery mechanism will then be used to latch onto it and reel it back in.

Locations

<table>
<thead>
<tr>
<th>Locations</th>
<th>Personnel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avila Point</td>
<td>Nichole Arm, Danika Cornejo, Luke Dutton, Matt Howard, Zacary Montgomery, Maya Netto</td>
</tr>
<tr>
<td>Morro Bay Point</td>
<td>35.2702244 x -120.7521989 35.3659445 x -120.8499924 Possible disembarking location, Team boarding location</td>
</tr>
</tbody>
</table>

Equipment

- DOV Seastang
### Project Personnel Roster
(Personnel to be present on each day of cruise listed above)

<table>
<thead>
<tr>
<th>Name</th>
<th>Affiliation</th>
<th>DAN #</th>
<th>Emergency Contact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nichole Arm</td>
<td>California Polytechnic State University at San Luis Obispo</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Danika Cornejo</td>
<td>California Polytechnic State University at San Luis Obispo</td>
<td>--</td>
<td></td>
</tr>
<tr>
<td>Luke Dutton</td>
<td>CPC</td>
<td>--</td>
<td></td>
</tr>
<tr>
<td>Matt Howard</td>
<td>--</td>
<td>--</td>
<td></td>
</tr>
<tr>
<td>Zacary Montgomery</td>
<td>Cardinal Point Captains</td>
<td>--</td>
<td></td>
</tr>
<tr>
<td>Maya Netto</td>
<td>California Polytechnic State University at San Luis Obispo</td>
<td>--</td>
<td></td>
</tr>
</tbody>
</table>

### Project Equipment Inventory
(Equipment required for use on each day of cruise listed above)

<table>
<thead>
<tr>
<th>Equipment Type</th>
<th>Size</th>
<th>Weight</th>
<th>Power Needs</th>
<th>Other Needs</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>DOV Seastang</td>
<td>0.51 x 0.79 x 1.41</td>
<td>75 lbs</td>
<td>Batteries will be charged off board, but vacuum pump to seal pressure spheres requires plug into 120V/60Hz power supply (standard wall plug).</td>
<td>--</td>
<td>Will have additional 20lb cast iron drop weight and accompany tool box, vacuum pump, recovery device.</td>
</tr>
</tbody>
</table>

### Supporting documents

<table>
<thead>
<tr>
<th>Document Name</th>
<th>Notes</th>
<th>Download Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>DOV Seastang Spec Sheet</td>
<td></td>
<td><a href="http://sanctuarysimon.org/vpm/docs/cruiseDocs/doc__1.jpg">http://sanctuarysimon.org/vpm/docs/cruiseDocs/doc__1.jpg</a></td>
</tr>
<tr>
<td>DOV Seastang Ops Sheet</td>
<td></td>
<td><a href="http://sanctuarysimon.org/vpm/docs/cruiseDocs/doc__1.docx">http://sanctuarysimon.org/vpm/docs/cruiseDocs/doc__1.docx</a></td>
</tr>
</tbody>
</table>
APPENDIX H-6: Principal Investigator Expectations

Principal Investigator (PI)/Project Lead Expectations – CINMS 2023

Prior to Cruise:
- Submit proposal via Vessel Project Manager (VPM)
- If awarded ship time, thoroughly read award letter to confirm any cost-sharing arrangements and plan for them. Read through all other attachments and contact the Vessel Operations Coordinator (VOC) with any questions or concerns.
- Inform VOC 60 days ahead of your planned sailing date if you would like to include foreign nationals in order to get pre-clearance from NOAA’s Office of Security.
- Discuss cruise dates with VOC early and get them on calendar. Check that they are blocked off as discussed here (click on Shearwater). For Minke please click here.
- Ensure all necessary permits are obtained, and plan for compliance with permit terms. Sean Hastings will be the contact for this along with the VOC.
- Ensure all diving operations are approved through Julie Bursek, CINMS Unit Dive Supervisor
- Confirm all cost-sharing details with VOC as needed.
- One month out: contact the VOC to re-confirm dates and arrange logistics, including:
  - Any equipment or loading assistance needed from vessel/crew
  - Detailed operations plan/locations to be entered on bridge computer
  - Who will meet vessel for loading and when
- Ensure that all cruise participants read safety document and comply with it.
- Two weeks out: enter cruise plan in VPM
- One week out: ensure all participant names and their emergency contact information is entered in VPM. If you have a large group that doesn’t change between cruise days, you may upload a spreadsheet with this information instead of entering it separately in VPM. Check weather.

Provided by science party:
- All food for overnight missions (including food for the crew).
- Drinking water sufficient for entire cruise (no potable water is supplied)
- HAZMAT:
  - Safety Data Sheets (SDS) for all chemicals brought on board
  - Spill Kit/means to cleanup potential spills
- Electronics and Batteries:
  - Proper charging equipment (i.e., 120v charger should be charging a 120v item; charge should match items capabilities not exceed or be less)
  - Proper storage/containment equipment (fire proof/containment bags are recommended if bringing on batteries that will need long (>10hrs) of charging
- COVID-19
  - Masks: voluntary during CDC COVID green level, recommended but not required during yellow/amber level, and required during red level COVID in Santa Barbara.
  - Vaccinations: COVID-19 vaccinations are required to sail aboard. This includes the booster.

During cruise:
- If day trip, conduct no more than 10 hours of operations slip-to-slip
- If 3-crew trip anchoring overnight, no more than 12 hours of operations
- Direct science operations and provide clear movement requests to vessel Captain. The Captain will do his or her best to meet mission objectives while maintaining safety.
- Assist crew with reporting all whale sightings via Whale Alert app or Spotter Pro app
- Keep wet personnel off cushions
- Do not throw any waste, including food scraps, overboard
- Only human waste and ship-provided toilet paper gets flushed down the toilet
- Nothing larger than a cell phone can be charged below deck in bunks
- If you have been issued a permit by CINMS (or other agencies), have it with you and abide by all terms

Vessel Cleanup:
(Captain may relax requirements depending on mission length and complexity. Depending on weather, some items may be safely completed during transit back to Santa Barbara.)

General:
- Ensure that all personal and mission-related gear is removed from the vessel
- Remove all trash and recyclables and dispose on shore
- Vacuum lab, bunk, galley, and settee areas. Mop as needed
- Collect used towels, pillowcases, etc. for laundering
- Make sure all lights and heaters are off
- Open all curtains and close all windows
- If inside windows are dirty, spray with Windex and wipe down
- Spray down back deck with fresh water

Galley:
- Clean, dry and put away all dishes and utensils
- Remove any expired food items from refrigerators and pantry cabinets. Leave any food items that your party did not bring on board
- Wipe down coffee maker, toaster, microwave, stove, and refrigerator
- Wipe down countertops, sink and galley table

Labs and Settee area:
- Wipe down sinks and countertops
- Clean out any cabinets used
- Clean out and wipe down sample refrigerator if used
- Wipe down/vacuum stools and settee bench
- Place stools on counters if floor is wet

Head:
- Remove all personal items from counter and shower
- Wipe down sink, shower and head with disinfecting wipes or lysol
- Shake out mats and hang up to dry on shower door
- Sweep deck and mop or hose out if necessary

Post - Cruise:
- Transfer any cost-sharing funds as previously agreed
- Complete post-cruise summary in VPM
- Provide the sanctuary copies of any products created upon project completion (outreach materials, reports, publications, etc.)

*Education/Outreach Cruises:

For outreach events, an additional crewmember or person other than the crew who is familiar with the boat and its emergency procedures is required for every 10 embarked persons aboard, in addition to the OIC and a crewmember (i.e., 25 students means 2 additional trained staff are required). Please work with Julie Bursek to coordinate this.

The minimum age for sailing on a NOAA vessel is 13 years old. One additional adult must be aboard for each 6 minors and only daytime operations are authorized. Additional safety gear may be required so please contact the VOC early if you would like to bring minors.

I acknowledge receipt of the above guidelines and agree to follow them.

Nichole "Nikki" Arm, Cal Poly ME Grad Student

Pl/Project lead (print name and position)  Signature and Date

8/4/2023
SAFETY AWARENESS ABOARD R/V SHEARWATER

In preparation for your trip aboard R/V Shearwater, please review the following regarding safety and the use of personal protective equipment aboard the vessel. If you have any questions, it is important that you address those with your Project Lead and Shearwater’s Vessel Operations Coordinator, ENS Daniel Lucas, prior to the day of departure. R/V Shearwater is located in Marina 4, End tie, Santa Barbara Harbor.

General Safety Considerations
Safety considerations aboard a vessel at sea are entirely different from those encountered at home or in the “average” workplace. Although R/V Shearwater is typically quite stable, it is important to note that the way in which any vessel behaves at sea is sometimes unpredictable. You should maintain a secure hold on the vessel with at least one hand at all times, especially when moving about the vessel. When transiting from the harbor to your working grounds and later back to the harbor, it is best practice to remain seated for as much of the transit as possible. If you think you may be prone to sea-sickness, you might want to consider taking over-the-counter motion sickness medication, as directed by the manufacturer. Read the directions carefully, as some motion sickness medications are most effective when taken the day before departure, and all medications have side effects.

Berthing: R/V Shearwater’s berthing is limited and as such, with the open-berthing spaces we have aboard, we do our best to keep gender separation, but that is not always possible. The bunk spaces in the hold will always be same gender. The only exception being married couples. There are privacy curtains on all permanent bunks. Changing should be done taking into consideration other people onboard, and should usually be accomplished in the bathroom (marine head) onboard, or alone behind the closed curtain of one of the berthing spaces. When entering a berthing space where the curtain is closed, please knock first.

Chain of Command and Implied Consent: When you come aboard the R/V Shearwater, be advised that you are consenting to comply with the Standing Orders of the vessel, posted signs, and the instructions of the crew. The Captain has the final authority and responsibility to make decisions on the safe operations of the vessel. All operations aboard the vessel are conducted by willing parties, and each person aboard the vessel has the right not to participate if he/she feels it is unsafe, short of an emergency. The management of the site also has authority to stop, or with consent of the captain, change or initiate operations.

Fitness and Health: Please take some time to consider your own fitness and state of health before coming aboard. You will likely encounter erratic rocking and rolling of the vessel while it is out at sea, and need to be able to safely move about the vessel and up and down the ladders. The vessel often takes spray over the side and decks may become slippery, making movement about the vessel more difficult than on land. An additional consideration concerning health is the remote nature of the Channel Islands. The Shearwater can operate as much as six hours from professional medical care and carries only basic first aid supplies and an AED. Please keep this in mind when considering whether to bring medications you have been prescribed. In the event of an emergency, you will be required to don a life vest and board an inflatable life boat from a height of four or more feet. Please consider these factors when determining whether or not to
come aboard. Also, be considerate of the fact that you will be in close proximity to your shipmates for long periods of time. Feel free to discretely inform the captain of medical conditions you feel might impact your own or other’s safety at sea.

**Safety Briefing:** Prior to departure, you will be required to attend a complete safety briefing with a vessel crewmember, to orient you to the layout of the vessel and the safety equipment carried aboard. The briefing will also address those safety requirements that are specific to your planned operations. Your undivided attention is required during the briefing, as that will be the perfect time to ask questions or communicate any last-minute concerns that you may have regarding your trip.

**Personal Protective Equipment:** The use of Personal Protective Equipment (PPE) is required whenever you are involved with operations that are being conducted aboard R/V *Shearwater*. The safety briefing provided at the start of your trip will include information on the specific safety equipment requirements for your planned mission(s). The following non-negotiable safety equipment rules apply to all operations, at all times.

1) **Closed toed, closed heel shoes** must be worn aboard the *Shearwater*. The only exception is on extended research trips and only inside the cabin. Dive booties are allowed during dive operations, but closed-toe shoes should be donned as soon as operations are complete. Composite-toed boots are highly recommended for any operations involving lifting.

2) **PFDs must be worn during all operations** with the safety chains down, line handling while underway, launching and riding in the skiff, launching and recovering equipment over the side, and especially when working from the swim step. A full wetsuit (zipped up) may substitute for a PFD during dive operations unless the Captain says otherwise.

3) **Hardhats must be worn** during all operations involving lifting equipment, and will be supplied by the boat.

4) **Hearing protection** is required whenever noise levels exceed the Occupational Safety and Health Administration’s (OSHA) 8-hour Time Weighted Average (TWA) for exposure to noise(s) over 80 Decibels. (Common, household devices that produce comparable noise levels include doorbells, ringing telephones, and coffee grinders.) The crew will provide specific guidance on those locations where hearing protection is necessary.

PPE such as hardhats, work vests, hearing protection, work gloves, safety glasses (both indoor and outdoor), and steel-toed rubber boots are carried aboard the vessel, and all embarked personnel will have access to PPE as necessary. Crewmembers will direct you to the locations in which PPE is stored when appropriate. Channel Islands National Marine Sanctuary (CINMS) strongly recommends, however, that you identify the safety requirements specific to your mission(s) and consider purchasing any required specialized equipment prior to departure. Most people are both safer and more comfortable in gear that fits them properly.
Dive Trips
If you are planning to conduct dives from the R/V Shearwater, a dive plan needs to be approved by the UDS (Unit Dive Supervisor) Julie Bursek before getting underway. There are extensive requirements to dive under a reciprocity agreement with NOAA. Please begin the process with the UDS at least one month prior to the start of operations. Conducting working dives such as mooring maintenance and equipment installation require specialty planning and reciprocity above scientific reciprocity.

Weather Considerations: The weather in the Channel Islands can vary greatly, even within the span of a few hours. Conditions in Santa Barbara Harbor are often deceptively calm, while offshore is quite rough. A risk analysis is conducted by the crew before getting underway to determine whether operations can be conducted safely and considers a wide range of factors. A good rule of thumb is, operations during small craft advisories are more often than not, cancelled. Operations or transits during Gale warnings are avoided in all but the most extreme circumstances. Further any sanctuary resource emergency can delay or cancel a cruise depending on severity and need for vessels as an aid/tool in mitigating the emergency.

Please contact the Vessel Operations Coordinator, ENS Daniel Lucas with any questions at voc.cinms@noaa.gov. Thank you for helping us to maintain safer, more efficient operations aboard R/V Shearwater, and we look forward to welcoming you aboard!
APPENDIX I: Third-Party Boat Deployment Quote for WEA

Shawn Stambback
805-550-6448

Invoice 08-29-2023

Bill to:
Nikki Arm
DOV Seastang – Picolander project

Shawn Stambback
1214 santa Ysabel
Los oscs, CA. 93402

Ship to:
Nikki Arm
DOV Seastang – Picolander project

Work Description

Provide Captain, Boat, and fuel. Safely transporting Crew members and Cal Poly DOV Seastang – Picolander to/from Offshore wind farm site. Assist in Deploying and Retrieving DOV Seastang – Picolander. Location of Deployment would be in the area of 35.4598 N, 121.5420 W. Boat would be rigged with lifting Davit for deployment and Retrieval.

<table>
<thead>
<tr>
<th>Item Description</th>
<th>Time</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commercial Boat Per day</td>
<td>1</td>
<td>3000.00</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Subtotal</td>
<td></td>
<td>3000.00</td>
</tr>
<tr>
<td>TOTAL</td>
<td></td>
<td>3000.00</td>
</tr>
</tbody>
</table>

Terms & Conditions

Shawn Stambback provides Boat, Fuel, Captain, for no more than 12 hours per day at the above rate. Equipment set up can be made anytime after 17:00 the day prior to charter. Loading and off loading will be made available at 1195 Embarcadero, Morro Bay, Ca 93402

Please Make checks Payable to Shawn Stambback
APPENDIX J: Existing Pressure Sphere Material Data Sheets

DURETHERAN® BKV 30 H

Polyamide 6
30% Glass-Reinforced, Heat-Stabilized Grade

ISO: 1874-PA6, MHF, 14-090, GF30

Description
Durethan BKV 30 H resin is a 30% glass-fiber-reinforced, heat-stabilized polyamide 6 for injection molding. It is a partially crystalline thermoplastic that combines high strength and toughness with an outstanding level of abrasion resistance and good chemical resistance.

Applications
Durethan BKV 30 H resin can be used in applications that require high rigidity, strength, and heat resistance. Examples of automotive applications include door handles, window handles, and fan blades. Consumer applications include power tool housings, lawn mower parts, and tractor parts.

Drying
Durethan polyamide resins are supplied in moisture-tight packaging, dry and ready for processing. However, resin that has absorbed moisture (i.e., regrind, material in opened or damaged bags, and/or color concentrates) must be dried to a moisture content of less than 0.1% prior to processing, in order to optimize property performance and appearance in molded parts. A desiccant dehumidifying hopper dryer is recommended with a maximum dew point of 0°F (-18°C) and an inlet air temperature of 175°F (80°C). Higher drying temperatures could result in discoloration of resin and pigment systems and therefore should be avoided.

Processing
Durethan BKV 30 H resin can be processed on all conventional injection molding machines. Optimum properties are achieved by keeping the melt temperature between 520–555°F (270–290°C). Melt temperatures above 555°F (290°C) can cause thermal degradation and loss of properties.

Typical processing parameters are noted below. Actual processing conditions will depend on machine size, mold design, material residence time, shot size, etc.

<table>
<thead>
<tr>
<th>Typical Injection Molding Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Barrel Temperatures:</strong></td>
</tr>
<tr>
<td>Rear: 470–480°F (245–250°C)</td>
</tr>
<tr>
<td>Middle: 480–510°F (250–265°C)</td>
</tr>
<tr>
<td>Front: 510–535°F (265–280°C)</td>
</tr>
<tr>
<td>Nozzle: 520–555°F (270–290°C)</td>
</tr>
<tr>
<td><strong>Melt Temperature:</strong></td>
</tr>
<tr>
<td>520–555°F (270–290°C)</td>
</tr>
<tr>
<td><strong>Mold Temperature:</strong></td>
</tr>
<tr>
<td>160–230°F (70–110°C)</td>
</tr>
<tr>
<td><strong>Injection Pressure:</strong></td>
</tr>
<tr>
<td>10,000–20,000 psi</td>
</tr>
<tr>
<td><strong>Hold Pressure:</strong> 50% of Injection Pressure</td>
</tr>
<tr>
<td><strong>Back Pressure:</strong> 50–150 psi</td>
</tr>
<tr>
<td><strong>Screw Speed:</strong> 60–100 rpm</td>
</tr>
<tr>
<td><strong>Injection Speed:</strong> Moderate to Fast</td>
</tr>
<tr>
<td><strong>Cushion:</strong> 1/8–1/4 in</td>
</tr>
<tr>
<td><strong>Clamp:</strong> 2–4 ton/in²</td>
</tr>
</tbody>
</table>

Additional information on processing may be obtained by consulting the LANXESS publication *Durethan Polyamide — A Processing Guide for Injection Molding* by contacting a LANXESS technical service representative.
Regrind Usage
Where end-use requirements permit, up to 10% Durethan resin regrind may be used with virgin material, provided that the material is kept free of contamination and is properly dried (see section on Drying). Any regrind used must be generated from properly molded parts, sprues, and/or runners. All regrind used must be clean, uncontaminated, and thoroughly blended with virgin resin prior to drying and processing. Under no circumstances should degraded, discolored, or contaminated material be used for regrind. Materials of this type should be discarded.

Improperly mixed and/or dried regrind may diminish the desired properties of Durethan resin. It is critical that you test finished parts produced with any amount of regrind to ensure that your end-use performance requirements are fully met. Regulatory or testing organizations (e.g., UL) may have specific requirements limiting the allowable amount of regrind. Because third party regrind generally does not have a traceable heat history, nor offer any assurance that proper temperatures, conditions, and/or materials were used in processing, extreme caution must be exercised in buying and using regrind from third parties.

The use of regrind material should be avoided entirely in those applications where resin properties equivalent to virgin material are required, including but not limited to color quality, impact strength, resin purity, and/or load-bearing performance.

Health and Safety Information
Appropriate literature has been assembled which provides information concerning the health and safety precautions that must be observed when handling the LANXESS products mentioned in this publication. For materials mentioned which are not LANXESS products, appropriate industrial hygiene and other safety precautions recommended by their manufacturers should be followed. Before working with any of these products, you must read and become familiar with the available information on their hazards, proper use, and handling. This cannot be overemphasized. Information is available in several forms, e.g., material safety data sheets and product labels. Consult your LANXESS Corporation representative or contact the Product Safety and Regulatory Affairs Department at LANXESS.
<table>
<thead>
<tr>
<th>Typical Properties* for Natural Resin</th>
<th>ASTM Test Method (Other)</th>
<th>Units</th>
<th>Dry as Molded</th>
<th>Conditioned</th>
</tr>
</thead>
<tbody>
<tr>
<td>General</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Specific Gravity</td>
<td>D 792</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Density</td>
<td>D 792</td>
<td>lb/ln³ (g/cm³)</td>
<td>1.36</td>
<td></td>
</tr>
<tr>
<td>Specific Volume</td>
<td>D 792</td>
<td>in³/lb (cm³/g)</td>
<td>0.049 (1.36)</td>
<td></td>
</tr>
<tr>
<td>Mold Shrinkage:</td>
<td>(LANXESS)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flow Direction</td>
<td></td>
<td>in/in (mm/mm)</td>
<td>20.4 (0.74)</td>
<td></td>
</tr>
<tr>
<td>Cross-Flow Direction</td>
<td></td>
<td>in/in (mm/mm)</td>
<td>0.003</td>
<td></td>
</tr>
<tr>
<td>Water Absorption (0.125-in [3.2-mm] Thickness):</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>24-Hour Immersion</td>
<td>D 570</td>
<td>%</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>Equilibrium (73°F [23°C])</td>
<td>(DIN 53495)</td>
<td>%</td>
<td>2.1</td>
<td></td>
</tr>
<tr>
<td>In Air (50% RH)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>In Water</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mechanical</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tensile Stress at Break</td>
<td>D 638</td>
<td>lb/in² (MPa)</td>
<td>26,100 (180)</td>
<td>14,500 (100)</td>
</tr>
<tr>
<td>Tensile Elongation at Break</td>
<td>D 638</td>
<td>%</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>Tensile Modulus</td>
<td>D 638</td>
<td>lb/in² (MPa)</td>
<td>1,334,000 (9.2)</td>
<td>812,000 (5.6)</td>
</tr>
<tr>
<td>Flexural Strength</td>
<td>D 790</td>
<td>lb/in² (MPa)</td>
<td>40,600 (280)</td>
<td>24,600 (170)</td>
</tr>
<tr>
<td>Flexural Modulus</td>
<td>D 790</td>
<td>lb/in² (MPa)</td>
<td>1,204,000 (8.3)</td>
<td>725,000 (5.0)</td>
</tr>
<tr>
<td>Impact Strength, Notched Izod:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.125-in (3.2-mm) Thickness 73°F (23°C)</td>
<td>D 266</td>
<td>ft-lb/in (J/m)</td>
<td>2.2 (120)</td>
<td>2.8 (150)</td>
</tr>
<tr>
<td>-40°F (-40°C)</td>
<td></td>
<td>ft-lb/in (J/m)</td>
<td>1.9 (100)</td>
<td>1.9 (100)</td>
</tr>
<tr>
<td>Thermal</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Deflection Temperature, Unannealed:</td>
<td>D 648</td>
<td>F (°C)</td>
<td>392 (200)</td>
<td></td>
</tr>
<tr>
<td>0.157-in (4.0-mm) Thickness 264-psi (1.82-MPa) Load</td>
<td></td>
<td>F (°C)</td>
<td>419 (215)</td>
<td></td>
</tr>
<tr>
<td>66-psi (0.46-MPa) Load</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Relative Temperature Index:</td>
<td></td>
<td>F (°C)</td>
<td>248 (120)</td>
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</tr>
<tr>
<td>Electrical</td>
<td></td>
<td>F (°C)</td>
<td>203 (95)</td>
<td></td>
</tr>
<tr>
<td>Mechanical with Impact</td>
<td></td>
<td>F (°C)</td>
<td>268 (130)</td>
<td></td>
</tr>
<tr>
<td>Mechanical without Impact</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flammability**</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>UL94 Flame Class:</td>
<td></td>
<td>Rating</td>
<td>HB</td>
<td></td>
</tr>
<tr>
<td>0.030-in (0.75-mm) Thickness</td>
<td></td>
<td>Rating</td>
<td>HB</td>
<td></td>
</tr>
<tr>
<td>0.059-in (1.5-mm) Thickness</td>
<td></td>
<td>Rating</td>
<td>HB</td>
<td></td>
</tr>
<tr>
<td>0.118-in (3.0-mm) Thickness</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weatherability</td>
<td></td>
<td></td>
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<tr>
<td>UV Light Exposure and Hot Water</td>
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<tr>
<td>Immersion Tests</td>
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</tr>
<tr>
<td>Rating</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Electrical</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Volume Resistivity (Tinfoil Electrodes)</td>
<td>(IEC 93)</td>
<td>ohm-cm</td>
<td>1.0 E+15</td>
<td>1.0 E+12</td>
</tr>
<tr>
<td>Surface Resistivity</td>
<td>(IEC 93)</td>
<td>ohm</td>
<td>1.0 E+14</td>
<td>1.0 E+12</td>
</tr>
<tr>
<td>Dielectric Strength:</td>
<td>(IEC 243)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.118-in (3.0-mm) Thickness 50 Hz</td>
<td>(IEC 250)</td>
<td>V/mil (kV/mm)</td>
<td>1.016 (40)</td>
<td>889 (35)</td>
</tr>
<tr>
<td>1 MHz</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dissipation Factor (Tinfoil Electrodes): 50 Hz</td>
<td>(IEC 250)</td>
<td></td>
<td>4</td>
<td>15</td>
</tr>
<tr>
<td>1 MHz</td>
<td></td>
<td></td>
<td>0.005</td>
<td>0.50</td>
</tr>
<tr>
<td>Arc Resistance (Tungsten Electrodes)</td>
<td>D 495</td>
<td>s</td>
<td>76</td>
<td></td>
</tr>
<tr>
<td>Comparative Tracking Index</td>
<td>D 3638</td>
<td>V</td>
<td>400</td>
<td></td>
</tr>
</tbody>
</table>

* These items are provided as general information only. They are approximate values and are not part of the product specifications.

** Flammability results are based on small-scale laboratory tests for purposes of relative comparison and are not intended to reflect the hazards presented by this or any other material under actual fire conditions.

a Subjected to one or more of the following tests: ultraviolet light, water exposure or immersion in accordance with UL746C, where the acceptability for use is to be determined by Underwriters Laboratories Inc.

Dry as Molded: Refers to a moisture content less than 0.2% by weight.
Conditioned: Refers to an equilibrium moisture content in a standard laboratory atmosphere of 73°F and 50% relative humidity.

Page 3 of 4 — Document contains important information and must be read in its entirety.
Note: The information contained in this publication is current as of May 2005. Please contact LANXESS Corporation to determine whether this publication has been revised.

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# Overview of materials for Nylon 66/6, 30% Glass Fiber Reinforced

**Categories:** Polymer, Thermoplastic; Nylon (Polyamide PA); Nylon 6:6; Nylon 66/6, 30% Glass Fiber Reinforced

**Material** This property data is a summary of similar materials in the MatWeb database for the category "Nylon 66/6, 30% Glass Fiber Reinforced". Specific grades with glass content between 25% and 34% are included. Each property range of values reported is minimum and maximum values of appropriate MatWeb entries. The comments report the average value, and number of data points used to calculate the average. The values are not necessarily typical of any specific grade, especially less common values and those that can be most affected by additives or processing methods.

**Vendors:** Click here to view all available suppliers for this material.

Please [click here](#) if you are a supplier and would like information on how to add your listing to this material.

## Physical Properties

<table>
<thead>
<tr>
<th>Property</th>
<th>Metric</th>
<th>English</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>1.23 - 1.62 g/cc</td>
<td>0.0444 - 0.0582 lb/in³</td>
<td>Average value: 1.39 g/cc Grade Count:112</td>
</tr>
<tr>
<td>Water Absorption</td>
<td>0.500 - 7.000 %</td>
<td>0.000 - 0.013 lb/in²</td>
<td>Average value: 3.03 % Grade Count:12</td>
</tr>
<tr>
<td>Moisture Absorption at Equilibrium</td>
<td>1.00 - 1.250 %</td>
<td>0.050 - 0.075 lb/in²</td>
<td>Average value: 2.83 % Grade Count:13</td>
</tr>
<tr>
<td>@ Temperature 70.0 - 70.0°C</td>
<td>1.00 - 1.250 %</td>
<td>0.050 - 0.075 lb/in²</td>
<td>Average value: 1.81 % Grade Count:14</td>
</tr>
<tr>
<td>Water Absorption at Saturation</td>
<td>3.50 - 6.50 %</td>
<td>0.020 - 0.037 lb/in²</td>
<td>Average value: 1.65 % Grade Count:15</td>
</tr>
<tr>
<td>Linear Mold Shrinkage, Transverse</td>
<td>0.000109 - 0.0200 cm/cm</td>
<td>0.000045 - 0.00080 in/in</td>
<td>Average value: 0.00045 cm/cm Grade Count:16</td>
</tr>
<tr>
<td>Melt Flow</td>
<td>2.00 - 45.0 g/10 min</td>
<td>2.00 - 45.0 g/10 min</td>
<td>Average value: 0.00670 cm/cm Grade Count:17</td>
</tr>
</tbody>
</table>

## Mechanical Properties

<table>
<thead>
<tr>
<th>Property</th>
<th>Metric</th>
<th>English</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ball Indentation Hardness</td>
<td>80.0 - 270 Mpa</td>
<td>11600 - 39200 psi</td>
<td>Average value: 184 Mpa Grade Count:18</td>
</tr>
<tr>
<td>Tensile Strength, Ultimate</td>
<td>45.0 - 200 Mpa</td>
<td>6530 - 29000 psi</td>
<td>Average value: 137 Mpa Grade Count:19</td>
</tr>
<tr>
<td>Tensile Strength, Yield</td>
<td>70.0 - 162 Mpa</td>
<td>10000 - 25000 psi</td>
<td>Average value: 112 Mpa Grade Count:20</td>
</tr>
<tr>
<td>Elongation at Break</td>
<td>1.80 - 35.0 %</td>
<td>1.80 - 35.0 %</td>
<td>Average value: 4.27 % Grade Count:21</td>
</tr>
<tr>
<td>Elongation at Yield</td>
<td>4.00 - 6.00 %</td>
<td>4.00 - 6.00 %</td>
<td>Average value: 4.38 % Grade Count:22</td>
</tr>
<tr>
<td>Modulus of Elasticity</td>
<td>1.80 - 99.4 Gpa</td>
<td>261 - 14000 ksi</td>
<td>Average value: 8.85 Gpa Grade Count:23</td>
</tr>
<tr>
<td>Flexural Yield Strength</td>
<td>56.0 - 275 Mpa</td>
<td>8120 - 39900 psi</td>
<td>Average value: 199 Mpa Grade Count:24</td>
</tr>
<tr>
<td>Flexural Modulus</td>
<td>3.70 - 10.5 Gpa</td>
<td>537 - 1530 ksi</td>
<td>Average value: 7.74 Gpa Grade Count:25</td>
</tr>
<tr>
<td>Poissons Ratio</td>
<td>0.320 - 0.400</td>
<td>0.320 - 0.400</td>
<td>Average value: 0.352 Grade Count:26</td>
</tr>
<tr>
<td>Izod Impact, Notched</td>
<td>0.550 - 1.500 J/cm</td>
<td>1.01 - 2.81 ft-lb/in</td>
<td>Average value: 1.13 J/cm Grade Count:27</td>
</tr>
<tr>
<td>Izod Impact, Notched (ISO)</td>
<td>4.00 - 21.0 kJ/m²</td>
<td>1.90 - 9.99 ft-lb/in²</td>
<td>Average value: 11.5 kJ/m² Grade Count:28</td>
</tr>
<tr>
<td>@ Temperature -40.0 - 22.0 °C</td>
<td>7.20 - 11.0 kJ/m²</td>
<td>3.43 - 5.21 ft-lb/in²</td>
<td>Average value: 8.48 kJ/m² Grade Count:29</td>
</tr>
<tr>
<td>Charpy Impact, Unnotched</td>
<td>2.50 J/cm² - NB</td>
<td>11.8 ft-lb/in² - NB</td>
<td>Average value: 6.44 J/cm² Grade Count:30</td>
</tr>
<tr>
<td>@ Temperature -40.0 - 22.0 °C</td>
<td>2.40 J/cm² - NB</td>
<td>11.4 ft-lb/in² - NB</td>
<td>Average value: 5.14 J/cm² Grade Count:31</td>
</tr>
<tr>
<td>Charpy Impact, Notched</td>
<td>0.599 - 8.50 J/cm²</td>
<td>1.90 - 30.5 ft-lb/in²</td>
<td>Average value: 1.22 J/cm² Grade Count:32</td>
</tr>
<tr>
<td>@ Temperature -40.0 - 22.0 °C</td>
<td>0.200 - 5.50 J/cm²</td>
<td>0.952 - 26.2 ft-lb/in²</td>
<td>Average value: 0.856 J/cm² Grade Count:33</td>
</tr>
</tbody>
</table>

## Electrical Properties

<table>
<thead>
<tr>
<th>Property</th>
<th>Metric</th>
<th>English</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrical Resistivity</td>
<td>1.00e+9 - 1.00e+15 ohm-cm</td>
<td>1.00e+9 - 1.00e+15 ohm-cm</td>
<td>Average value: 1.72e+14 ohm-cm Grade Count:34</td>
</tr>
<tr>
<td>Surface Resistance</td>
<td>1.00e+10 - 1.00e+15 ohm</td>
<td>1.00e+10 - 1.00e+15 ohm</td>
<td>Average value: 1.29e+14 ohm-cm Grade Count:35</td>
</tr>
<tr>
<td>Dielectric Constant</td>
<td>3.00 - 4.30</td>
<td>3.00 - 4.30</td>
<td>Average value: 3.69 Grade Count:36</td>
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<tr>
<td>Dielectric Strength</td>
<td>12.0 - 60.0 kV/mm</td>
<td>305 - 1520 kV/in</td>
<td>Average value: 30.2 kV/mm Grade Count:37</td>
</tr>
<tr>
<td>Dissipation Factor</td>
<td>0.00500 - 0.1000</td>
<td>0.00500 - 0.1000</td>
<td>Average value: 0.026 Grade Count:38</td>
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<tr>
<td>Arc Resistance</td>
<td>60.0 - 120 sec</td>
<td>60.0 - 120 sec</td>
<td>Average value: 90.0 sec Grade Count:39</td>
</tr>
<tr>
<td>Comparative Tracking Index</td>
<td>175 - 650 V</td>
<td>175 - 650 V</td>
<td>Average value: 534 V Grade Count:40</td>
</tr>
<tr>
<td>Hot Wire Ignition, HWI</td>
<td>120 sec</td>
<td>120 sec</td>
<td>Average value: 120 sec Grade Count:41</td>
</tr>
<tr>
<td>High Amp Arc Ignition, HAI</td>
<td>120 arcs</td>
<td>120 arcs</td>
<td>Average value: 120 arcs Grade Count:42</td>
</tr>
<tr>
<td><strong>Material Properties</strong></td>
<td><strong>Metric</strong></td>
<td><strong>English</strong></td>
<td><strong>Comments</strong></td>
</tr>
<tr>
<td>-------------------------------------</td>
<td>------------</td>
<td>-------------</td>
<td>--------------</td>
</tr>
<tr>
<td><strong>CTE, Linear</strong></td>
<td>14.0 - 20.0 μm/m·°C</td>
<td>0.78 - 1.11 μm/in·°F</td>
<td>Average value: 15.3 μm/m·°C Grade Count 6</td>
</tr>
<tr>
<td><strong>CTE, Linear, Transverse to Flow</strong></td>
<td>10.0 - 17.0 μm/m·°C</td>
<td>0.56 - 1.11 μm/in·°F</td>
<td>Average value: 11.3 μm/m·°C Grade Count 6</td>
</tr>
<tr>
<td><strong>Specific Heat Capacity</strong></td>
<td>2.00 - 2.00 J/g·°C</td>
<td>0.478 - 0.478 BTU/lb·°F</td>
<td>Average value: 2.00 J/g·°C Grade Count 1</td>
</tr>
<tr>
<td><strong>Thermal Conductivity</strong></td>
<td>0.250 - 0.250 W/m·K</td>
<td>1.74 - 1.74 BTU/hr·ft·°F</td>
<td>Average value: 0.250 W/m·K Grade Count 1</td>
</tr>
<tr>
<td><strong>Melting Point</strong></td>
<td>260 - 312 °C</td>
<td>475 - 572 °F</td>
<td>Average value: 263 °C Grade Count 81</td>
</tr>
<tr>
<td><strong>Deflection Temperature at 0.46 MPa (66 psi)</strong></td>
<td>215 - 300 °C</td>
<td>392 - 545 °F</td>
<td>Average value: 246 °C Grade Count 21</td>
</tr>
<tr>
<td><strong>Vicat Softening Point</strong></td>
<td>50.0 - 204 °C</td>
<td>122 - 399 °F</td>
<td>Average value: 139 °C Grade Count 35</td>
</tr>
<tr>
<td><strong>Flammability, UL94</strong></td>
<td>HB - HB</td>
<td>HB - HB</td>
<td>Grade Count 1</td>
</tr>
<tr>
<td><strong>Flame Spread</strong></td>
<td>80.0 mm/min</td>
<td>0.00 in/min</td>
<td>Average value: 80.0 mm/min Grade Count 3</td>
</tr>
<tr>
<td><strong>Oxygen Index</strong></td>
<td>23.0 - 42.0 %</td>
<td>23.0 - 42.0 %</td>
<td>Average value: 34.5 % Grade Count 12</td>
</tr>
<tr>
<td><strong>Glow Wire Test</strong></td>
<td>650 - 960 °C</td>
<td>1200 - 1760 °F</td>
<td>Average value: 850 °C Grade Count 18</td>
</tr>
</tbody>
</table>

Some of the above values may have been converted from their original units and/or rounded in order to display the information in a consistent format. Use caution when using more precise data for scientific or engineering calculations. Click here to view all the properties for this material as they were originally entered into MatWeb.
APPENDIX K: Global Ocean Design Existing Sphere Test Results

APPENDIX K-1: 1 Kilometer Sphere

**10-2100-NG - Atlantic Floats Denmark A/S**

**Atlantic Floats**

Item no. 10-2100-NG

Atlantic trawl floats are made from the best materials available, and are designed to withstand heavy blows and high pressure.

<table>
<thead>
<tr>
<th>Item No.</th>
<th>10-2100-NG</th>
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</thead>
<tbody>
<tr>
<td>Diameter</td>
<td>10&quot; / 254 mm</td>
</tr>
<tr>
<td>Volume</td>
<td>8 L</td>
</tr>
<tr>
<td>Weight</td>
<td>3460 g</td>
</tr>
<tr>
<td>Maximum depth</td>
<td>2900 m</td>
</tr>
<tr>
<td>Working depth (4h)</td>
<td>2100 m</td>
</tr>
<tr>
<td>Buoyancy</td>
<td>5350 g</td>
</tr>
<tr>
<td>Impact strength</td>
<td>40 kgf</td>
</tr>
<tr>
<td>Colour</td>
<td>Green</td>
</tr>
<tr>
<td>Shipping data per box / pallet</td>
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</tr>
<tr>
<td>Quantity, box / pallet</td>
<td>6 / 96 pcs</td>
</tr>
<tr>
<td>Weight, box / pallet</td>
<td>22 / 369 kg</td>
</tr>
<tr>
<td>Measurements, box / pallet</td>
<td>0.13 / 1.93 m³</td>
</tr>
</tbody>
</table>

*Buoyancy has been measured in fresh water. In salt water the buoyancy increases.*
# Pressure Test Record

<table>
<thead>
<tr>
<th>Customer:</th>
<th>Global Ocean Designs SO 401351</th>
<th>Test Date:</th>
<th>12-8-2016</th>
</tr>
</thead>
<tbody>
<tr>
<td>Item Tested: (Model No.)</td>
<td>Boyancy Ball</td>
<td>Item Tested: (Serial No.)</td>
<td>N/A</td>
</tr>
<tr>
<td>Test Pressure:</td>
<td>1500 psi</td>
<td>No. of Cycles</td>
<td>1 @ 8 hrs.</td>
</tr>
<tr>
<td>Sidus Technician:</td>
<td>Nick Ruiz</td>
<td>Witnessed By:</td>
<td>Ruben Aguirre</td>
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<table>
<thead>
<tr>
<th>Test Equipment</th>
<th>Gauge</th>
<th>Pressure Vessel</th>
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</thead>
<tbody>
<tr>
<td>Make</td>
<td>Crystal Pressure</td>
<td>HYSTAT</td>
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<tr>
<td>Model</td>
<td>M1 Digital</td>
<td>SW53555</td>
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<tr>
<td>Serial Number</td>
<td>470449</td>
<td>A.11303</td>
</tr>
<tr>
<td>Calibration Date</td>
<td>8-31-2016</td>
<td>N/A</td>
</tr>
<tr>
<td>Next Cal Due Date</td>
<td>8-31-2017</td>
<td>N/A</td>
</tr>
<tr>
<td>Pressure Range</td>
<td>10-10,000 psi</td>
<td>10,000 psi max.</td>
</tr>
</tbody>
</table>

## Test Data

<table>
<thead>
<tr>
<th>Cycle No.</th>
<th>Target Pressure</th>
<th>Actual Pressure</th>
<th>Start Time (At pressure)</th>
<th>Stop Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1500 psi</td>
<td>1510 psi</td>
<td>8:30 AM</td>
<td>2:30 PM</td>
</tr>
<tr>
<td>2</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
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</tr>
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</tr>
<tr>
<td>8</td>
<td></td>
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<td>9</td>
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</tr>
<tr>
<td>10</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

## Results and Remarks

No visual imperfections of unit, no defects noted. Unit appears same shape/configuration after pressure test vs as was prior to test=Pass

## Test Operator

<table>
<thead>
<tr>
<th>Name (print)</th>
<th>Signature</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nick Ruiz/Ruben Aguirre</td>
<td>Nick Ruiz/Ruben Aguirre</td>
<td>12-08-2016</td>
</tr>
</tbody>
</table>

## QC Approval

<table>
<thead>
<tr>
<th>Name (print)</th>
<th>Signature</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carl Wilson</td>
<td>Carl Wilson</td>
<td>12-08-2016</td>
</tr>
</tbody>
</table>
## Pressure Test Record

<table>
<thead>
<tr>
<th>Customer:</th>
<th>GLOBAL OCEAN DESIGNS SO 401351</th>
<th>Test Date:</th>
<th>09/06/16</th>
</tr>
</thead>
<tbody>
<tr>
<td>Item Tested: (Model No.)</td>
<td>BOYANCY BALLS</td>
<td>Item Tested: (Serial No.)</td>
<td>N/A</td>
</tr>
<tr>
<td>Test Pressure:</td>
<td>1500</td>
<td>No. of Cycles</td>
<td>2 @ 1HR &amp; 30 MIN HOLD</td>
</tr>
<tr>
<td>Sidus Technician:</td>
<td>NICK RUIZ</td>
<td>Witnessed By:</td>
<td>ALLAN GRAY</td>
</tr>
</tbody>
</table>

### Test Equipment
- **Make**: Crystal Pressure
- **Model**: M1 Digital
- **Serial Number**: 470449
- **Calibration Date**: 8-31-2016
- **Next Cal Due Date**: 8-31-2017
- **Pressure Range**: 10-10,000 psi

### Pressure Vessel
- **Make**: HYSTAT
- **Model**: SW53555
- **Serial Number**: A.11303
- **Calibration Date**: N/A
- **Next Cal Due Date**: N/A
- **Pressure Range**: 10,000 psi max.

### Test Data

<table>
<thead>
<tr>
<th>Cycle No</th>
<th>Target Pressure</th>
<th>Actual Pressure</th>
<th>Start Time (At pressure)</th>
<th>Stop Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1500</td>
<td>1513</td>
<td>9:43 AM</td>
<td>10:45 AM</td>
</tr>
<tr>
<td>2</td>
<td>1500</td>
<td>1520</td>
<td>11:00 AM</td>
<td>12:07 PM</td>
</tr>
<tr>
<td>3</td>
<td>10000</td>
<td>10007</td>
<td>12:45 PM</td>
<td>1:15 PM</td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
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<tr>
<td>10</td>
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</tbody>
</table>

### Results and Remarks

UNIT DID NOT BREAK OR SEPARATE DURING ALL TEST CYCLES

### Test Operator
- **Name (print)**: NICK RUIZ
- **Signature**: [Signature]
- **Date**: 9-14-16

### QC Approval
- **Name (print)**: CARL WILSON
- **Signature**: [Signature]
- **Date**: 9-14-16
# Pressure Test Record

**Customer:**
GLOBAL OCEAN DESIGNS  
SO 401351  

**Test Date:**
09/07/16  

**Item Tested:**
BOYANCY BALLS  

**Item Tested:**
(Serial No.)
N/A  

**Test Pressure:**
1500  

**No. of Cycles:**
1 @ 8 HR  

**Sidus Technician:**
NICK RUIZ  

**Witnessed By:**
ALLAN GRAY  

<table>
<thead>
<tr>
<th>Test Equipment</th>
<th>Gauge</th>
<th>Pressure Vessel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Make</td>
<td>Crystal Pressure</td>
<td>HYSTAT</td>
</tr>
<tr>
<td>Model</td>
<td>M1 Digital</td>
<td>SW53555</td>
</tr>
<tr>
<td>Serial Number</td>
<td>470449</td>
<td>A.11303</td>
</tr>
<tr>
<td>Calibration Date</td>
<td>8-31-2016</td>
<td>N/A</td>
</tr>
<tr>
<td>Next Cal Due Date</td>
<td>8-31-2017</td>
<td>N/A</td>
</tr>
<tr>
<td>Pressure Range</td>
<td>10-10,000 psi</td>
<td>10,000 psi max.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cycle No</th>
<th>Target Pressure</th>
<th>Actual Pressure</th>
<th>Start Time (At pressure)</th>
<th>Stop Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1500</td>
<td>1513</td>
<td>9:00 AM</td>
<td>5:00 PM</td>
</tr>
<tr>
<td>2</td>
<td></td>
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<td>10</td>
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<td></td>
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</tr>
</tbody>
</table>

**Results and Remarks**

UNIT DID NOT BREAK OR SEPARATE DURING TEST CYCLE

**Test Operator**

<table>
<thead>
<tr>
<th>Name (print)</th>
<th>Signature</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>NICK RUIZ</td>
<td></td>
<td>9-14-16</td>
</tr>
</tbody>
</table>

**QC Approval**

<table>
<thead>
<tr>
<th>Name (print)</th>
<th>Signature</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>CARL WILSON</td>
<td></td>
<td>9-14-16</td>
</tr>
</tbody>
</table>
APPENDIX K-2: 2 Kilometer Sphere

Atlantic Floats

Item no. 10-3800-NG
Atlantic trawl floats are made from the best materials available, and are designed to withstand high impact and high pressure.

THE STRONGEST PLASTIC FLOAT IN THE WORLD / LONG-TERM- LOAD

<table>
<thead>
<tr>
<th>Item no.</th>
<th>10-3800-NG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diameter</td>
<td>10&quot; / 254 mm</td>
</tr>
<tr>
<td>Volume</td>
<td>8 L</td>
</tr>
<tr>
<td>Weight</td>
<td>3750 g</td>
</tr>
<tr>
<td>Maximum depth</td>
<td>4900 m</td>
</tr>
<tr>
<td>Working depth (th)</td>
<td>3800 m</td>
</tr>
<tr>
<td>Working depth 1 year</td>
<td>2300 m</td>
</tr>
<tr>
<td>Buoyancy</td>
<td>5120 g</td>
</tr>
<tr>
<td>Impact strength</td>
<td>60 kNm</td>
</tr>
<tr>
<td>Colour</td>
<td>Green or White</td>
</tr>
<tr>
<td>Shipping data per box / pallet:</td>
<td></td>
</tr>
<tr>
<td>Quantity, box / pallet</td>
<td>6 / 96 pcs</td>
</tr>
<tr>
<td>Weight, box / pallet</td>
<td>22.5 / 380 kg</td>
</tr>
<tr>
<td>Measurement, box / pallet</td>
<td>0.13 / 1.91 m²</td>
</tr>
</tbody>
</table>
Atlantic trawl floats are made from the best materials available, and are designed to withstand high impact and high pressure.

**THE STRONGEST PLASTIC FLOAT IN THE WORLD / LONG-TERM-LOAD**

<table>
<thead>
<tr>
<th>Item no.</th>
<th>10-3800-NG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diameter</td>
<td>10&quot; / 254 mm</td>
</tr>
<tr>
<td>Volume</td>
<td>8 l</td>
</tr>
<tr>
<td>Weight</td>
<td>3750 g</td>
</tr>
<tr>
<td>Maximum depth</td>
<td>NO WAY 4500 m</td>
</tr>
<tr>
<td>Working depth (4h)</td>
<td>NO WAY 3800 m</td>
</tr>
<tr>
<td>Working depth 1 year</td>
<td>PROBABLY 2300 m</td>
</tr>
<tr>
<td>Buoyancy</td>
<td>5120 g</td>
</tr>
<tr>
<td>Impact strength</td>
<td>60 kgm</td>
</tr>
<tr>
<td>Colour</td>
<td>Green or White</td>
</tr>
</tbody>
</table>

**Shipping data per box / pallet:**
- Quantity, box / pallet: 6 / 96 pcs
- Weight, box / pallet: 22.5 / 380 kg
- Measurement, box / pallet: 0.13 / 1.91 m³

*Buoyancy has been measured in fresh water. In salt water the buoyancy increases.*

---

8/21/20

2 samples white implemented at 4700 PSI = 3175 m
4800 PSI = 3243 m

Previous:
3 olive samples 4400 = 2973 m
4500 = 2939 m
4300 = 2905 m
August 21, 2020

Customer: GLOBAL OCEAN DESIGN

Sidus Quotation number: 604085

Test all spheres separately to avoid sympathetic implosion.

**Test 1 (White sphere W1):**

10" plastic sphere (W1) (10-3800-NG) to break. Pressurize at 7.5 psi/sec (5m/sec; ~300m/minute). Interior will be blocked to reduce implodable force. I hope to see in the area of 4km, but we’ll see! Manufacturer data sheet attached.

Recover shards from chamber and place in separate bucket for later customer evaluation.

**Test 2 (White sphere W2):**

10" plastic sphere (W2) (10-3800-NG) to break. Pressurize at 7.5 psi/sec (5m/sec; ~300m/minute). Interior will be blocked to reduce implodable force. I hope to see in the area of 4km, but we’ll see! Manufacturer data sheet attached.

Recover shards from chamber and place in separate bucket for later customer evaluation.

**Test 3**

8" plastic sphere (08-1200-CO) to break. Pressurize at 7.5 psi/sec (5m/sec; ~300m/minute). Max depth is listed as 1650m (~5400psi)

This sphere is fused and cannot be opened to add blocking to the interior. Manufacturer data sheet attached.

Recover shards from chamber and place in separate bucket for later customer evaluation.

**Test 4**

10" green plastic sphere with transducer to 1630psi (1100m). Pressurize at 7.5 psi/sec (5m/sec; ~300m/minute). Interior will be blocked to reduce implodable force. Hold 30 minutes. Depressurize at 7.5 psi/sec (5m/sec; ~300m/minute).

Do Not Crush!

Test report requested.
## Post Pressure Test Inspection

<table>
<thead>
<tr>
<th>Housing</th>
<th>PASS / FAIL / NA</th>
<th>Free of Water Intrusion</th>
<th>PASS / FAIL / NA</th>
<th>Post Functionality Test</th>
<th>PASS / FAIL / NA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Window/Lens</td>
<td>PASS / FAIL / NA</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

## Test Report:

Test 1. The interior blocking beads created a significant cleanup problem. Vessel had to be cleared before resuming. Attempted to use cloth bag (pillow case) to contain the spread of material.

Test 2. Unit 2 had a trapdoor fracture and the cloth is stuck in the remnants.

Test 3. Circular implosion, interesting

Test 4. Unremarkable.

Pressure Test Technician: ___________________________ Date: ________________

Signature: ________________________________________

Pressure Test Witness: ___________________________ Date: 08-21-20

Signature: ________________________________________
APPENDIX K-3: 8” Buoyancy Sphere Side-Floats

08-1200-CO

Atlantic Floats

Item no. 08-1200-CO

Atlantic trawl floats are made from the best materials available, and are designed to withstand heavy blows and high pressure.

Trawl floats with centre hole, designed for general trawling. Strong and durable.

<table>
<thead>
<tr>
<th>Item no.</th>
<th>08-1200-CO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diameter</td>
<td>8 / 200 mm</td>
</tr>
<tr>
<td>Volume</td>
<td>.41</td>
</tr>
<tr>
<td>Weight</td>
<td>1500 g</td>
</tr>
<tr>
<td>Maximum depth</td>
<td>1650 m</td>
</tr>
<tr>
<td>Working depth (min)</td>
<td>1400 m</td>
</tr>
<tr>
<td>Buoyancy</td>
<td>2400 p</td>
</tr>
<tr>
<td>Impact strength</td>
<td>45 kgm</td>
</tr>
<tr>
<td>Hole size</td>
<td>21 mm</td>
</tr>
<tr>
<td>Lacing hole</td>
<td>Y-curve</td>
</tr>
<tr>
<td>Colour</td>
<td>Orange</td>
</tr>
<tr>
<td>Shipping data per box / pallet:</td>
<td></td>
</tr>
<tr>
<td>Quantity, box / pallet</td>
<td>18 / 216 pcs</td>
</tr>
<tr>
<td>Weight, box / pallet</td>
<td>20 / 1000 kg</td>
</tr>
<tr>
<td>Measurement, box / pallet</td>
<td>0.143 / 1.716 m²</td>
</tr>
<tr>
<td>Item no.</td>
<td>08-1200-CO</td>
</tr>
<tr>
<td>-----------------</td>
<td>------------</td>
</tr>
<tr>
<td>Diameter</td>
<td>67 x 300 mm</td>
</tr>
<tr>
<td>Volume</td>
<td>4L</td>
</tr>
<tr>
<td>Weight</td>
<td>1200 g</td>
</tr>
<tr>
<td>Maximum depth</td>
<td>1650 m</td>
</tr>
<tr>
<td>Working depth</td>
<td>1200 m</td>
</tr>
<tr>
<td>Buoyancy</td>
<td>2000 g</td>
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<tr>
<td>Impact strength</td>
<td>35 kN</td>
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<tr>
<td>Hole size</td>
<td>21 mm</td>
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<tr>
<td>Lacing hole</td>
<td>Centre</td>
</tr>
<tr>
<td>Colour</td>
<td>Orange</td>
</tr>
</tbody>
</table>

**Shipping data per box / pallet:**
- 18 / 216 pcs
- 38 / 336 kg
- 0.143 / 1.72 m³

*Buoyancy has been measured in fresh water. In salt water the buoyancy increases.*
## Pressure Test Certification

### Customer: Global Ocean Design

<table>
<thead>
<tr>
<th>Item Model Number:</th>
<th>Pressure Test #: 1098</th>
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<tbody>
<tr>
<td>Max Test Pressure:</td>
<td>6000 psi</td>
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### Test Equipment

<table>
<thead>
<tr>
<th>Make</th>
<th>Crystal Engineering</th>
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<tbody>
<tr>
<td>Model</td>
<td>M1-10kpsi</td>
</tr>
<tr>
<td>Serial Number</td>
<td>470449</td>
</tr>
<tr>
<td>Calibration Date</td>
<td>11/04/2019</td>
</tr>
<tr>
<td>Calibration Due Date</td>
<td>11/04/2020</td>
</tr>
<tr>
<td>Pressure Range</td>
<td>0-10,000 psi</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Pressure Vessel</th>
<th>Hystat</th>
</tr>
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<tbody>
<tr>
<td>Serial Number</td>
<td>LB-33.3-690-305-SWS53555</td>
</tr>
<tr>
<td>Calibration Date</td>
<td>August 2014</td>
</tr>
<tr>
<td>Calibration Due Date</td>
<td>N/A</td>
</tr>
<tr>
<td>Pressure Range</td>
<td>0-10,000 psi</td>
</tr>
</tbody>
</table>

### Pressure Test Data

<table>
<thead>
<tr>
<th>Cycle #</th>
<th>Starting Pressure</th>
<th>Target Pressure</th>
<th>Start Time</th>
<th>End Time</th>
<th>Hold Time</th>
<th>Functionality Test Under Pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>4800</td>
<td>0840</td>
<td>0904</td>
<td>0</td>
<td>PASS / FAIL / NA</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>4700</td>
<td>1023</td>
<td>1032</td>
<td>0</td>
<td>PASS / FAIL / NA</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>2900</td>
<td>1048</td>
<td>1056</td>
<td>0</td>
<td>PASS / FAIL / NA</td>
</tr>
<tr>
<td>4</td>
<td>0</td>
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<td>1123</td>
<td>1159</td>
<td>30</td>
<td>PASS / FAIL / NA</td>
</tr>
<tr>
<td></td>
<td>1530</td>
<td>0</td>
<td>1200</td>
<td>1204</td>
<td></td>
<td>PASS / FAIL / NA</td>
</tr>
<tr>
<td>5</td>
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<td></td>
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</table>

914000000 - Revision G 05/18/2020
### Post Pressure Test Inspection

<table>
<thead>
<tr>
<th>Housing</th>
<th>PASS / FAIL / NA</th>
<th>Free of Water Intrusion</th>
<th>PASS / FAIL / NA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Window/Lens</td>
<td>PASS / FAIL / NA</td>
<td>Post Functionality Test</td>
<td>PASS / FAIL / NA</td>
</tr>
</tbody>
</table>

### Test Report:

Test 1. The interior blocking beads created a significant cleanup problem. Vessel had to be cleared before resuming. Attempted to use cloth bag (pillow case) to contain the spread of material.

Test 2. Unit 2 had a trapdoor fracture and the cloth is stuck in the remnants.

Test 3. Circular implosion, interesting

Test 4. Unremarkable.

---

Pressure Test Technician: ____________________________  Date: __________

Signature: _________________________________________

Pressure Test Witness:  Do o Nguyen  Date: 08-21-20

Signature: _________________________________________
Dear Jackie,

I just spoke with Production and we can change the pressure testing to tomorrow at 8am. If you drop them off today you can just deliver them to the back door someone will be there until 4pm, if not you can bring them in the morning at 8am and the Techs will be here.

I have attached the quote again, can I get a PO for it so I can send you an order confirmation.

Copied from previous email: see below

Dear Jackie,

I received the machined spheres last night. I could have them ready to deliver this afternoon if you still have time available in the chamber tomorrow.

There will be three tests tomorrow, and if I hustle, possibility 4.

Tests 1 and 2:
10" plastic sphere (10-3800-NG) to break. Pressurize at 7.5 psi/sec (5m/sec; ~300m/minute). Interior will be blocked to reduce implodable force. I hope to see in the area of 4km, but we'll see! Manufacturer data sheet attached.

Test 3
8" plastic sphere (08-1200-CO) to break. Pressurize at 7.5 psi/sec (5m/sec; ~300m/minute). Max depth is listed as 1650m (~5400psi). 24.42 psi. This sphere is fused and cannot be opened to add blocking to the interior. Manufacturer data sheet attached.

Test 4
10" plastic sphere with transducer to 1630psi (1100m). Pressurize at 7.5 psi/sec (5m/sec; ~300m/minute). Interior will be blocked to reduce implodable force. Hold 30 minutes. Depressurize at 7.5 psi/sec (5m/sec; ~300m/minute).

Test report requested.

Thanks,

Kevin
APPENDIX L: Excel Spreadsheet for Unit Tracking in Abaqus

Abaqus Sheet

On this sheet, yellow numbers are constant values innate to the sphere, green cells can be edited based on the model being analyzed, and red cells are results from other inputs and should not be edited.

### Material Database Sheet

This sheet contains critical material properties that can be pulled up in the Abaqus Sheet using the green “MATERIAL” drop down menu.
**APPENDIX M: Theoretical Sphere Analysis Hand-Calcs**

**Thick Pressure Vessels**

This page provides the sections on the analysis of thick pressure vessels from the “Stress Analysis Manual,” Air Force Flight Dynamics Laboratory, October 1986.

Other related chapters from the Air Force “Stress Analysis Manual” can be seen to the right.

---

**Analysis of Pressure Vessels**

1. Simple Thin Pressure Vessels
2. Stiffened Thin Pressure Vessels
3. Thick Pressure Vessels
4. Anisotropic Pressure Vessels

---

**Nomenclature for Thick Pressure Vessels**

- \( a \) = inside radius of thick sphere or cylinder
- \( b \) = outside radius of thick sphere or cylinder
- \( F_{mer} \) = meridional or axial stress
- \( F_r \) = radial stress
- \( F_{max} \) = maximum radial stress
- \( F_t \) = tangential or circumferential stress
- \( p_i \) = internal pressure
- \( p_o \) = external pressure
- \( r \) = cylindrical or polar coordinate

---

**8.4.2 Thick Spherical Pressure Vessels**

The radial and tangential stresses at a distance \( r \) from the center of a spherical pressure vessel of inner radius \( a \) and outer radius \( b \) are given by Equations (8-44) and (8-45).

\[
F_r = \frac{p_i b^3 (r^3 - a^3)}{r^3 (a^3 - b^3)} + \frac{p_i (b^3 - r^3)}{r^3 (a^3 - b^3)} \\
F_t = \frac{p_o b^3 (2r^3 + a^3)}{2r^3 (a^3 - b^3)} - \frac{p_i a^3 (2r^3 + b^3)}{2r^3 (a^3 - b^3)}
\]  
(8-44) \hspace{1cm} (8-45)

\[ b = 5 \text{ in}, \quad p_o = 2939.18 \text{ psi}; \quad p_i = -8.70226 \text{ psi}; \quad r = \alpha = 4.2\text{ in}; \]

\[ \alpha = 4.2\text{ in}; \quad F_r = \frac{p_o b^3 (r^3 - a^3) a^3}{(5\text{ in})^3 (4.2\text{ in})^3} \]

\[ F_t = \frac{p_o b^3 (2r^3 + a^3)}{2r^3 (a^3 - b^3)} - \frac{p_i a^3 (2r^3 + b^3)}{2r^3 (a^3 - b^3)}
\]

Note: Eqn 8-44 above from AFFDL has a typo in the yellow highlighted term which is added in my calculation in red below [11].
Find Principal Stresses using 3-D Mohr's Circle

\[ \sigma_r = 8.70226 \frac{\text{atm}}{\text{in}^2} \]
\[ \sigma_\theta = -10847.833 \frac{\text{atm}}{\text{in}^2} \]
\[ \sigma_\phi = -10847.833 \frac{\text{atm}}{\text{in}^2} \]

Since pressures add to act \( \perp \) to surfaces, Assume \( \tau_{rs} = \tau_{s\phi} = \tau_{\phi s} = 0 \)

\[ r = \theta \] Plane

\[ \sigma_{\theta r} = \frac{\sigma_r + \sigma_\theta}{2} = -5499.5654 \frac{\text{atm}}{\text{in}^2} \]
\[ R = \sqrt{(\sigma_r - \sigma_\theta)^2 + 4 \tau_{sr}^2} = 5428.2676 \frac{\text{atm}}{\text{in}^2} \]
\[ \sigma_{\text{max}} = \sigma_{\theta r} + R = 8.70226 \frac{\text{atm}}{\text{in}^2} \]
\[ \sigma_{\text{min}} = \sigma_{\theta r} - R = -10847.833 \frac{\text{atm}}{\text{in}^2} \]
\[ \tau_{\text{max}} = \frac{1}{2} | \sigma_{\text{max}} - \sigma_{\text{min}} | = 5428.2676 \frac{\text{atm}}{\text{in}^2} \]

\[ r = \phi \] Plane

\[ \sigma_{\phi r} = \frac{\sigma_r + \sigma_\phi}{2} = -5499.5654 \frac{\text{atm}}{\text{in}^2} \]
\[ R = \sqrt{(\sigma_r - \sigma_\phi)^2 + 4 \tau_{sr}^2} = 5428.2676 \frac{\text{atm}}{\text{in}^2} \]
\[ \sigma_{\text{max}} = \sigma_{\phi r} + R = 8.70226 \frac{\text{atm}}{\text{in}^2} \]
\[ \sigma_{\text{min}} = \sigma_{\phi r} - R = -10847.833 \frac{\text{atm}}{\text{in}^2} \]
\[ \tau_{\text{max}} = \frac{1}{2} | \sigma_{\text{max}} - \sigma_{\text{min}} | = 5428.2676 \frac{\text{atm}}{\text{in}^2} \]

\[ \theta = \phi \] Plane

\[ \sigma_{\theta \phi} = \frac{\sigma_\theta + \sigma_\phi}{2} = -10847.833 \frac{\text{atm}}{\text{in}^2} \]
\[ R = \sqrt{(\sigma_\theta - \sigma_\phi)^2 + 4 \tau_{\theta \phi}^2} = 0 \frac{\text{atm}}{\text{in}^2} \]
\[ \sigma_{\text{max}} = \sigma_{\theta \phi} + R = -10847.833 \frac{\text{atm}}{\text{in}^2} \]
\[ \sigma_{\text{min}} = \sigma_{\theta \phi} - R = -10847.833 \frac{\text{atm}}{\text{in}^2} \]
\[ \tau_{\text{max}} = \frac{1}{2} | \sigma_{\text{max}} - \sigma_{\text{min}} | = 0 \frac{\text{atm}}{\text{in}^2} \]

From Mohr's Circle above,

We can see the principal stresses are

\[ \sigma_{\text{max}} = 8.70226 \frac{\text{atm}}{\text{in}^2} \]
\[ \sigma_{\text{min}} = -10847.833 \frac{\text{atm}}{\text{in}^2} \]

and the maximum shear stress is

\[ \tau_{\text{max}} = 5428.2676 \frac{\text{atm}}{\text{in}^2} \]
<table>
<thead>
<tr>
<th>File Name Mesh #</th>
<th>Mesh #</th>
<th>Radial Node Spacing</th>
<th>Circumferential Node Spacing</th>
<th>Max. Maximum Principal Stress</th>
<th>Min. Minimum Principal Stress</th>
<th>Avg. Contact Opening</th>
<th>Max. Contact Pressure</th>
<th>Min. Contact Pressure</th>
<th>% Difference between Min. Min. Principal Stress</th>
<th>% Error from Theoretical</th>
<th>Theoretical</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>1</td>
<td>0.50</td>
<td>0.75</td>
<td>-8.75E+02</td>
<td>-1.05E+04</td>
<td>-1.42E-03</td>
<td>1.63E+04</td>
<td>9.68E+03</td>
<td></td>
<td></td>
<td>-3.11%</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>0.25</td>
<td>0.50</td>
<td>-5.82E+02</td>
<td>-1.05E+04</td>
<td>-8.93E-04</td>
<td>1.05E+04</td>
<td>9.57E+03</td>
<td>0.66%</td>
<td>2.46%</td>
<td>-1.08E+04</td>
</tr>
<tr>
<td>4</td>
<td>3</td>
<td>0.20</td>
<td>0.25</td>
<td>-6.52E+02</td>
<td>-1.05E+04</td>
<td>-4.63E-04</td>
<td>1.05E+04</td>
<td>9.52E+03</td>
<td>0.377%</td>
<td>2.10%</td>
<td>-1.08E+04</td>
</tr>
<tr>
<td>5</td>
<td>4</td>
<td>0.15</td>
<td>0.20</td>
<td>-3.63E+02</td>
<td>-1.05E+04</td>
<td>-3.69E-04</td>
<td>1.06E+04</td>
<td>9.49E+03</td>
<td>0.37%</td>
<td>1.73%</td>
<td>-1.08E+04</td>
</tr>
<tr>
<td>6</td>
<td>5</td>
<td>0.10</td>
<td>0.15</td>
<td>-2.25E+02</td>
<td>-1.07E+04</td>
<td>-2.77E-04</td>
<td>1.07E+04</td>
<td>9.46E+03</td>
<td>0.655%</td>
<td>1.08%</td>
<td>-1.08E+04</td>
</tr>
<tr>
<td>7</td>
<td>6</td>
<td>0.05</td>
<td>0.10</td>
<td>-1.08E+02</td>
<td>-1.07E+04</td>
<td>-1.82E-04</td>
<td>1.07E+04</td>
<td>9.62E+03</td>
<td>0.558%</td>
<td>0.533%</td>
<td>-1.08E+04</td>
</tr>
<tr>
<td>8</td>
<td>7</td>
<td>0.001</td>
<td>0.005</td>
<td>-1.05E+04</td>
<td>-1.05E+04</td>
<td>-9.19E-06</td>
<td>1.08E+04</td>
<td>9.39E+03</td>
<td>0.55%</td>
<td>-0.020%</td>
<td>-1.08E+04</td>
</tr>
</tbody>
</table>

**Excel Spreadsheet for Mesh Convergence Study**

**Diagram 1:**
- Min. Minimum Principal Stress
  - Mesh Convergence
  - Theoretical
  - Poly (Mesh Convergence)

**Diagram 2:**
- Percent Difference from Previous Mesh

**Diagram 3:**
- Percent Difference
  - From Last Mesh
  - From Theoretical
  - Poly (From Last Mesh)
  - Poly (From Theoretical)

**Diagram 4:**
- Percent Difference from Theoretical
APPENDIX O: Excel Spreadsheet for Wall Thickness Test

<table>
<thead>
<tr>
<th>Sphere #</th>
<th>Wall Thickness (in)</th>
<th>Max Pressure (psi)</th>
<th>Max Depth (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.8</td>
<td>3,954</td>
<td>2690.5</td>
</tr>
<tr>
<td>2</td>
<td>1.0</td>
<td>4593</td>
<td>3125.4</td>
</tr>
<tr>
<td>3</td>
<td>1.5</td>
<td>5827</td>
<td>3965.1</td>
</tr>
<tr>
<td>4</td>
<td>2.0</td>
<td>6695</td>
<td>4555.7</td>
</tr>
<tr>
<td>5</td>
<td>2.5</td>
<td>7325</td>
<td>4984.4</td>
</tr>
<tr>
<td>6</td>
<td>3.0</td>
<td>7790</td>
<td>5300.8</td>
</tr>
<tr>
<td>7</td>
<td></td>
<td></td>
<td>0.0</td>
</tr>
</tbody>
</table>

### Wall Thickness vs Max Depth

**Equation:**

\[ y = -377.02x^2 + 2596.3x + 884.34 \]

**R^2:** 0.9992

### Wall Thickness vs Max Depth

**Equation:**

\[ y = 2E-07x^2 - 0.001x + 1.9096 \]

**R^2:** 0.9983
APPENDIX P: Cylindrical Equatorial Ring SolidWorks Drawing
APPENDIX Q: Spherical Equatorial Ring + Mod. Hemisphere SolidWorks Drawings
APPENDIX R: Material Data Sheets for Composites

APPENDIX R-1: BT250E-1 Toray Epoxy

Toray BT250E-1

PRODUCT DATA SHEET

DESCRIPTION
Toray BT250E-1 resin system is a 121°C (250°F) cure epoxy prepreg system with excellent toughness and strength. It provides an outstanding surface finish under vacuum-bag/oven-cure only. The resin system, which is self-adhesive to honeycomb and foam core, is MIL-R-9300 qualified and makes a great choice for many applications in the low-to-medium-service temperature range.

FEATURES
- Excellent system for out of autoclave cure
- Toughened for good impact resistance
- MIL-R-9300 qualified
- Ideal for low-to-medium service temperature applications

TYPICAL APPLICATIONS
- Secondary aircraft structures
- Radomes with glass, quartz, and Kevlar®
- Reflectors
- Sporting goods
- Knee braces and other related medical items
- General purpose composites

SHELF LIFE

<table>
<thead>
<tr>
<th>Property</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tack Life</td>
<td>Up to 30 days at ambient</td>
</tr>
<tr>
<td>Out Life</td>
<td>Up to 30 days at ambient</td>
</tr>
<tr>
<td>Frozen Storage Life</td>
<td>12 months at -18°C (&lt; 0°F)</td>
</tr>
</tbody>
</table>

Tack life is the time during which the prepreg retains enough tack, drape, and handling for component lay-up.

Out life is the maximum time allowed at ambient temperature before cure. *Ambient is 18-22°C (65-72°F)

*Out life tested by SBS on 8-ply 15 x 15 cm (6 x 6") fabric laminate, cured in an out-of-autoclave/vacuum-bag only (OEA/VBO) environment with 914-948 mbar (27-28 inHg).

Users may need to separately evaluate out life limits on thicker, larger, and more complex parts.

TYPICAL NEAT RESIN PROPERTIES

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>1.17 g/cc</td>
</tr>
<tr>
<td>T&lt;sub&gt;s&lt;/sub&gt;</td>
<td>125°C (257°F)</td>
</tr>
<tr>
<td>Dielectric Constant</td>
<td>3.0 at 10 GHz</td>
</tr>
<tr>
<td>Loss Tangent</td>
<td>0.019 at 10 GHz</td>
</tr>
<tr>
<td>Moisture Absorption</td>
<td>2.0% after 24 hr water boil</td>
</tr>
<tr>
<td>Tensile Strength</td>
<td>75 MPa (10.9 ksi)</td>
</tr>
<tr>
<td>Tensile Modulus</td>
<td>3.0 GPa (0.44 Msi)</td>
</tr>
<tr>
<td>Tensile Strain</td>
<td>2.5%</td>
</tr>
<tr>
<td>Compression Strength</td>
<td>115 MPa (16.7 ksi)</td>
</tr>
<tr>
<td>Compression Modulus</td>
<td>2.8 GPa (0.4 Msi)</td>
</tr>
<tr>
<td>Flexural Strength</td>
<td>156 MPa (22.6 ksi)</td>
</tr>
<tr>
<td>Flexural Modulus</td>
<td>3.4 GPa (0.50 Msi)</td>
</tr>
<tr>
<td>Flexural Strain</td>
<td>5.5%</td>
</tr>
<tr>
<td>CTE</td>
<td>71 ppm/°C (39 ppm/°F)</td>
</tr>
<tr>
<td>Dielectric Constant at 10 GHz</td>
<td>3.26</td>
</tr>
<tr>
<td>Loss Tangent at 10 GHz on 4581 quartz</td>
<td>0.0081</td>
</tr>
</tbody>
</table>
## Electrical Properties of Composite Laminates

<table>
<thead>
<tr>
<th></th>
<th>BT250E-1 (7781 Gp)</th>
<th>C/X Band 8–18 GHz</th>
<th>Ku/K Band 18–26.5 GHz</th>
<th>Ka Band 26.5–40 GHz</th>
<th>Q &amp; U Band 40–60 GHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dielectric Constant</td>
<td>4.52</td>
<td>4.48</td>
<td>4.45</td>
<td>4.42</td>
<td></td>
</tr>
<tr>
<td>Loss Tangent</td>
<td>0.019</td>
<td>0.018</td>
<td>0.017</td>
<td>0.016</td>
<td></td>
</tr>
</tbody>
</table>

## Mechanical Properties

### Property

<table>
<thead>
<tr>
<th>Property</th>
<th>Condition</th>
<th>Methods</th>
<th>Results A</th>
<th>Results B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tensile Strength 0°</td>
<td>RTD</td>
<td>ASTM D 3039</td>
<td>767 MPa</td>
<td>112 ksi</td>
</tr>
<tr>
<td>Tensile Modulus 0°</td>
<td>RTD</td>
<td>ASTM D 3039</td>
<td>57.3 GPa</td>
<td>8.3 Msi</td>
</tr>
<tr>
<td>Compressive Strength 0°</td>
<td>RTD</td>
<td>ASTM D 3410</td>
<td>518 MPa</td>
<td>75 ksi</td>
</tr>
<tr>
<td>Compressive Modulus 0°</td>
<td>RTD</td>
<td>ASTM D 3410</td>
<td>55.2 GPa</td>
<td>8.0 Msi</td>
</tr>
<tr>
<td>Flexural Strength 0°</td>
<td>RTD</td>
<td>ASTM D 7264</td>
<td>752 MPa</td>
<td>109 ksi</td>
</tr>
<tr>
<td>Flexural Modulus 0°</td>
<td>RTD</td>
<td>ASTM D 7264</td>
<td>51.2 GPa</td>
<td>7.4 Msi</td>
</tr>
<tr>
<td>Short Beam Shear Strength</td>
<td>RTD</td>
<td>ASTM D 2344</td>
<td>61.9 MPa</td>
<td>9.0 ksi</td>
</tr>
</tbody>
</table>

* Laminate data - 781 Gp reinforcement, 300gsm FAW.
* All properties normalized to 60% fiber volume except ILSS (Fiber volume 40–50%)

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  - t: +44 (0)1773 530899

TORAY_BT250E-1_PDS_v3.1_2022-12-13
Page 3/5
**PRODUCT DATA SHEET**

**BT250E-1 Epoxy Prepreg: Cure cycle**

- **Held at 127°C (260°F) for 2 hours minimum.**
- **Part must be dwell at this temp. Oven temperature may not reflect actual part temperature.**

- **Apply 25 inHg vacuum minimum.**
- **Apply 1–3.4 bar, 30–100 psi pressure to autoclave (optional).**

**BT250E-1, Lot# 041801-3.3M2, 1.5°C (3°F)/min, 25°C–121°C (77°F–250°F), held 60 min**

- Min. min. temp. = 77°C
- Max. max. temp. = 121°C
- Cool time = 4,905 s (81.8 min.)
- Cool time at 121°C = 4,905 s (81.8 min.)
- Viscosity at gel time = 96,800,000 cp
PRODUCT DATA SHEET

EPOXY PREPREG, ADHESIVE, AND RESIN GUIDELINES AND HANDLING PROCEDURES

The following guidelines are provided to our customers to assure that best practices are used to attain the best results from Toray Advanced Composites epoxy products. Keep in mind that these procedures represent best practices for all composite prepreg and adhesive materials.

FREEZER STORAGE

Epoxy resin materials have good shelf life at room temperature; however, the life and performance of the material is best preserved with the following basic guidelines. Refer to the shelf life included in the product certifications. The epoxy material should be sealed in an airtight bag and kept frozen below -18°C (0°F) when not being used for longest life and most consistent performance. A good safety measure is to have a bag of desiccant (silica moisture absorber) in the core of the prepreg roll to assure the best protection from moisture ingress.

MOISTURE ABSORPTION AND SENSITIVITY

While very resistant to moisture absorption after cure, epoxies can be adversely affected by moisture uptake prior to cure. For this reason, all materials must be completely thawed to room temperature prior to opening the sealed bag to avoid condensation on the material. Also, it is good practice to keep prepreg and in-process hardware in a sealed bag or vacuum bag if it will be exposed to the atmosphere for long periods of time.

HANDLING OF MATERIALS

When handling any prepreg materials, one should always wear clean, powder-free latex gloves. This will assure that no hand oils are transferred to the prepreg and/or composite during processing. The presence of oils in the part could lead to problems in both mechanical and electrical performance of the part. This also guards against dermatitis that may occur with some users.

NONMETALLIC HONEYCOMB AND FOAM CORE USE

When using nonmetallic honeycomb and foam core materials for sandwich structures, the materials should always be dried in an oven prior to lay-up to drive off any moisture that may be in the core. The core should be cooled in the presence of a desiccant to avoid moisture uptake. Following drying, it is always best to use the material as soon as possible. Recommended core dry time/temp: 121°C (250°F) for 3–4 hours.

DEBULK LAY-UP MATERIAL SEQUENCE FROM TOOL SURFACE TO BAGGING MATERIALS

1. Bottom Tool
2. Non-porous FEP
3. Prepreg
4. Porous TX1040
5. Non-porous FEP
6. Caul plate
7. Breather (woven or thick breather)
8. Vacuum bag
9. Repeat above procedure

A robust debulking procedure is necessary to minimize entrapped air between plies as shown in Figure 1. Vacuum level should be at least at 27 inHg. BT250E-1 was debulked at ambient every 4 plies for 5–10 minutes. An additional ply of porous Teflon coated glass (TX1040) was used to help with the removal of entrapped air, and it was replaced every 2–3 cycles.
TYPICAL COMPOSITE LAMINATE STACKING SEQUENCE

List of Materials
1. Tool – aluminum, steel, Invar, composite (tool plates must be release coated or film covered).
2. Release coat or film – Frekote 700NC or 770NC, FEP, TEDLAR
   Lay-up part using standard debulking procedures
3. Silicone edge dams for cure – slightly thicker than laminate
4. Laminate
5. Release coat or film – Frekote 700NC or 770NC, FEP, TEDLAR
6. Caul plate – aluminum, steel, Invar, silicone rubber sheet (metal caulk plates must be release coated or wrapped)
7. 2.2 oz/yd² polyester breather, 1 or more
8. Vacuum bag
9. Vacuum sealant
10. Glass yarn string (alternatively or additionally breather may wrap over top of dam to contact edge)

Follow the provided Toray Advanced Composites cure cycle for the particular resin system.

Figure 1
### APPENDIX R-2: 584 3K-8HS HexForce Carbon Fiber

**HexForce™ 584 Carbon Fabric**

**Product Data**

<table>
<thead>
<tr>
<th>STYLE 584</th>
<th>US System</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Type of Yarns</strong></td>
<td><strong>US System</strong></td>
</tr>
<tr>
<td>Warp Yarn:</td>
<td>3K Carbon, 33MSi</td>
</tr>
<tr>
<td>Fill Yarn:</td>
<td>3K Carbon, 33MSi</td>
</tr>
<tr>
<td><strong>Fabric Weight, Dry</strong></td>
<td>11.00 oz/yd²</td>
</tr>
<tr>
<td><strong>Weave Style</strong></td>
<td>8 Harness Satin</td>
</tr>
</tbody>
</table>

**CONSTRUCTION**

<table>
<thead>
<tr>
<th>Nominal Construction</th>
<th><strong>US System</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Warp Count:</td>
<td>24/in</td>
</tr>
<tr>
<td>Fill Count:</td>
<td>24/in</td>
</tr>
<tr>
<td><strong>Fabric Thickness</strong></td>
<td>13.50 mil</td>
</tr>
</tbody>
</table>

---

**IMPORTANT**

All information is believed to be accurate but is given without acceptance of liability. All values have been generated from limited data. The values listed for weight, thickness and breaking strengths are typical greige values, unless otherwise noted. Users should make their own assessment of the suitability of any product for the purpose required. All sales are made subject to our standard terms of sales which include limitations on liability and other important terms. The fabric style listed may not be available from inventory and minimum order quantities may apply.

---

**FOR FURTHER INFORMATION, PLEASE CONTACT US**

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Seguin, Texas 78155  
Phone: 830-379-1580  
Fax: 830-379-9544  
Customer Service Toll Free: 1-866-601-5430

For European sales office numbers and a full address list, please go to:  
[http://www.hexcel.com/contact/salesoffices](http://www.hexcel.com/contact/salesoffices)

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## APPENDIX R-3: 282 3K-PW HexForce Carbon Fiber

### HexForce™ 282

**Carbon Fabric**

### Product Data

<table>
<thead>
<tr>
<th>STYLE 282</th>
<th>US System</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Type of Yarns</strong></td>
<td><strong>Warp Yarn:</strong> 3K Carbon, 33MSI</td>
</tr>
<tr>
<td><strong>Fill Yarn:</strong> 3K Carbon, 33MSI</td>
<td></td>
</tr>
<tr>
<td><strong>Fabric Weight, Dry</strong></td>
<td>5.80 oz/yd²</td>
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<tr>
<td><strong>Weave Style</strong></td>
<td>Plain</td>
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</table>

### CONSTRUCTION

<table>
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<tr>
<th>Nominal Construction</th>
<th><strong>Warp Count:</strong> 12/in</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fill Count:</strong> 12/in</td>
<td></td>
</tr>
<tr>
<td><strong>Fabric Thickness</strong></td>
<td>10.10 mil</td>
</tr>
</tbody>
</table>

### IMPORTANT

All information is believed to be accurate but is given without acceptance of liability. All values have been generated from limited data. The values listed for weight, thickness and breaking strengths are typical geige values, unless otherwise noted. Users should make their own assessment of the suitability of any product for the purpose required. All sales are made subject to our standard terms of sales which include limitations on liability and other important terms. The fabric style listed may not be available from inventory and minimum order quantities may apply.

### FOR FURTHER INFORMATION, PLEASE CONTACT US

1913 North King Street  
Seguin, Texas 78155  
Phone: 830-379-1580  
Fax: 830-379-9544  
Customer Service Toll Free: 1-866-601-5430

For European sales office numbers and a full address list, please go to:  
http://www.hexcel.com/contact/salesoffices

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™ HexForce is a trademark of Hexcel Corporation, Stamford, Connecticut.
APPENDIX R-4: 7781FG HexForce Fiber Glass

HexForce™ 7781
Fiber Glass Fabric

Product Data

<table>
<thead>
<tr>
<th>STYLE 7781</th>
<th>US System</th>
<th>SI Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of Yarns</td>
<td>Warp Yarn:</td>
<td>ECDE 75 1/0</td>
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<tr>
<td></td>
<td>Fill Yarn:</td>
<td>ECDE 75 1/0</td>
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<tr>
<td>Fabric Weight, Dry</td>
<td>8.81 oz/yd²</td>
<td>299 g/m²</td>
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<tr>
<td>Weave Style</td>
<td>8 Harness Satin</td>
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</tr>
</tbody>
</table>

CONSTRUCTION

| Nominal Construction | Warp Count: | 57/in | 22.44/cm |
|                      | Fill Count: | 54/in | 21.25/cm |
| Fabric Thickness | 8.6 mil | 0.22 mm |

Breaking Strength

| Warp | 570 lbf/in |
| Filling | 450 lbf/in |

IMPORTANT

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APPENDIX S: United by Excellence and Pier Open House Demonstration Content

Deployment Highlight Reel: https://youtu.be/yyx1ZeS6g28?si=2Rs0RewSpfopoAgk

Senior Project Poster: [1]
APPENDIX T: Laminated Composite Model Convergence Excel Sheet

APPENDIX T-1: Material Properties

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<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
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<tbody>
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<td>584 3K 8HS/BT250E-1</td>
<td>282 3K PW/BT250E-1</td>
<td>7781FG/BT250E-1</td>
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<tr>
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APPENDIX T-2: Fiber Stress (S11) Convergence

584 Depth Convergence

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282 Depth Convergence

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### 7781 Depth Convergence

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<td>Difference</td>
<td>Max Stress</td>
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### Comparison to Original

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<thead>
<tr>
<th>A</th>
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<th>Model Failure Pressure</th>
<th>Percent Change from Original</th>
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<td>(psi)</td>
<td>(%)</td>
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<td></td>
<td>Sphero Material</td>
<td>(m)</td>
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<td>Original</td>
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**APPENDIX T-3: Tsai-Hill / Tsai-Wu (TSAIH / TSAIW) Convergence**

### 584 Depth Convergence

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<th>A</th>
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<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
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<td>Difference</td>
<td>TSAIW</td>
<td>Difference</td>
<td>Max Stress</td>
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### 282 Depth Convergence

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<th>F</th>
<th>G</th>
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<td>Ext Press</td>
<td>TSAIH</td>
<td>Difference</td>
<td>TSAIW</td>
<td>Difference</td>
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### 7781 Depth Convergence

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<tr>
<td>1</td>
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### Comparison to Original

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<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
</tr>
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<tbody>
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<td>Sphere Material</td>
<td>Model Failure Pressure</td>
<td>Percent Change from Original</td>
<td>% change from stress</td>
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APPENDIX U: R/V Shearwater November Documentation

APPENDIX U-1: Vessel Project Manager – Float Plan

FLOAT PLAN

Cruise Date: 2023-11-05

VEssel Description

Vessel Name: R/V Shearwater
Hull Type: Aluminum catamaran
Length: 62
Hull ID: R6201
Other: Engine type/manufacturer: Two Detroit Diesel series 60; Manufacturer: All American Marine; Owner: CINMS/NOAA; Width: 24 ft; Draft: 6 ft; Max POB: 14 research cruises, 32 Eda cruises; Fuel Capacity 1200 gallons of Diesel; Range 300NM at 18kts
Alternate Shore Contact: Sean Hastings

Communications

Boat Cell Phone: Boatsat Phone: Radio Channels:
Other: MMSI AIS Equipped; EPIRB # NPS Radio call sign: Radio Callsign: (back-up Sat phone on board)
Sat Phone dial then, when prompted, dial

Crew

Role Name Phone Emergency Contact Emergency Phone
First Mate Howard, Matt
OIC Montgomery, Zacary

Embarked Personnel

# Name Emergency Contact Emergency Phone
1 Burger, Kourtney
2 Lenssen, Kieran
3 Pearson, Virginia
4 Rankin, Shannon
5 Reeb, Deiray
6 Simonis, Anne

Mission Description

Project Title: Central Coast Collaborative Passive Acoustic Monitoring (CCC-PAM) - 2023

*By COB Friday, Nov. 3rd, Shearwater VOC will make a call about Sunday’s transit and the HARP deployment. If the weather is marginal, the priority is transitioning to Morro Bay to begin CCC-PAM operations on Monday. We will need to skip the HARP deployment if it will affect the ship’s ability to get to Morro Bay in time to load the science gear that evening.

Itinerary:
0600: Load HARP onto Shearwater
0700: Crew and Kieren Lenssen (Scripps mooring tech) depart Santa Barbara harbor for Point Arguello. HARP will be deployed ~3 miles offshore
1000: HARP deployment
1500: ADMPT science team mobilize in Morro Bay, load science gear
1800: Finish mobilization and vessel preparations for sailing early the next day

Locations:
- Morro Bay Harbor -- Point (Anchorage location)
- Santa Barbara Harbor -- Area
Equipment: - drifting buoys  
- HARP Package (SCRIPPS)

EMERGENCY/SHORE SIDE CONTACT

Shoreside Contact: Todd Jacobs  
Primary Phone:  
Secondary Phone:  

Prepared By: Lindsey Peavey Reeves  
Date: 2023-11-03  
Approved By: LTJG Daniel Lucas  
Date: 11/3/2023

FLOAT PLAN

Cruise Date: 2023-11-06

VESSEL DESCRIPTION

Vessel Name: R/V Shearwater  
Length: 62  

Hull Type: Aluminum catamaran  
Hull ID: R6201

Other: Engine type/manufacturer: Two Detroit Diesel series 60; Manufacturer: All American Marine; Owner: CINMS/NOAA; Width: 24ft; Draft: 6ft; Max POB: 14 research cruise, 32 Edu cruise; Fuel Capacity 1200 gallons of Diesel; Range 300NM at 18kts  
Alternate Shore Contact: Sean Hastings

COMMUNICATIONS

Boat Cell Phone:  
Boat Sat Phone:  
Radio Channels:  

Other:

CREW

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MISSION DESCRIPTION
Project Title: Central Coast Collaborative Passive Acoustic Monitoring (CCC-PAM) - 2023

*The ADRIFT buoys need to be deployed at the start of the cruise, as much as weather conditions will allow. This will enable the maximum soak time throughout the cruise. These buoys are recovered at the end of the cruise. As of the 3rd, there is a decent weather window to deploy the drifting buoys on the 6th. The Captain will make the final call on Nov 5th.

0600: Leave Morro Bay as early as possible and transit 40 nm to the first station (35.62906 N, -121.636278 W). While underway throughout the day, 4 dedicated observers will conduct a marine mammal and seabird visual survey from the flying bridge.
1100: Following first buoy deployment, transit 5 nm between stations for a total of 32 nm along a 2x4 station grid. Each buoy deployment requires ~30 mins, or ~4 hours total for all buoy deployments.
1500: Transit ~40 nm to Morro Bay to arrive no later than 12 hours after departure.
While underway at any time, tow hydrophone array or deploy temporary drifting buoy on opportunistic sightings (e.g., marine mammal sighting of interest) and weather allows.
1700 (no later than): Dock in Morro Bay overnight (science personnel stay off ship for the entire cruise)

- **ADRIFT drop 1** -- Point (Study location)
  Drifting buoys are dropped at these locations and will drift with currents for hours up to days. While drifting they are tracked by satellite and VHF and retrieved from the back deck of a research platform.

- **ADRIFT drop 2** -- Point (Study location)
  Drifting buoys are dropped at these locations and will drift with currents for hours up to days. While drifting they are tracked by satellite and VHF and retrieved from the back deck of a research platform.

- **ADRIFT drop 3** -- Point (Study location)
  Drifting buoys are dropped at these locations and will drift with currents for hours up to days. While drifting they are tracked by satellite and VHF and retrieved from the back deck of a research platform.

- **ADRIFT drop 4** -- Point (Study location)
  Drifting buoys are dropped at these locations and will drift with currents for hours up to days. While drifting they are tracked by satellite and VHF and retrieved from the back deck of a research platform.

- **ADRIFT drop 5** -- Point (Study location)
  Drifting buoys are dropped at these locations and will drift with currents for hours up to days. While drifting they are tracked by satellite and VHF and retrieved from the back deck of a research platform.

- **ADRIFT drop 6** -- Point (Study location)
  Drifting buoys are dropped at these locations and will drift with currents for hours up to days. While drifting they are tracked by satellite and VHF and retrieved from the back deck of a research platform.

- **ADRIFT drop 7** -- Point (Study location)
  Drifting buoys are dropped at these locations and will drift with currents for hours up to days. While drifting they are tracked by satellite and VHF and retrieved from the back deck of a research platform.

- **ADRIFT drop 8** -- Point (Study location)
  Drifting buoys are dropped at these locations and will drift with currents for hours up to days. While drifting they are tracked by satellite and VHF and retrieved from the back deck of a research platform.

- **Morro Bay Harbor** -- Point (Anchorage location)

Locations:

Equipment: - drifting buoys

**EMERGENCY/SHORE SIDE CONTACT**

Shoreside Contact: Daniel Lucas  Primary Phone: (call)  Secondary Phone: (call)
Cruise Date: 2023-11-07

VESSSEL DESCRIPTION

Vessel Name: R/V Shearwater  
Hull Type: Aluminum catamaran  
Length: 62  
Hull ID: R6201  
Engine type/manufacturer: Two Detroit Diesel series 60; Manufacturer: All American Marine; Owner: CINMS/NOAA; Width: 24ft; Draft: 6ft; Max POB: 14 research cruise, 32 edu cruise; Fuel Capacity 1200 gallons of Diesel; Range 300NM at 18kts Alternate Shore Contact: Sean Hastings

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Boat Sat Phone:  
Radio Channels:  
Other:

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MISSION DESCRIPTION

Project Title: Central Coast Collaborative Passive Acoustic Monitoring (CCC-PAM) - 2023

Itinerary:
0700: Science team and guests board vessel and prepare for departure / safety brief  
0730: Depart dock and transit to CH01 station (35.46903, -121.02367, nearshore and @~19m) [approx. 12 nm and a ~1 hour transit @14 knots]
0930: Turnaround CH01 stationary mooring with MBARI colleagues [1 hour on station]
1000: Transit to MB05 while conducting visual survey, transect lines can be flexible with nearshore and offshore lines depending on weather conditions
Once near station, deploy the CalPoly deep sea BRUV for soaking (up to 2 hours, will have time for at least 30 mins)
Complete MB05 turnaround with MBARI colleagues [1 hour on station]
Recovery CalPoly deep sea BRUV
If interesting animal is sighted to or from MB05 and/or Morro Bay, may drop a drifting buoy and photo ID and spend time with animals
Tow hydrophone array as opportunity and weather allows
1500 (or sooner): Transit back to Morro Bay
Visual survey while transitting, transect lines can be flexible with nearshore and offshore lines depending on weather conditions and time
Tow hydrophone array as opportunity and weather allows
If interesting animal is sighted, may drop a drifting buoy and photo ID and spend time with animals (up to ~30 mins)
1700 (no later than): Dock in Morro Bay overnight

- CH-01 -- Point (Study location)
  This sound recording mooring sits at 19m and was first deployed in June 2022.

- MB-05 -- Point (Study location)
  This sound recording mooring rests at ~98m depth in La Cruz Canyon. It was first deployed in April 2022.

- Morro Bay Harbor -- Point (Anchorage location)

Equipment:
- CalPoly deep water BRUV
- SoundTrap mooring

EMERGENCY/SHORE SIDE CONTACT

Shoreside Contact: Daniel Lucas
Primary Phone:       Secondary Phone:     
Prepared By: Lindsey Peavey Reeves Date: 2023-11-03 Approved By: Date: 

FLOAT PLAN

Cruise Date: 2023-11-08

VESSEL DESCRIPTION

Vessel Name: R/V Shearwater Length: 62
Hull Type: Aluminum catamaran Hull ID: R6201
Other: Engine type/manufacturer: Two Detroit Diesel series 60; Manufacturer: All American Marine; Owner: CINMS/NOAA; Width: 24ft; Draft: 6ft; Max POB: 14 research crew; Fuel Capacity 1200 gallons of Diesel; Range 300NM at 18kts
Alternate Shore Contact: Sean Hastings

COMMUNICATIONS

Boat Cell Phone:          Boat Sat Phone:   Radio Channels: 
Other:                    

CREW

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MISSION DESCRIPTION

Project Title: Central Coast Collaborative Passive Acoustic Monitoring (CCC-PAM) - 2023

Itinerary: 0630 [can be later depending on weather and science ops]: Science team and crew meet to discuss day’s objectives and for safety brief 0700 [can be later depending on weather and science ops]: Depart Morro Bay to complete visual surveys with opportunistic drifting recordings (~30 mins), locations TBD based on weather and conditions.  - Visual surveys  - Deploy temporary drifting buoy on opportunistic sightings (e.g. marine mammal sighting of interest) as time and weather allows  - Transit back to Morro Bay 1700 (no later than): Dock in Morro Bay overnight. Load NRS-13, if possible.

Locations:

- **CH-01** -- Point (Study location)
  This sound recording mooring sits at 19m and was first deployed in June 2022.

- **MB-05** -- Point (Study location)
  This sound recording mooring rests at ~96m depth in La Cruz Canyon. It was first deployed in April 2022.

- **Morro Bay Harbor** -- Point (Anchorage location)

Equipment:

EMERGENCY/SHORE SIDE CONTACT

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FLOAT PLAN
Cruise Date: 2023-11-09

VESSEL DESCRIPTION

Vessel Name: R/V Shearwater
Hull Type: Aluminum catamaran
Length: 62
Hull ID: R6201

Other: Engine type/manufacturer: Two Detroit Diesel series 60; Manufacturer: All American Marine; Owner: CINMS/NOAA; Width: 24ft; Draft: 6ft, Max POB: 14 research cruise, 32 EdU cruise; Fuel Capacity 1200 gallons of Diesel; Range 300NM at 18kts
Alternate Shore Contact: Sean Hastings

COMMUNICATIONS

Boat Cell Phone: 
Boat Sat Phone: 
Radio Channels: 

CREW

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MISSION DESCRIPTION

Project Title: Central Coast Collaborative Passive Acoustic Monitoring (CCC-PAM) - 2023

Itinerary:
- 0530: PMEL and CalPoly science teams arrive to load BRUV and BRUV gear [2 hour]
- 0715: Rest of science personnel board vessel and prepare for departure / safety brief
- Science team meet with crew to discuss how to best program the BRUV
- (1) Ideally it is best to be in the area when the lander surfaces as it can drift off quickly, so need to decide what time to have the lander surface by.
- (2) BRUV has a dual burn-wire system for the lander to drop its weights. The two are normally spaced out such that the second would only activate after the first had given enough time to recover the lander in order to avoid using both unnecessarily. However, since it takes ~36 min for the lander to ascend, it likely be an hour difference so possible hour delay if for some reason the first burn wire didn’t go off. Need to decide whether to set both burn wires to go off at the same time and just have us plan on losing both wires and the chain, or set them to stagger.
- 0730: Transit to NRS-13 (35.312267 N, -121.586983 W, approx. 36 nm) (~2.5 hour transit @14 knots)
- 1000: Deploy BRUV [30 mins]
- 1030: NRS-13 turnaround [2-4 hours]
- 1430: Recover BRUV [30 mins]
- 1500: Transit to Morro Bay while conducting visual surveys and deploying opportunistic drifting recorders as time and weather...
allows. 1700 (no later than): Dock in Morro Bay overnight

- CalPoly BRUV Morro Bay WEA test location -- Point (Study location)

- Morro Bay Harbor -- Point (Anchorage location)

- NRS-13 -- Point (Study location)
  This Noise Reference Station will be initiated in March 2023 and will sit at around 900m.

Equipment:
- CalPoly deep water BRUV
- NRS mooring

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**EMERGENCY/SHORE SIDE CONTACT**

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<th>Primary Phone:</th>
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**FLOAT PLAN**

Cruise Date: 2023-11-10

**VESSEL DESCRIPTION**

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Other:
- Engine type/manufacturer: Two Detroit Diesel series 60; Manufacturer: All American Marine; Owner: CINMS/NOAA; Width: 24ft; Draft: 6ft; Max POB: 14 research cruise; 32 Edu cruise; Fuel Capacity 1200 gallons of Diesel; Range 3000NM at 18kts
- Alternate Shore Contact: Sean Hastings

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### MISSION DESCRIPTION

**Project Title:** Central Coast Collaborative Passive Acoustic Monitoring (CCC-PAM) - 2023

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<td>[can be later if not recovering any drifting buoys]: Science team and crew meet to discuss day's objectives and for safety briefing.</td>
</tr>
<tr>
<td>0700</td>
<td>[can be later if not recovering any drifting buoys]: Depart Morro Bay for closest (most southern) drifting buoy if necessary and begin retrieving drifting buoys from south to north (locations TBD - will have drifted with currents). If no buoy recovery is necessary, complete visual surveys with opportunistic drifting recordings (~30 mins), locations TBD based on weather and conditions.</td>
</tr>
</tbody>
</table>

**Itinerary:**
- Visual surveys
- Deploy temporary drifting buoy on opportunistic sightings (e.g., marine mammal sighting of interest) as time and weather allows
- Transit back to Morro Bay
- 1700 (no later than): Dock in Morro Bay overnight

**Locations:**
- Morro Bay Harbor -- Point (Anchorage location)

**Equipment:**

---

### EMERGENCY/SHORE SIDE CONTACT

<table>
<thead>
<tr>
<th>Shoreside Contact</th>
<th>Primary Phone</th>
<th>Secondary Phone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daniel Lucas</td>
<td></td>
<td></td>
</tr>
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**Prepared By:** Lindsey Peavey Reeves  
**Date:** 2023-11-03  
**Approved By:**  
**Date:**

---

### VESSEL DESCRIPTION

<table>
<thead>
<tr>
<th>Vessel Name</th>
<th>Length</th>
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<tbody>
<tr>
<td>R/V Shearwater</td>
<td>62</td>
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</table>

<table>
<thead>
<tr>
<th>Hull Type</th>
<th>Hull ID</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum catamaran</td>
<td>R6201</td>
</tr>
</tbody>
</table>

**Other:**
- Engine type/manufacturer: Two Detroit Diesel series 60; Manufacturer: All American Marine; Owner: CINMS/NOAA; Width: 24ft; Draft: 6ft, Max POB: 14 research cruise, 32 Edu cruise; Fuel Capacity 1200 gallons of Diesel; Range 300NM at 18kts
- Alternate Shore Contact: Sean Hastings

---

### COMMUNICATIONS

<table>
<thead>
<tr>
<th>Boat Cell Phone</th>
<th>Boat Sat Phone</th>
<th>Radio Channels</th>
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<tbody>
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**Other:**

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344
CREW

<table>
<thead>
<tr>
<th>Role</th>
<th>Name</th>
<th>Phone</th>
<th>Emergency Contact</th>
<th>Emergency Phone</th>
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<tbody>
<tr>
<td>First Mate</td>
<td>Howard, Matt</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OIC</td>
<td>Montgomery, Zacary</td>
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EMBARKED PERSONNEL

<table>
<thead>
<tr>
<th>#</th>
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<td>1</td>
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<td>Palmer, Kaitlin</td>
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<td>4</td>
<td>Pearson, Virginia</td>
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<td>5</td>
<td>Simonis, Anne</td>
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<td>6</td>
<td>Vanfleet Brown, Jackson</td>
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MISSION DESCRIPTION

Project Title: Central Coast Collaborative Passive Acoustic Monitoring (CCC-PAM) - 2023

0630: Science team and crew meet to discuss day’s objectives and for safety brief
0700: Depart Morro Bay for closest (most southern) drifting buoy and begin retrieving drifting buoys from south to north (locations TBD - will have drifted with currents)
Deploy temporary drifting buoy on opportunistic sightings (e.g. marine mammal sighting of interest) as time and weather allows Transit back to Morro Bay to finish cruise
1700 (no later than): Dock in Morro Bay overnight. Unload ADRIFT gear if time allows. Otherwise, unload the next morning.

- Morro Bay Harbor -- Point (Anchorage location)
- Drifting buoys

EMERGENCY/SHORE SIDE CONTACT

<table>
<thead>
<tr>
<th>Shoreside Contact:</th>
<th>Primary Phone:</th>
<th>Secondary Phone:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daniel Lucas</td>
<td>(cell)</td>
<td>(cell)</td>
</tr>
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Prepared By: Lindsey Peavey Reeves Date: 2023-11-03 Approved By: Date:

FLOAT PLAN

Cruise Date: 2023-11-12

VESSEL DESCRIPTION

<table>
<thead>
<tr>
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<th>R/V Shearwater</th>
<th>Length:</th>
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</tr>
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<td></td>
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<td>1</td>
<td>Roche, Lauren</td>
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</table>

**MISSION DESCRIPTION**

- **Project Title:** Central Coast Collaborative Passive Acoustic Monitoring (CCC-PAM) - 2023
- **Itinerary:**
  - 0800: Crew and science personnel meet at ship to move science equipment on/off ship.
  - 0930: Depart Morro Bay for Santa Barbara Harbor.
  - 1700: Dock ship in Santa Barbara Harbor home slip.

- **Locations:**
  - Morro Bay Harbor -- Port (Anchorage location)
  - Santa Barbara Harbor -- Area

**EMERGENCY/SHORE SIDE CONTACT**

- **Shoreside Contact:** Daniel Lucas
- **Primary Phone:** cell
- **Secondary Phone:** cell

**Prepared By:** Lindsey Peavey Reeves  **Date:** 2023-11-03  **Approved By:**  **Date:**

**Cruise Date:** 2023-11-13

**VESSSEL DESCRIPTION**

- **Vessel Name:** R/V Shearwater
- **Hull Type:** Aluminum catamaran
- **Length:** 62
- **Hull ID:** R6201
- **Other:**
  - Engine type/manufacturer: Two Detroit Diesel series 60; Manufacturer: All American Marine; Owner: CINMS/NOAA; Width: 24ft; Draft: 6ft, Max POB: 14 research cruise, 32 Edu cruise; Fuel Capacity 1200 gallons of Diesel; Range 300NM at 18kts
  - Alternate Shore Contact: Sean Hastings

**COMMUNICATIONS**

- **Boat Cell Phone:**
- **Boat Sat Phone:**
- **Radio Channels:**
CREW

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<td>1</td>
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<td>Millar, Christine</td>
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<td>7</td>
<td>Roche, Lauren</td>
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<td>Ryan, John</td>
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<td>Stroud, Ashley</td>
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<td>10</td>
<td>Zollett, Erika</td>
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</tbody>
</table>

MISSION DESCRIPTION

Project Title: Central Coast Collaborative Passive Acoustic Monitoring (CCC-PAM) - 2023

0700: PMEL and other science personnel arrive for safety brief
0730: Transit to NRS-05 (33.9 N, -119.58 W)

Itinerary:
1030: NRS-05 turnaround [2-4 hours]
1430: Transit to Santa Barbara Harbor
1700: Dock in Santa Barbara Harbor home slip

- NRS-05 -- Point (Study location)
  This long-term low frequency hydrophone records for 2 years and this location will be updated after each re-deployment.

Locations:
- Santa Barbara Harbor -- Area

Equipment: NRS mooring

EMERGENCY/SHORE SIDE CONTACT

Shoreside Contact: Daniel Lucas
Primary Phone: [cell]
Secondary Phone: [cell]

Prepared By: Lindsey Peavey Reeves Date: 2023-11-03
Approved By: Date:
APPENDIX U-2: Vessel Project Manager – Cruise Plan

Cruise Plan: CCC-PAM November 2023
Vessel: R/V Shearwater
Project: Central Coast Collaborative Passive Acoustic Monitoring (CCC-PAM) - 2023

Prepared by: Lindsay Peavey Reeves
Last modified: 2023-11-03
Point of Contact: Lindsey Peavey
Affiliation: NOAA NOS CINMS
Phone: 
Email: lindsey.peavey@noaa.gov
ONMS contact: Todd Jacobs

Details

Planned number of vessel use days (incl. mobilization and demobilization): 9
Planned Dive Operations: No

Cruise purpose:
MRRMS, the proposed CHNMS, and CINMS are nearshore federally protected areas of the ecologically productive California Current, parts of which are adjacent or near to highly populated cities serving as epicenters of shipping, military, fishing, offshore renewable energy development, construction, and recreational activity. All of these human activities generate sound on varying levels and can negatively impact living marine resources, such as marine mammals, fish, and invertebrates. NOAA is charged with supporting multiple uses of sanctuary waters and a thriving blue economy, while minimizing negative impacts to living resources and habitat. Underwater noise presents a unique challenge in balancing these objectives because it is widespread and variable, and is also influenced by the environment, including the changing climate. Additionally, sound data is uniquely useful in providing insight into the presence of marine animals, environmental conditions, and human uses -- and importantly how all three overlap in time and space. In two of the three sanctuaries (MRNMS & CINMS), ONMS has been characterizing baseline sound levels at a number of stationary shallow monitoring locations since 2018, and in some locations (e.g., MRRMS observatory in MRNMS; some parts of the SB Channel in CINMS) partners have been monitoring sound for longer. A deep-water Noise Reference Station has been recording low frequency sound on the backside of Santa Cruz Island in CINMS since 2014, and in March 2023 we deployed a new Noise Reference Station just south of the Morro Bay Wind Energy Area, inside the proposed CHNMS boundaries. In addition, NMFS and other partners conduct offshore ecosystem surveys that have included sanctuary waters, and mobile passive acoustic monitoring is a part of those periodic but ongoing efforts.

Notes:
All operations flexible with weather. Current itineraries are subject to change.

Day 1: 2023-11-05

Itinerary

*By COB Friday, Nov. 3rd, Shearwater VOC will make a call about Sunday’s transit and the HARP deployment. If the weather is marginal, the priority is to transit to Morro Bay to begin CCC-PAM operations on Monday. We will need to skip the HARP deployment if it will affect the ship’s ability to get to Morro Bay in time to load the science gear that evening.

0600: Load HARP onto Shearwater
0700: Crew and Kieron Lenssen (Scrpps mooring tech) depart Santa Barbara harbor for Point Arguelo. HARP will be deployed ~3 miles offshore
1000: HARP deployment
1500: ADRIFT science team mobilize in Morro Bay, load science gear
1600: Finish mobilization and vessel preparations for sailing early the next day

Detailed procedures to be performed

Once in Morro Bay Harbor, if time and daylight allow (preference!) ADRIFF science team will load their equipment onto the vessel.

Transit approximately 105 miles from SB to Morro Bay

Note: Kieren will sleep or ship on the 4th (in SB Harbor) and 5th (in Morro Bay Harbor)

Locations

- Morro Bay Harbor — Point (Anchorage location) x
- Santa Barbara Harbor — Area North: West: x South: East

Personnel

- Kourtney Burger
- Matt Howard
- Kieron Lenssen
- Zacary Montgomery
- Virginia Pearson
- Shannon Rankin
- Desray Reeb
- Anne Simonis

Equipment

- drifting buoys
- HARP Package (SCRIPPS)

Day 2: 2023-11-06

Itinerary

*The ADRIFT buoys need to be deployed at the start of the cruise, as much as weather conditions will allow. This will enable the maximum soak time throughout the cruise. These buoys are recovered at the end of the cruise. As of the 3rd, there is a decent weather window to deploy the drifting buoys on the 6th. The Captain will make the final call on Nov 5th.

0500: Leave Morro Bay as early as possible and transit 40 nm to the first station

Detailed procedures to be performed

ADRIFF DAS to deploy 8 buoys:

Longitude Latitude
-121.636 35.62906
-121.754 35.62906
-121.851 35.62906
-121.948 35.62906
While underway throughout the day, four dedicated observers will conduct a marine mammal and seabird visual survey from the flying bridge.

1100: Following first buoy deployment, transit 5 nm between stations for a total of 32 nm along a 2x4 station grid. Each buoy deployment requires ~30 mins, or ~4 hours total for all buoy deployments.

1500: Transit ~40 nm to Morro Bay to arrive no later than 12 hours after departure. While underway at any time, tow hydrophone array or deploy temporary drifting buoy on opportunistic sightings (e.g., marine mammal sighting of interest) and weather allows.

1700 (no later than): Dock in Morro Bay overnight (science personnel stay off ship for the entire cruise)

---

### Locations

<table>
<thead>
<tr>
<th>Location</th>
<th>Coordinates</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADRIFT drop 1 -- Point (study location)</td>
<td>35.798267 x -122.190733</td>
<td>Drifting buoys are dropped at these locations and will drift with currents for hours up to days. While drifting they are tracked by satellite and VHF and retrieved from the back deck of a research platform.</td>
</tr>
<tr>
<td>ADRIFT drop 2 -- Point (study location)</td>
<td>35.8005 x -122.088667</td>
<td>Drifting buoys are dropped at these locations and will drift with currents for hours up to days. While drifting they are tracked by satellite and VHF and retrieved from the back deck of a research platform.</td>
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<td>ADRIFT drop 3 -- Point (study location)</td>
<td>35.80185 x -121.984017</td>
<td>Drifting buoys are dropped at these locations and will drift with currents for hours up to days. While drifting they are tracked by satellite and VHF and retrieved from the back deck of a research platform.</td>
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<td>ADRIFT drop 4 -- Point (study location)</td>
<td>35.80385 x -121.877383</td>
<td>Drifting buoys are dropped at these locations and will drift with currents for hours up to days. While drifting they are tracked by satellite and VHF and retrieved from the back deck of a research platform.</td>
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<td>ADRIFT drop 5 -- Point (study location)</td>
<td>35.713917 x -121.1861</td>
<td>Drifting buoys are dropped at these locations and will drift with currents for hours up to days. While drifting they are tracked by satellite and VHF and retrieved from the back deck of a research platform.</td>
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<td>ADRIFT drop 6 -- Point (study location)</td>
<td>35.71575 x -122.085283</td>
<td>Drifting buoys are dropped at these locations and will drift with currents for hours up to days. While drifting they are tracked by satellite and VHF and retrieved from the back deck of a research platform.</td>
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<td>ADRIFT drop 7 -- Point (study location)</td>
<td>35.715583 x -121.981633</td>
<td>Drifting buoys are dropped at these locations and will drift with currents for hours up to days. While drifting they are tracked by satellite and VHF and retrieved from the back deck of a research platform.</td>
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<tr>
<td>ADRIFT drop 8 -- Point (study location)</td>
<td>35.715583 x -121.876783</td>
<td>Drifting buoys are dropped at these locations and will drift with currents for hours up to days. While drifting they are tracked by satellite and VHF and retrieved from the back deck of a research platform.</td>
</tr>
</tbody>
</table>

---

### Personnel

- Erin Boyce
- Kourtney Burger
- Matt Howard
- Justin Ionely
- Melissa Kjelvik
- Zacary Montgomery
- Kaitlin Palmer
- Virginia Pearson
- Shannon Rankin
- Desray Reb
- Tammy Russell
- Anne Simonis

---

### Equipment

- Drifting buoys

---

PMEL team will have NRS-13 gear staged for loading Monday evening, or Tuesday morning.

Will remain flexible to load gear / swap science operations as weather permits.

---

349
Day 3: 2023-11-07

**Itinerary**

0700: Science team and guests board vessel and prepare for departure / safety brief
0730: Depart dock and transit to CH01 station (35.46803, -121.02367, near shore and @~19m) (approx. 12 nm and a ~1 hour transit @14 knots)
0930: Turnaround CH01 stationary mooring with MBARI colleagues [1 hour on station]
1000: Transit to MB05 while conducting visual survey, transect lines can be flexible with nearshore and offshore lines depending on weather conditions
Once near station, deploy the CalPoly deep sea BRUV for soaking (up to 2 hours, will have time for at least 30 mins)
Complete MB05 turnaround with MBARI colleagues [1 hour on station]
Recovery CalPoly deep sea BRUV
If interesting animal is sighted to or from MB05 and/or Morro Bay, may drop a drifting buoy and photo ID and spend time with animals
1500 (or sooner): Transit back to Morro Bay
Visual survey while transiting; transect lines can be flexible with nearshore and offshore lines depending on weather conditions and time
Tow hydrophone array as opportunity and weather allows
If interesting animal is sighted, may drop a drifting buoy and photo ID and spend time with animals (up to ~30 mins)
1700 (no later than): Dock in Morro Bay overnight

**Locations**

- CH-01 -- Point (Study location)
  - 35.4682 x 121.1735
- MB-05 -- Point (Study location)
  - 35.7666 x 121.4332
- Morro Bay Harbor -- Point (Anchorage location)

**Personnel**

- Nikki Arm
- Ingrid Biedron
- Kourtney Burger
- Samara Haver
- Matt Howard
- Justin Inouye
- Anastasia Kunz
- Caitlin Manley
- Christine Miller
- Zacary Montgomery
- Maya Netto
- Will Osetreich
- Kati Lin Palmer
- Virginia Pearson
- Lindsey Poavey Reeves
- Tammy Russell
- Anne Simons

**Equipment**

- CalPoly deep water BRUV
- SoundTrap mooring

**Detailed procedures to be performed**

Two ONMS sound mooring swaps (MB05 & CH01); CalPoly BRUV survey at MB05; visual surveys; opportunistic drifting recorder (~30 mins in duration) deployment(s) on animals of interest.

As of Nov. 3rd, weather picks up throughout the day. These two moorings do not need to be serviced on the same day, they can be spread out throughout the week, according to weather. There is no time sensitivity as to when wither is serviced, as long as we can get to each of them at some point during the cruise.

Day 4: 2023-11-08

**Itinerary**

0630 [can be later depending on weather and science ops]: Science team and crew meet to discuss day’s objectives and for safety brief
0700 [can be later depending on weather and science ops]: Depart Morro Bay to complete visual surveys with opportunistic drifting recordings (~30 mins), locations TBD based on weather and conditions.
- Visual surveys
- Deploy temporary drifting buoy on opportunistic sightings (e.g. marine mammal sighting of interest) as time and weather allows
- Transit back to Morro Bay
1700 (no later than): Dock in Morro Bay overnight. Load NRS-13, if possible.

**Locations**

- CH-01 -- Point (Study location)
  - 35.4682 x 121.1735
- MB-05 -- Point (Study location)
  - 35.7666 x 121.4332

**Personnel**

- Nikki Arm
- Kourtney Burger
- Danika Cornejo
- Samara Haver
- Matt Howard
- Justin Inouye
- Anastasia Kunz
- Caitlin Manley
- Christine Miller

**Equipment**

Service MB05 and/or CH01 if not yet completed, if already completed - visual survey & opportunistic busy recordings. Also - if possible, pull into PGE harbor to see what real world conditions are like. This can be a quick 'turn' during a transit in the vicinity.

If possible, load NRS-13 mooring onto the vessel ahead of Nov. 9th (or whatever day we end up heading out to that site).

350
Day 5: 2023-11-09

Itinerary

0530: PMEL and CalPoly science teams arrive to load NRS-13 and BRUV gear [2 hour]
0715: Rest of science personnel board vessel and prepare for departure / safety brief
Science team meet with crew to discuss how to best program the BRUV
(1) Ideally it is best to be in the area where the lander surfaces as it can drift off quickly,
so need to decide what time to have the lander surface by.
(2) BRUV has a dual burn-wire system for the lander to drop its weights. The two are
normally spaced out such that the second would only activate after the first had given
enough time to recover the lander in order to avoid using both unnecessarily. However,
since it takes ~36 min for the lander to ascend, it would likely be an hour difference so
possible hour delay if for some reason the first burn wire didn't go off. Need to decide
whether set both burn wires to go off at the same time and just have us plan on
losing both wires and the chain, or set them to stagger.
0730: Transit to NRS-13 (35.312267 N, -121.586983 W, approx. 36 nm) [~2.5 hour
transit @14 knots]
1000: Deploy BRUV [30 mins]
1030: NRS-13 turnaround [2-4 hours]
1430: Recover BRUV [30 mins]
1500: Transit to Morro Bay while conducting visual surveys and deploying opportunistic
drifting recorders as time and weather allows.
1700 (no later than): Dock in Morro Bay overnight

Locations

- CalPoly BRUV test location -- Point (Study location)
  - Morro Bay WEA
  - NRS-13 -- Point (Study location)

Detailed procedures to be performed
Since we have pushed the NRS-13 servicing to later in the
cruise due to weather, the mooring may already be loaded
onto the vessel. If so, we will push off the dock ASAP to
take advantage of any weather window.
NRS-13 mooring turnaround just south of the Morro Bay
Wind Energy Area; CalPoly deep water seafloor baited
video camera (BRUV) survey.

Personnel

- Nicki Arm
- Emma Beretta
- Ingrid Beddrom
- Erin Boydstun
- Kourtney Burger
- Danika Cornejo
- Matt Howard
- Zacary Montgomery
- Maya Netto
- Kaitlin Palmer
- Virginia Pearson
- Lindsey Peavey Reeves
- Lauren Roche
- Tammy Russell
- John Ryan
- Anne Simonis

Equipment

- CalPoly deep water BRUV
- NRS mooring

Day 6: 2023-11-10

Itinerary

0630 (can be later if not recovering any drifting buoys): Science team and crew meet to
discuss day’s objectives and for safety brief
0700 (can be later if not recovering any drifting buoys): Depart Morro Bay for closest
(most southern) drifting buoy if necessary and begin retrieving drifting buoys from south
to north (locations TBD - will have drifted with currents). If no buoy recovery is
necessary, complete visual surveys with opportunistic drifting recordings (~30 mins),
locations TBD based on weather and conditions.
Visual surveys
Deploy temporary drifting buoy on opportunistic sightings (e.g. marine mammal sighting
of interest) as time and weather allows
Transit back to Morro Bay
1700 (no later than): Dock in Morro Bay overnight

Locations

- Morro Bay Harbor -- Point (Anchorage location)

Detailed procedures to be performed
Recover drifting buoys if necessary. If not - visual survey &
opportunistic buoy recordings. Drifting buoys will need to
be recovered on Nov. 10th and Nov. 11th so that the
Shearwater can transit back to Santa Barbara as planned
on the 12th. We do not want to delay Santa Barbara-based
science missions scheduled for the week of Nov. 13th. If
all buoys are recovered on the 10th, the ship can transit
south early (on Nov. 11th), if that makes sense, weather-
wise.

Personnel

- Kourtney Burger
- Leigh Fitzgerald
- Matt Howard
- Anastasia Kunz

Equipment

- CalPoly deep water BRUV
- NRS mooring
### Day 7: 2023-11-11

**Itinerary**

0630: Science team and crew meet to discuss day's objectives and for safety brief  
0700: Depart Morro Bay for closest (most southern) drifting buoy and begin retrieving drifting buoys from south to north (locations TBD – will have drifted with currents)  
Deploy temporary drifting buoy on opportunistic sightings (e.g. marine mammal sighting of interest) as time and weather allows  
Transit back to Morro Bay to finish cruise  
1700 (no later than): Dock in Morro Bay overnight. Unload ADRIFT gear if time allows. Otherwise, unload the next morning.

**Locations**
- Morro Bay Harbor -- Point  
  (Anchorage location)

**Personnel**
- Emma Beretta  
- Kourtney Burger  
- Matt Howard  
- Zacary Montgomery  
- Karlton Palmer  
- Virginia Pearson  
- Anne Simons  
- Jackson Vanfleet Brown

**Equipment**
- Drifting buoys

### Day 8: 2023-11-12

**Itinerary**

0800: Crew and science personnel meet at ship to move science equipment on/off ship  
0930: Depart Morro Bay for Santa Barbara Harbor  
1700: Dock ship in Santa Barbara Harbor home slip

**Locations**
- Morro Bay Harbor -- Point  
  (Anchorage location)  
- Santa Barbara Harbor -- Area  
  North: West  
  South: East

**Personnel**
- Matt Howard  
- Zacary Montgomery  
- Lauren Roche

**Equipment**

### Day 9: 2023-11-13

**Itinerary**

0700: PMEL and other science personnel arrive for safety brief  
0730: Transit to NRS-05 (33.9 N, -119.58 W)  
1030: NRS-05 turnaround [2-4 hours]  
1430: Transit to Santa Barbara Harbor  
1700: Dock in Santa Barbara Harbor home slip

**Locations**
- NRS-05 -- Point  
  (Study location)  
  33.8979 x  
  -119.5450

**Personnel**
- Mathias Gradilla  
- Matt Howard  
- Anastasia Kunz  
- Christine Millar  
- Michaela Miller  
- Zacary Montgomery  
- Elle Pesney

**Equipment**
- NRS mooring
## Appendix

### Project Personnel Roster
(Peronnel to be present on each day of cruise listed above)

<table>
<thead>
<tr>
<th>Name</th>
<th>Affiliation</th>
<th>DAN #</th>
<th>Emergency Contact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nikki Arm</td>
<td>CalPoly undergrad student</td>
<td>--</td>
<td></td>
</tr>
<tr>
<td>Emma Beretta</td>
<td>CalPoly student &amp; NMSF summer intern</td>
<td>--</td>
<td></td>
</tr>
<tr>
<td>Ingrid Biedron</td>
<td>BOEM</td>
<td>--</td>
<td></td>
</tr>
<tr>
<td>Erin Boydston</td>
<td>BOEM</td>
<td>--</td>
<td></td>
</tr>
<tr>
<td>Kourtney Burger</td>
<td>SWFSC</td>
<td></td>
<td></td>
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<tr>
<td>Danika Cornejo</td>
<td>CalPoly undergrad student</td>
<td>--</td>
<td></td>
</tr>
<tr>
<td>Leigh Fitzgerald</td>
<td>Poway Unified School District teacher</td>
<td>--</td>
<td></td>
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<tr>
<td>Matt Stadler</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Justin Inouye</td>
<td>CPC</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Melissa Kjemvik</td>
<td>Data Nuggets</td>
<td>--</td>
<td></td>
</tr>
<tr>
<td>Anastasia Kunz</td>
<td>CMSF &amp; NMSF</td>
<td>--</td>
<td></td>
</tr>
<tr>
<td>Kieran Lenissen</td>
<td>Scripps Institution of Oceanography</td>
<td>--</td>
<td></td>
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<tr>
<td>Danny Lucas</td>
<td>NOAA/CINMS</td>
<td>--</td>
<td></td>
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<tr>
<td>Caitlin Manley</td>
<td>Knauss Marine Policy Fellow, USFWS</td>
<td>--</td>
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<tr>
<td>Christine Millar</td>
<td>Photographer</td>
<td>--</td>
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<tr>
<td>Michaela Miller</td>
<td>National Marine Sanctuary Foundation</td>
<td>--</td>
<td></td>
</tr>
<tr>
<td>Zacary Montgomery</td>
<td>Cardinal Point Captains</td>
<td>--</td>
<td></td>
</tr>
<tr>
<td>Maya Nettto</td>
<td>CalPoly undergrad student</td>
<td>--</td>
<td></td>
</tr>
<tr>
<td>Name</td>
<td>Affiliation</td>
<td></td>
<td></td>
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<td>------------------------</td>
<td>-------------------</td>
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<td></td>
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<tr>
<td>Lucy Nosbisch</td>
<td>CalPoly student</td>
<td></td>
<td></td>
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<tr>
<td>Will Ostreich</td>
<td>MBARI</td>
<td></td>
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<tr>
<td>Isaiah Orlando</td>
<td>CalPoly student</td>
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<tr>
<td>Kaitlin Palmer</td>
<td>SWFSC</td>
<td></td>
<td></td>
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<tr>
<td>Allison Payne</td>
<td>UCSC PhD Student</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Virginia Pearson</td>
<td>SeatTech Student</td>
<td></td>
<td></td>
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<tr>
<td>Ellie Peavey</td>
<td>(retired) Teacher</td>
<td></td>
<td></td>
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<tr>
<td>Lindsey Peavey Reeves</td>
<td>NOAA ONMS / NMSF</td>
<td></td>
<td></td>
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<tr>
<td>Shannon Rankin</td>
<td>NMFS SWFSC</td>
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<td>Dersay Reeb</td>
<td>BOEM</td>
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<tr>
<td>Lauren Roche</td>
<td>NOAA NMFS PMEL</td>
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<td></td>
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<tr>
<td>Tammy Russell</td>
<td>Nancy Foster Scholar, UCSD</td>
<td></td>
<td></td>
</tr>
<tr>
<td>John Ryan</td>
<td>MBARI</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anne Simonis</td>
<td>NMFS SWFSC</td>
<td></td>
<td></td>
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<tr>
<td>Ashley Stroud</td>
<td>UCSB</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jackson Vanfleet Brown</td>
<td>SFSU Student</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Erika Zollett</td>
<td>UCSB Environmental Leadership Incubator</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Project Equipment Inventory**

(Equipment required for use on each day of cruise listed above)

<table>
<thead>
<tr>
<th>Equipment Type</th>
<th>Size</th>
<th>Weight</th>
<th>Power Needs</th>
<th>Other Needs</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>CalPoly deep water BRUV</td>
<td>1.4 m x 0.8 m x 0.5 m</td>
<td>95 lb</td>
<td>none</td>
<td>Need to use the A-frame and winch to deploy and recover.</td>
<td>The equipment is rated to 1.5kn depth.</td>
</tr>
<tr>
<td>Drifting buoys</td>
<td>3 x 0.5 m</td>
<td>75 lbs</td>
<td>Buoys/sensor batteries and reflectors provided by science team. Power to forward capstan needed for buoy recovery.</td>
<td>GPS, satellite, and VHF tracking systems (scientists will provide)</td>
<td>Typically have up to 9 total on a multi-day cruise.</td>
</tr>
<tr>
<td>NRS mooring</td>
<td>150 x 2</td>
<td>1660</td>
<td>power to winch and crane</td>
<td>Winch / crane to recover and deploy large and heavy mooring; equipment storage on deck and in dry lab</td>
<td>Store on deck: 1 railroad wheel anchor on pallet, 40&quot;x40&quot;x20&quot;, 900 lb 1 syntactic foam float, 40&quot;x40&quot;x20&quot;, 650 lb 1 empty reel, 30&quot;x30&quot;x35&quot;, 80 lb 1 reel stand, 40&quot;x40&quot;x40&quot;, 30 lb Store inside: 1 acoustic release, 43&quot;x12&quot;x15&quot;, 120 lb 1 deck unit and transducer, 31&quot;x12&quot;x20&quot;, 4l lb 1 hydrophone, 72&quot;x15&quot;x15&quot;, 150 lb 1 hardware box, small, ~50lb</td>
</tr>
<tr>
<td>SoundTrap mooring</td>
<td>.35 x .1 m</td>
<td>400 lbs</td>
<td>Project will provide: sensor batteries. From ship, we need a basic power (three-prong plug) to test the acoustic release; and GPS. If necessary, we can use the battery power for the deck</td>
<td>Crane, and potentially the A-frame. Quick release line. Deployment could be up to 500m but will likely be shallower. May need to load the SoundTrap itself weighs 11 lbs, but the entire mooring will weigh ~400lbs including lines, acoustic releases and anchor.</td>
<td></td>
</tr>
</tbody>
</table>

354
| **HARP Package** (SCRIPPS) | 47x | 830 | -- | box to communicate with the acoustic releases. | equipment the day before, and from a pier. | hydrophone to give release commands when recovering. | A-Frame deployed and recovered |

**Supporting documents**

<table>
<thead>
<tr>
<th>Document Name</th>
<th>Notes</th>
<th>Download Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>NOAA Protected Resources Permit</td>
<td>NMFS Permit No 22306 (PI-Shannon Rankin, SWFSC)</td>
<td><a href="http://sanctuariesimon.org/vpm/docs/cruiseDocs/doc_1.pdf">http://sanctuariesimon.org/vpm/docs/cruiseDocs/doc_1.pdf</a></td>
</tr>
<tr>
<td>NOAA Sanctuary Permit</td>
<td>MULTI-2019-005 (PI-Shannon Rankin, SWFSC)</td>
<td><a href="http://sanctuariesimon.org/vpm/docs/cruiseDocs/doc_1.pdf">http://sanctuariesimon.org/vpm/docs/cruiseDocs/doc_1.pdf</a></td>
</tr>
<tr>
<td>NOAA Sanctuary Permit-map</td>
<td>MULTI-2019-005, maps of relevant sanctuaries (PI-Shannon Rankin, SWFSC)</td>
<td><a href="http://sanctuariesimon.org/vpm/docs/cruiseDocs/doc_1.pdf">http://sanctuariesimon.org/vpm/docs/cruiseDocs/doc_1.pdf</a></td>
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<tr>
<td>NRS Mooring Diagram</td>
<td></td>
<td><a href="http://sanctuariesimon.org/vpm/docs/cruiseDocs/doc_1.jpg">http://sanctuariesimon.org/vpm/docs/cruiseDocs/doc_1.jpg</a></td>
</tr>
<tr>
<td>SWFSC Drifting Buoy Diagram</td>
<td></td>
<td><a href="http://sanctuariesimon.org/vpm/docs/cruiseDocs/doc_1.jpg">http://sanctuariesimon.org/vpm/docs/cruiseDocs/doc_1.jpg</a></td>
</tr>
<tr>
<td>SWFSC Drifting Buoy Map</td>
<td>Map of deployment locations for drifting buoys</td>
<td><a href="http://sanctuariesimon.org/vpm/docs/cruiseDocs/doc_1.jpg">http://sanctuariesimon.org/vpm/docs/cruiseDocs/doc_1.jpg</a></td>
</tr>
<tr>
<td>NRS-13, MB-05, and CH-01 Stations Map</td>
<td>Map of seafloor mooring locations</td>
<td><a href="http://sanctuariesimon.org/vpm/docs/cruiseDocs/doc_1.jpg">http://sanctuariesimon.org/vpm/docs/cruiseDocs/doc_1.jpg</a></td>
</tr>
<tr>
<td>SoundTrap mooring (MB-05 and CH-01) diagram</td>
<td></td>
<td><a href="http://sanctuariesimon.org/vpm/docs/cruiseDocs/doc_1.JPG">http://sanctuariesimon.org/vpm/docs/cruiseDocs/doc_1.JPG</a></td>
</tr>
<tr>
<td>Maps of Potential Loading Piers in Morro Bay</td>
<td>1) &quot;Otter viewing&quot; T-dock: boat crane can be used to retrieve gear from flatbed truck onto the boat. Need to contact Harbormaster; first-come, first-serve 2) Guest slip near &quot;Wine Bistro&quot; has convenient parking</td>
<td><a href="http://sanctuariesimon.org/vpm/docs/cruiseDocs/doc_1.jpg">http://sanctuariesimon.org/vpm/docs/cruiseDocs/doc_1.jpg</a></td>
</tr>
<tr>
<td>MBNMS research permit</td>
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<td><a href="http://sanctuariesimon.org/vpm/docs/cruiseDocs/doc_1.pdf">http://sanctuariesimon.org/vpm/docs/cruiseDocs/doc_1.pdf</a></td>
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<tr>
<td>NRS-05 CINMS research permit</td>
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<td><a href="http://sanctuariesimon.org/vpm/docs/cruiseDocs/doc_1.pdf">http://sanctuariesimon.org/vpm/docs/cruiseDocs/doc_1.pdf</a></td>
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# APPENDIX V: SPOT Trace Battery Life Data Sheet

## SPOT Trace Battery Life Chart

<table>
<thead>
<tr>
<th>Mode</th>
<th>100% Clear view of the sky and stored in room temperature</th>
<th>50% Clear view of the sky/50% Obstructed</th>
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</thead>
<tbody>
<tr>
<td>5 MINUTE TRACK PROGRESS</td>
<td>~ 8 Days</td>
<td>~ 4 Days</td>
</tr>
<tr>
<td>(if constantly moving)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 MINUTE TRACK PROGRESS</td>
<td>~ 25 Days</td>
<td>~ 13 Days</td>
</tr>
<tr>
<td>(with 8 hours of movement per day)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 MINUTE TRACK PROGRESS</td>
<td>~ 4.5 Months</td>
<td>~ 2 Months</td>
</tr>
<tr>
<td>(with 1 hour of movement per day)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.5 MINUTE TRACK PROGRESS</td>
<td>~ 6 Days</td>
<td>~ 3 Days</td>
</tr>
<tr>
<td>(if constantly moving)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.5 MINUTE TRACK PROGRESS</td>
<td>~ 18 Days</td>
<td>~ 10 Days</td>
</tr>
<tr>
<td>(with 8 hours of movement per day)</td>
<td></td>
<td></td>
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<tr>
<td>2.5 MINUTE TRACK PROGRESS</td>
<td>~ 2.7 Months</td>
<td>~ 1.3 Months</td>
</tr>
<tr>
<td>(with 1 hour of movement per day)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Deep Ocean Vehicle Applications & Modifications

Presented By: Nikki Arm
Committee Members: Dr. Andrew Davol (Chair, ME),
Dr. Jim Widmann (ME), Dr. Crow White (MSCI)

Several years in the making, this thesis builds upon past projects to further enable ocean research through technological advancement. This project had two primary goals: (1) to implement the existing deep ocean vehicle in active scientific research, and (2) to explore opportunities to further the lander’s reach using alternative pressure spheres. Join Nikki as she discusses her work with Dr. Crow White and his marine science undergraduate students in planning and executing at sea deployments while accounting for budgeting, weather, permitting, and multi-organizational logistics. Working with both NOAA and the Cal Poly Marine Operations staff has enabled numerous pier and boat deployments to be executed by Nikki and her team – greatly enabling scientific studies. Additionally, she will share details about her work to gain a greater understanding in the limitations and design choices made for existing pressure spheres, as well as exploration of alternative designs and materials for pressure spheres used in deep-sea applications. With a focus on laminated composites, she utilized Finite Element Analysis (FEA) in combination with real world test results to determine what changes could be made to the existing technology to enable her lander to go deeper than ever before!

A Master’s Thesis Defense in Mechanical Engineering
California Polytechnic State University, San Luis Obispo

Thursday November 16th, 2023, 9:10 AM
Building 13, Room 124B
Zoom Meeting ID: 826 8687 2697
Deep Ocean Vehicle
Applications + Modifications

A MECHANICAL ENGINEERING MASTER'S THESIS DEFENSE
BY NIKKI ARM

COMMITTEE: DR. ANDREW DAVOL [CHAIR],
DR. JIM WIDMANN, & DR. CROW WHITE

Project History + Purpose

- History
  - Summer '21 – Global Ocean Design Internship
  - 2021-'22 School Year – Interdisciplinary Senior Project

- Purpose
  - Explore Potential Design Improvements
    - Alternate Pressure Sphere Designs + Materials
  - Continue Assisting Dr. White’s Research
    - BACI Windfarm Study off Morro Bay
    - Mentor Undergraduates
    - Deployment Operations + Procedures
DOV SeaStang

Danka Comejo  Marine Science, ’24
Maya Netto  Biology, ’25

Existing Pressure Sphere Analysis
Types of Existing Pressure Spheres

<table>
<thead>
<tr>
<th>Sphere Name</th>
<th>Material Make-Up</th>
<th>Depth Rating</th>
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<tbody>
<tr>
<td>Green</td>
<td>15% Glass Fiber 85% Nylon</td>
<td>1 km</td>
</tr>
<tr>
<td>White or Olive</td>
<td>30% Glass Fiber 70% Nylon</td>
<td>2 km</td>
</tr>
<tr>
<td>Glass</td>
<td>100% Glass</td>
<td>10 km</td>
</tr>
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Current Pressure Sphere Testing

Photos Provided by Kevin Hardy at Global Ocean Design
Current Pressure Sphere Testing

Photos Provided by Kevin Hardy at Global Ocean Design

<table>
<thead>
<tr>
<th>Sphere Type</th>
<th>Manufacturer Max Depth (m)</th>
<th>Manufacturer 4hr Working Depth (m)</th>
<th>Manufacturer 1yr Working Depth (m)</th>
<th>Test Implosion Pressure (psi)</th>
<th>Final Depth Rating (m)</th>
<th>Factor of Safety</th>
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<tbody>
<tr>
<td>White</td>
<td>4.500</td>
<td>3.800</td>
<td>2.300</td>
<td>4,700</td>
<td>3.175</td>
<td>2,000</td>
</tr>
<tr>
<td>White</td>
<td>4.500</td>
<td>3.800</td>
<td>2.300</td>
<td>4,800</td>
<td>3.243</td>
<td>2,000</td>
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<tr>
<td>Olive</td>
<td>4.500</td>
<td>3.800</td>
<td>2.300</td>
<td>4,400</td>
<td>2.973</td>
<td>2,000</td>
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<tr>
<td>Olive</td>
<td>4.500</td>
<td>3.800</td>
<td>2.300</td>
<td>4,350</td>
<td>2.939</td>
<td>2,000</td>
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<tr>
<td>Olive</td>
<td>4.500</td>
<td>3.800</td>
<td>2.300</td>
<td>4,300</td>
<td>2.905</td>
<td>2,000</td>
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<tr>
<td><strong>Average</strong></td>
<td><strong>4.500</strong></td>
<td><strong>3.800</strong></td>
<td><strong>2.300</strong></td>
<td><strong>4,510</strong></td>
<td><strong>3.047</strong></td>
<td><strong>2,000</strong></td>
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Current Pressure Sphere Modeling

- Finite Element Analysis
- No Dimensions in Abaqus

<table>
<thead>
<tr>
<th>Fundamental Unit</th>
<th>English Unit</th>
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<tbody>
<tr>
<td>Length</td>
<td>Inches</td>
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<tr>
<td>Force</td>
<td>Pounds</td>
</tr>
<tr>
<td>Time</td>
<td>Seconds</td>
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</table>

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Value</th>
<th>Units</th>
</tr>
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<tbody>
<tr>
<td>OD</td>
<td>10.0</td>
<td>in</td>
</tr>
<tr>
<td>T</td>
<td>0.8</td>
<td>in</td>
</tr>
<tr>
<td>W</td>
<td>0.14</td>
<td>in</td>
</tr>
<tr>
<td>D</td>
<td>0.072</td>
<td>in</td>
</tr>
<tr>
<td>t</td>
<td>0.168</td>
<td>in</td>
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</table>
Current Pressure Sphere Specs

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
<th>Units</th>
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</thead>
<tbody>
<tr>
<td>Density</td>
<td>0.049</td>
<td>lb/in³</td>
</tr>
<tr>
<td>Water Absorption: 24-Hour Immersion</td>
<td>1.0</td>
<td>%</td>
</tr>
<tr>
<td>Water Absorption: Equilibrium [73°F in Water]</td>
<td>7.0</td>
<td>%</td>
</tr>
<tr>
<td>Tensile Stress at Break</td>
<td>14,500</td>
<td>lb/in²</td>
</tr>
<tr>
<td>Tensile Modulus</td>
<td>812,000</td>
<td>lb/in²</td>
</tr>
<tr>
<td>Flexural Strength</td>
<td>24,600</td>
<td>lb/in²</td>
</tr>
<tr>
<td>Flexural Modulus</td>
<td>725,000</td>
<td>lb/in²</td>
</tr>
<tr>
<td>Poisson’s Ratio</td>
<td>0.352</td>
<td>-</td>
</tr>
</tbody>
</table>

Simple Axisymmetric Model

- Surface-to-Surface Contact Interaction
- Fixed Point
- Internal Pressure
- External Pressure
Model Failure

- **Failure Stress:** 14,500 psi
- **External Pressure:** 3,954 psi
- **Depth:** 2,690 meters
- **7.36% Error**
- Shallower than Experiments
- Conservative

---

O-Ring Groove Effects
Electrical Port Hole Effects

Alternate Pressure Sphere Designs
Incompressible Fluid-Filled Sphere

- Fluid-Filled
- External Pressure: 12,670 psi
- Depth: 8.621 meters
- More than 3x Max Depth Air-Filled

Varied Wall Thickness

\[ T = 2 \times 10^{-7} d^2 - 0.001d + 1.9096 \]
Cylindrical Equatorial Ring

<table>
<thead>
<tr>
<th>Material</th>
<th>Failure Pressure (psi)</th>
<th>Failure Depth (m)</th>
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<tbody>
<tr>
<td>No Ring</td>
<td>3.954</td>
<td>2.690</td>
</tr>
<tr>
<td>30% Glass 70% Nylon</td>
<td>2.351</td>
<td>1.600</td>
</tr>
<tr>
<td>Aluminum</td>
<td>2.702</td>
<td>1.838</td>
</tr>
<tr>
<td>Stainless Steel</td>
<td>3.017</td>
<td>2.053</td>
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Spherical Equatorial Ring

<table>
<thead>
<tr>
<th>Material</th>
<th>Failure Pressure (psi)</th>
<th>Failure Depth (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Ring</td>
<td>3.954</td>
<td>2.690</td>
</tr>
<tr>
<td>30% Glass 70% Nylon</td>
<td>3.053</td>
<td>2.077</td>
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<tr>
<td>Stainless Steel</td>
<td>3.915</td>
<td>2.664</td>
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Alternate Pressure Sphere Materials

Types of Laminated Composites

[Images of different types of laminated composites]
Laminated Composite Properties

<table>
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<tr>
<th>Property</th>
<th>584 Carbon</th>
<th>282 Carbon</th>
<th>7781 Fiber Glass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
<td>HexForce 8 Harness Satin 3K Carbon Fiber &amp; Toray Prepreg Resin Epoxy</td>
<td>HexForce Plain Weave 3K Carbon Fiber &amp; Toray Prepreg Resin Epoxy</td>
<td>HexForce 8 Harness Satin Fiber Glass &amp; Toray Prepreg Resin Epoxy</td>
</tr>
<tr>
<td>CPT (in)</td>
<td>0.0169</td>
<td>0.0094</td>
<td>0.0095</td>
</tr>
<tr>
<td>Ten. Stress (psi)</td>
<td>92,600</td>
<td>112,120</td>
<td>58,900</td>
</tr>
<tr>
<td>Comp. Stress (psi)</td>
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<td>70,130</td>
<td>58,900</td>
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<tr>
<td>Shear Stress (psi)</td>
<td>14,360</td>
<td>14,140</td>
<td>8,000</td>
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</table>

Laminated Composite Lay-Ups

- Close to 0.8” Thick as Possible
- Quasi-Isotropic:
  - Symmetric
  - Consistent Lamina Angles
  - Each Lamina has Same
    - Fiber-Resin Ratio
    - Layer Thickness
    - Fiber Type + Geometry

371
Laminated Composite Lay-Ups

<table>
<thead>
<tr>
<th>Material</th>
<th>584 Carbon</th>
<th>282 Carbon</th>
<th>7781 Fiber Glass</th>
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<tr>
<td>Lamina Thickness (in)</td>
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<td>0.0095</td>
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<tr>
<td># of Lamina</td>
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<td>88</td>
<td>88</td>
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<tr>
<td>Laminate Thickness (in)</td>
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<td>New OD (in)</td>
<td>10.0224</td>
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<td>Lay-Up</td>
<td>$[[[-45/45/0/90]]]_4$, $[[[-45/45/0/90]]]_s$, $[[[-45/45/0/90]]]_l$,</td>
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</table>

48 + 88 Layer Visuals

[Images of composite lay-ups]
### Stress Failure Comparison

<table>
<thead>
<tr>
<th>Sphere Type</th>
<th>Model Failure Pressure (psi)</th>
<th>Percent Change from Original (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Original</td>
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<td>2,690</td>
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<tr>
<td>584 Carbon</td>
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<td>13,906</td>
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<tr>
<td>282 Carbon</td>
<td>19,506</td>
<td>13,273</td>
</tr>
<tr>
<td>7781 Fiber Glass</td>
<td>16,510</td>
<td>11,234</td>
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</table>

### Tsai-Hill/Wu Failure

![Tsai-Hill/Wu Failure Diagram]

TSAI

\[ \text{TSAI} = -0.979167, \text{Layer} = 1 \]

Average: 75%

TSAI

\[ \text{TSAI} = -0.979167, \text{Layer} = 1 \]

Average: 75%
Tsai-Wu Failure Comparison

<table>
<thead>
<tr>
<th>Sphere Type</th>
<th>Model Failure Pressure (psi)</th>
<th>Model Failure Pressure (m)</th>
<th>Percent Change from Original (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Original</td>
<td>3,954</td>
<td>2.690</td>
<td>0.00%</td>
</tr>
<tr>
<td>584 Carbon</td>
<td>10,000</td>
<td>6.804</td>
<td>152.91%</td>
</tr>
<tr>
<td>282 Carbon</td>
<td>9.242</td>
<td>6.289</td>
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<tr>
<td>7781 Fiber Glass</td>
<td>6.630</td>
<td>4.511</td>
<td>67.68%</td>
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</table>

Limitations of Current Analysis

- Additional Features
  - Equatorial Rings
  - Electrical Port Holes
  - View Ports
- Manufacturing Imperfections
  - Creation of Voids/Porosity

- Decrease Depth Rating
  - Stress Concentrations
  - Failure Points
Scientific Equipment Updates

Light Filter Caps
Large Vessel Recovery Device

Sketches by Kevin Hardy

Deployments + Operations
Pier Deployments

Danika + Maya's Solo Deployment
NOAA's Ships

- R/V Fulmar
- R/V Shearwater

Photos by NOAA

Port Deployment Test on Fulmar
Summer Shearwater Deployment

Harmony Deployment Footage
Nov. Shearwater Deployments

Next Steps
Pressure Sphere Analysis

- Models Including
  - Equatorial Ring
  - Electrical Ports
  - View Ports
- Manufacturing + Testing Spheres
  - Compare to Models
- Moisture Absorption
  - Increase Moisture
  - Decrease Strength
- Fatigue Life-Cycles
  - # of Deployments Before Needs to be Replaced
- Cost Comparison
  - Depth Rating v. Cost

Acknowledgments

- Funding provided by Warren J. Baker & Robert D. Koob Endowments
- Special Thanks to
  - Dr. Andrew Davol, Dr. Crow White, & Dr. Jim Widmann
  - Danika Cornejo & Maya Netto
  - Kevin Hardy at Global Ocean Design
  - Paul Kuhl at General Atomics
  - Dr. Lindsey Peavey & the rest of the NOAA Team
  - Tom Moylan & Jason Felton
Thank You!

Questions?

Works Cited


What Happened to Seastang?

- Current Theories
  - Stuck in the Mud?
  - Super Soft Sediment
  - Cover Burn Wires
  - Catch Bait Arm
  - Tangled in Ghost Net/Fishing Line

- How to Get Her Back
  - SPOT Trace GPS
    - Battery can last up to 1.3 Months
  - “If Found Please Recover” Sticker
    - My Contact Info Attached

Photo by Pirates of the Caribbean

Weave Types

- Plain
- 4-harness satin
- 5-harness satin
- 8-harness satin
- Twill
Mesh Convergence Study

Mesh Sizes
Min. Principal Stress Results

Radial Node Spacing vs. Stress (psi)

- Mesh Convergence
- Theoretical
- Poly. (Mesh Convergence)

Final Mesh

- Mesh #6
- 0.05 Radial Spacing
- 0.10 Circumferential Spacing
- 0.533% Error from Theoretical
APPENDIX Y: Full Deployment Details

APPENDIX Y-1: Pier Deployments

APPENDIX Y-1.1: Port San Luis Pier

While we had access to the Cal Poly pier and have used it in the past for test deployments as a part of my senior project, we had found the height of the pier made it difficult to deploy the lander due to the need to hoist it 10-15 feet into the air to reach the lower-level platform. While this was doable in senior project, it had also led to an incident where the lander had hit the underside of the pier damaging one of the counterweights and its visibility flagpole. The flagpole had been snapped but was able to be repaired, while the counterweights had to be scrapped and new ones needed to be made. To prevent this risk of damages and make deployment operations easier, the team made the unanimous decision to instead deploy from the Port San Luis Pier in Avila. These deployments were completed on the piers lower-level floating platform used for boarding small watercraft and were positioned in a way to ensure the platform could still be used by the rest of the public without interfering with the lander operations.

![Port San Luis Pier Lower Platform](image1)

*Figure Y-1: Photograph of Port San Luis Pier Lower Platform*

The first deployment we completed was a training demonstration deployment where I completed a full deployment (set-up through clean-up) as Danika and Maya watched and asked questions,
explaining the lander’s base operations and showing how to use it. This deployment not only allowed them to learn how the lander operates but gave them a better idea of its uses and limitations while developing their survey experiment methodology for Dr. White. This deployment was completed prior to any modifications made to the lander as discussed in Section 2.1 and was part of the team’s basis in determining what modifications needed to be made for their research.

After developing Maya and Danika’s basic engineering skills and familiarizing them with hand tools, I ran them through a dry-land deployment which is where we complete all the preparations leading up to a deployment, and clean-up/analysis for after, but the lander never leaves the project room. This was a great first practice for getting more hands-on experience with the lander and its components without the stress of travel and unpredictable environments. With this under their belts, we then set about completing a group deployment where they were hands-on and actively involved in the lander’s set-up, assembly, deployment, recovery, clean-up, and analysis. A large part of this deployment was familiarizing them with how to operate the lander and safely ensure its function and return in marine environments as discussed in Section 4.2.1.2 above. Additionally, it provided them with experience maneuvering the lander manually, transporting it, and increased their confidence levels in the lander’s reliability and function. It’s easy to question if something will work by watching someone else do it, but having done it yourself teaches you about it in an entirely different way – they were truly Learning by Doing.

![Figure Y-2: Team with Lander for Pier Deployment](image-url)
They also had the opportunity to experience imperfect conditions. As you can see in the figure below, the visibility of the water this day was low such that there were times we couldn’t see the bait arm, let alone any fish at its base.

![Figure Y-3: First Team Lander Deployment Footage](image)

Now that they had a deployment under their belts, it was time to begin preparing them for their next milestone – a solo deployment. This deployment would be completed with me present and
watching, able to step in incase a catastrophic mistake that would permanently damage the lander was going to be made, but otherwise be hands off and quiet – letting them prove to themselves they are capable of doing the deployment without me. With this goal in mind, I started answering all their questions and having them take notes about how to complete a deployment. I helped them develop a Packing List for what to bring with them on deployments and a Deployment/Recovery Checklist highlighting key steps along the way. The basis of these was the existing Operations Sheet I created with my senior project team and updated for NOAA, then Maya and Danika worked together to tweak it as they thought would be most helpful to their understanding by adding notes as we talked through procedures together and asking questions along the way. Once their checklist was done and final questions were asked, it was time for them to begin their solo deployment.

While completing this deployment, Danika and Maya worked very well together and did a great job. I'm very happy that any questions they had for me during this test were able to be answered in a way where they either remembered or found the answer to their own question: For example, “Which way does the burn wire go [while bolting it onto the lander]?” was answered through asking them questions about the purpose of the burn wire and placement of the other burn wire already on the lander in order for them to determine its proper orientation without me outright telling them. Overall, this test was a success! The burn wires went off successfully, the lander came back on its first burn, and they completed nearly everything by themselves – the only time I put my hands on the lander was when asked to help hold something at their request since sometimes a third set of hands makes the job a lot easier.

That said, there were a few things that did not go according to plan. The first was that they did not document what time they had set the burn-wire timers for and got it mixed-up such that the lander came up half an hour earlier than they expected. This was however in line with the time I remembered them initially discussing at the beginning of their lander set up, so I know if they had taken the extra couple seconds to document burn times, this error would not be repeated. Having them experience this however, will help with their memory of documenting such decisions in
future operations. More importantly, and more disappointingly to them, was that the camera and lights did not turn on or record during the deployment. This was unfortunate because this was the first deployment since adding the light filter caps to the lander, and they were excited to see how it worked underwater, but was not a big loss in my books as we learned an important detail I had been unaware of before: We discovered that if you unplug the CamDo after setting camera times, it will reset the device and you will need to resynch it and start that step over after reattaching it to the GoPro. Afterwards, I discussed with them their thoughts on the operations and had two main take aways: (1) they now felt a lot more confident in how to operate the lander; and (2) they wished we had done a solo “dry deployment” test run on campus first. In hindsight, this makes a lot of sense, and I can definitely understand how a solo “dry deployment” as an intermediary step would have been beneficial so will be sure for any future students and scientists to add this step into my plans for their training.

Figure Y-4: Danika and Maya’s Solo Deployment

This was supposed to be the completion of our pier deployments for the summer, however, as will be discussed in the next section, there were some complications in our plans to go to sea with NOAA in July. Unfortunately, we were unable to go to sea on the R/V Fulmar due to poor weather conditions making the area unsafe for operation at the time. However, because of this we decided to complete a final pier deployment on the day we were supposed to go to sea with Fulmar in order to test our light filters. Since Maya’s research showed that blue light was better for shallow water studies, we swapped the light filters back to blue instead of the red we had planned on
using with NOAA and set out for the pier. The deployment went smoothly, and we used this opportunity to practice utilizing the large vessel recovery device we developed in preparation for deep-water operations which also went well. We learned when analyzing the footage that the blue lights are so bright and vibrant, they can sometimes wash out the fish making it difficult to determine the species seen. We believe this was partially caused due to the turbidity in the water at the pier making poor visibility conditions and more particles in the water to reflect the blue light.

Figure Y-5: Pier Deployment Blue Light Filter Test
APPENDIX Y-1.2: Cal Poly Pier

While we had originally planned on not doing any deployments off the Cal Poly Pier, this decision changed in late October at the request of Dr. White. He wanted us to work with another one of his undergraduate students, Sierra Bentti (Marine Science, Class of 2024), who was developing lesson plans for high school curriculum and was going to use lander footage as a part of her lessons. Because of this, when I returned to campus for the Cal Poly Pier Open House on October 27th, we decided to do a deployment as well.

When I first got back to campus the day before, our group participated in Cal Poly’s United by Excellence program. As Dr. White explained to us, United by Excellence is a one-day event hosted by the Office of Admissions. It is designed to provide access to educational resources, equitable learning experiences, and higher education preparation to underrepresented and historically underserved student scholars interested in pursuing higher education. The session we helped host was tied into Admissions’ Latinx/e heritage event. I, Danika, Maya, Dr. White, and Sierra presented to 8 groups, each made up of 4 high school students from underrepresented communities and taught them about our research. To do this, we showed them the lander in person, explaining how it functions, and played highlight reels of footage for them as we explained the impacts this research had on our knowledge of the deep sea. Together, we represented the biology department and took turns presenting and interacting with students. This was also my first-time meeting Sierra and her first time seeing the lander in person.

![United by Excellence Presentation Team](image.png)

*Figure Y-6: United by Excellence Presentation Team*
After completing the United by Excellence event, Maya, Danika and I prepared the lander for the next day’s deployment after open house. For this, we set-up the camera and burn-wire timers as well as decided on an exact deployment time. We also decided to use a new battery set up suggested to us by Kevin to enable longer video recordings. For this we removed the internal GoPro battery and instead relied entirely on the back-up battery it was plugged into. This was done because past deployment recordings were being cut short of our 90-minute goal at 88-minutes due to the battery dying, and Kevin informed me that when the original battery was in place it would over-ride the backup battery and not have it be used by the system. Once everything was set up, we loaded Maya’s car with everything needed for Open House and the deployment before dropping everything off at the pier.

![Image](image1.png)

*Figure Y-7: Cal Poly Pier Open House [32]*

The next day, we woke up bright and early and got to the pier to set up our stall for Open House. Here we had a very similar set up to that from United by Excellence where we showed the lander and highlights reel, but with the addition of the poster made by my senior project team [1]. Both the highlights reel and poster used can be found in Appendix S. Danika, Maya, and I collectively presented to the local community, encouraging more enthusiasm from the public for our research. Overall, I had a great time, and everything went off without a hitch. In total we had 2,120 visitors.
to the pier, 500 of which arrived within the first hour of opening. My favorite interaction was with one little girl (7 or 8 years old) who, upon finding out what our project was, got the widest eyes and biggest smile – literally shaking with excitement – and said, "I LOVE THE DEEP-SEA!" She loved hearing about the lander, and I don’t think could have moved faster when I directed her to our videos she could watch!

Once Open House was complete and we finished helping with clean up, we were joined by Sierra as well as Kyle Walsh (one of my Senior Project team members) and Jake Roth (current Cal Poly Marine Science student) who all helped us complete our pier deployment. Because I have long standing shoulder problems, I knew I would not be able to reliably hold the lander’s weight while lowering and lifting the lander from the pier’s lower platform, which is why I called in reinforcements to assist in our operations. Kyle and Jake helped spot Maya and Danika in lifting and lowering the lander into the water and Kyle was able to give them great advice from having deployed the lander in this location many times. Jake unfortunately had to leave after the deployment began, but everyone else stayed around for the entire operation. Things went great overall, with deployment and recovery going relatively smoothly and a great learning experience for Danika and Maya.
That said, there were a few take-aways from this deployment. At the time, we were unsure why but after the lights turned on at the time of deployment, they then immediately turned off again. After further investigation though, we found that the video did record for these couple seconds and all the electrical ports were properly plugged in but the back-up battery was entirely dead. From this we concluded that the backup battery had died on us prior to the lander ending up in the water. We believe this occurred since we set the times for the deployment more than 24 hours in advance. However, I have done this in the past with the GoPro battery attached and did not have this issue, so we believe the back-up battery had less power than the built-in option. For this reason, we decided for our NOAA deployment to return to our original set up and plan to further investigate the camera battery situation in the future. Additionally, we successfully determined that Maya and Danika can deploy the lander but believe at least 3 people able to lift the lander are required to do a deployment off the pier safely (for both people and lander safety). For future deployments we determined that it would be best not to have the lander's visibility flag attached, nor the support rod for the lifting bale. This is because these poles are very fragile and can easily be caught on the underside of the pier during recovery. In fact, as mentioned earlier in this section, we even had the flagpole snap on us for this reason in a previous deployment for
senior project. Since the lander is easily visible from the platform without the flag, and the recovery rope is already attached to the bail (meaning it doesn’t need to be held aloft for a boat hook to grab), it was decided these components were unnecessary for this type of operation and could be safely neglected.

Figure Y-10: Cal Poly Pier Deployment Footage

APPENDIX Y-2: Boat Deployments

APPENDIX Y-2.1: NOAA Deployments

The most exciting deployments we completed as a part of this project were done in coordination with the National Oceanic and Atmospheric Administration (NOAA). Dr. White was able to connect me with one of his friends who now works at NOAA, Dr. Lindsey Peavey, it was thanks to her that we were able to make all these operations possible. Lindsey knew we had a tight budget but was also working on research with her own team that would be taking place along the central coast, including within the Wind Energy Area (WEA) itself. Because of this, Lindsey and I worked together with the rest of the NOAA operations team to find ways for us to tag along on their already scheduled operations to complete our lander deployments and conduct our research in conjunction with them.
The first trip we planned was to go to sea with Lindsey and her team on the R/V Fulmar in July of 2023. The plan for this trip was to go out with them for two days, the first completing a shallow water test in the Monterey Bay National Marine Sanctuary (MBNMS) while the crew serviced a data buoy (MB05) they have stationed there, and the second being inside the WEA while the team serviced another buoy in the area. This planning was all happening simultaneously with the training Danika and Maya were receiving from me and happening in parallel to our pier test deployment operations and manufacturing of lander modifications. While the plan for us to join on the Fulmar had been set months in advance, the true operations planning began in the few weeks leading up to the actual deployment date.

![NOAA's R/V Fulmar Ship](image)

*Figure Y-11: NOAA’s R/V Fulmar Ship [33]*

The first of these planning meetings was coordinating with Jean de Marignac, the Field Operations Coordinator for the Fulmar trip. As a part of this, I provided Jean with a Specs Sheet I made for the lander and an updated version of the lander’s Ops Sheet to share with the crew. Additionally, I had a phone meeting with Jean where I explained to him how the lander operates, what my teams’ needs were for the deployments, and most importantly how the deployment and recovery operations would function. This was the most complicated part of our discussion and raised the most questions since the Fulmar is a far larger vessel than those I had deployed the
lander off of in the past (a 67-foot ship instead of the Cal Poly TL Richards which is a 26-foot boat). On smaller vessels, I had been able to manually lift the lander over the side of the boat and place it in the water by hand, as well as use a boat hook to bring the lander next to the boat before lifting it back on deck manually. This, however, would not be possible on the Fulmar or any other large vessels we deploy the lander off of due to the deck being significantly higher above the water’s surface. Jean and I developed a plan for lowering the lander into the water using a line with one end tied to the ship, and the other end loose and looped through the lander’s recovery bale. With this we could then slowly lower the lander overboard by letting out more line from the loose end, and letting go once it was in the water and the free end would then simply slide out of the loop as the lander sunk. We were unfortunately unsure what the best recovery method for the lander would be however, so at his advice I reached out to my mentor Kevin Hardy at Global Ocean Design who I built the original lander with to get his advice since I knew he had deployed landers off larger vessels before. As discussed in Section 4.1, Kevin advised I create a new large vessel recovery device which we could then use on the Fulmar to recover the lander safely. A full description of these plans and the final decided operations can be found in Appendix F.

When first making plans for the Fulmar trip, there was a miscommunication within NOAA where we had been told we did not need any permits for our planned operations. However, two weeks before our planned deployments we learned that in order to deploy on the first day in the MBNMS we would in fact need a permit. At this point Dr. White was out of town through our deployment dates on vacation with his family, so I stepped up and took the lead role in filing for the permit. Lindsey was a great help to me as I had never filed for a permit before, and she also worked with Sophie De Beukelaer (NOAA Permit Coordinator) to help expedite our permit application and thankfully we were able to get our permit before the cruise. Documentation of the entire permitting process can be found in Appendix C. Sadly, however, we were unable to use the permit for this cruise as poor weather rolled into the central coast at the time of our boat trip. While at first the cruise was simply delayed by a few days, it was ultimately cancelled due to unsafe operating conditions at sea making it hazardous for my team to execute any lander operations. To make up
for this though and give my team a chance to both meet Lindsey, her team of scientists, and the Fulmar crew we organized a time to meet them in port in Morro Bay to complete a practice run of deployment and recovery operations for the lander off the vessel.

Even though we did not get out to sea on the Fulmar, we had a fantastic experience meeting everyone on board and it was a great learning experience for performing lander operations on such a large vessel. Completing our deployment and recovery operations was a success and learning how to use the ships A-frame, winch, and quick release devices was extremely useful in both planning and confidence levels for future deployments. Additionally, we determined the best location for our team to complete lander set up inside the ship next to the galley and became familiar with the ship’s layout and how at-sea procedures function. The entire crew was extremely welcoming and encouraging, I loved learning about their research operations and getting the opportunity to share with them about our research as well as teach them how the lander operates.

![Figure Y-12: R/V Fulmar Port Test Operations (Photos courtesy of NOAA crew)](image)

Even though we were unable to go to sea with NOAA in July on the R/V Fulmar, Lindsey suggested we reach out to the R/V Shearwater (a 62-foot vessel with nearly identical layout and equipment as the Fulmar) crew since she knew they would be in the central coast in August. While the crew was very willing to accommodate us, we learned this trip was being funded by a research group from Stanford who were performing research in the area. Because of this we
were told we would need their permission to join, so I was connected to Dr. Marilla Lippert who was the Principal Investigator (PI) of this trip. After talking with Marilla, it was very fun to learn that she had actually worked in Dr. White’s lab when she was an undergraduate student at Cal Poly, so she was thrilled to find a way to incorporate us into their cruise. Because their research was primarily close to shore dive operations, they would not be making any trips out to the WEA but said they were still happy to include us on one of their day trips to get practice doing a real deployment/recovery off one of NOAA’s ships. It was decided we would be joining them on their day from Morro Bay to the Harmony Headlands dive sites. There we would stop near their second dive location to drop the lander, then proceed to the first dive location, wait for them to complete their dive, and return to the second dive site where they would do their second dive before we go to recover the lander.

Figure Y-13: NOAA’s R/V Shearwater Ship [34]

The next step in the planning process was to begin official paperwork and planning for our cruise. As a part of this I learned how to use NOAA’s Vessel Project Manager (VPM) system which is an online portal where I can create project proposals, float plans, cruise plans, and more, such that NOAA can track what equipment and people will be on their vessels on any given day. For this process I worked with Danny Lucas, the vessel operation coordinator for the Shearwater. It began with a quick email summary of our project and explanation of our goals for the cruise, then was elaborated in a zoom call where I answered his questions more in depth and learned how the vessel operates more fully. Thanks to my previous planning with Jean on the Fulmar, it was very
easy to explain our new deployment and recovery operations to Danny in order for him to relay it all to the crew. Additionally, Danny explained to me what my role as PI of our project would be. I was responsible for completing all VPM documentation, relaying safety guidelines to my team, and ensuring all were followed. Additionally, during the time we were completing our operations on the ship, I was responsible for managing my team’s time and interfacing with the crew for all ship operations. With all documentation and planning complete, we were ready to go to sea. All documentation for this cruise can be found in Appendix H.

The only thing standing between us and deploying the lander now was the weather. This however proved to be more interesting than we had expected because the same weekend I was scheduled to travel back to SLO for the deployment was the very same weekend southern California was hit by hurricane Hillary. Due to the high wind and surf caused by the storm, the Shearwater’s departure from Santa Barbara was delayed by a day but was thankfully still able to get to Morro Bay for our deployment on August 22\textsuperscript{nd}, 2023. Since I had completed my coursework in the Spring of 2023, I had moved home to San Diego meaning I was planning to take the train north on the very day Hillary hit San Diego. Almost all trains between Los Angeles and San Diego that weekend had been canceled as a safety measure, but miraculously mine had not. So, with a rain jacket and umbrella at the ready, I made my way to the station and was relieved when we began heading north. Unfortunately, the Category 1 hurricane raging overhead was not the only trouble we would face that day, but a 5.2 magnitude earthquake would strike Ojai, California – ultimately making the tracks unsafe to pass during the storm and stopping us in Los Angeles for the night. Luckily my brother lives only 10-minutes from the station we were stopped at, so he came to my rescue, and I was able to stay with him for the eventful night of flash flood and tornado warnings and witnessing the eye of the storm. The next morning, the tracks had been cleared and I was able to hit the road again. I successfully survived the great Hurri-quake of 2023, making it back to SLO in time to begin preparations for going to sea the next day!

We joined the crew on the R/V Shearwater that afternoon in Morro Bay. After introductions and loading both projects supplies aboard, we left port and headed to the Harmony Headlands. We
deployed the lander at 35.455379, -121.008636 (west of Harmony 1 Dive site) at a depth of approximately 60ft. On our way to the drop site, Danika, Maya, and I completed the entire set up on a moving ship with 4-5ft swells which made maneuvering parts a bit challenging. Regardless, we worked together like a well-oiled machine, effectively setting up the lander with no delays. With the lander set-up complete, it was time for deployment operations. First, the lander recovery bale was attached to a quick-release mechanism. The quick-release was attached to the end of a line which was passed through a pulley on the ship’s A-frame and whose length is controlled by a mechanical winch system. Additionally, two guidelines were looped through the side body of the lander. The ship’s crew manned the A-Frame and winch controls, slowly moving the lander up and away from the ship before lowering it into the water such that the orange side floats were at the water’s surface. While the lander moved, Maya and Danika manned the guidelines, ensuring the lander remains stable and did not swing wildly to injure anyone. I manned the quick release wire, giving instructions about lander placement and position to the crew and releasing the lander once properly located on the surface. The entire process went very smoothly.

Figure Y-14: R/V Shearwater Deployment Operations
After deploying, we left the area to go to Harmony 2 for Marilla's team's first dive operation. While we waited for their dive operations, we got to watch a pod of humpback whales breaching along the horizon of the water. Two even came closer to the ship, with their tail fins visible only a couple hundred feet from the bow! Once all divers were back on board, we went back to Harmony 1 and our team watched for the lander to surface while the divers were in the water for the second time. One of the NOAA crew was the first to spot it on the surface since the lander was very far away on the horizon. Once spotted, our team then continued to keep an eye on it while we waited for divers to finish and return. While Maya and Danika kept an eye on the lander, I began setting up for recovery. We attached the recovery clip to the end of the line looped through the A-frame pulley and driven by mechanical winch system, just like we had done with the quick release mechanism for deployment, but with extra slack. The recovery clip/line was then attached to the end of the recovery pole. Once the dive team was back, we sailed towards the lander, approaching from down swell to allow the lander to gently come to us. I then used the recovery device to reach overboard and clip onto the lander's recovery bale. While I was doing this, Maya was responsible for spotting me to ensure I did not fall overboard due to unexpected swell while leaning over the edge of the ship. Once clipped, I removed the recovery pole and passed it to Danika. The Shearwater crew then used the A-frame and winch to reel in the lander. I stood on deck ready to catch the lander to prevent it from swinging wildly and helped guide it back on deck. Once all was back on deck, we returned the safety wires across the aft deck and began to clean up. The excess bait was disposed overboard, and the bait arm was tied back in an up-right position. The lander and all equipment that came into contact with salt water was then washed off with fresh water to prevent salt build up on our equipment. With the day a success for both projects and a fantastic learning experience, we returned to port.

Once back on shore, we returned the lander to the shop, stopping to acquire the SD card from the camera. The deployment was shallow enough that there was still good atmospheric light, so we couldn't get a great read as to whether the red light was sufficient in lighting the species seen on camera for deep water deployments, but unlike our blue light test at the pier, its brightness did
not inhibit our ability to identify species seen on the video. From our recordings we saw a total of five different species of fish, three sea pens (one of which was seen recoiling its comb on camera), but most exciting was one fish species that came to visit SeaStang – a wolf eel!

![Wolf Eel](image)

*Figure Y-15: Wolf Eel visits DOV Seastang at Harmony Headlands*

It was extremely rewarding, being able to share our results with the Shearwater crew and Marilla’s team but was even more rewarding as a mentor to hear all the compliments from both the NOAA and Stanford teams about how impressed they were with our team and their excitement to work with us again in the future.

In November, we had the opportunity to do just that by joining Dr. Lindsey Peavey and her team of scientists on the R/V Shearwater for the Central Coast Collaborative Passive Acoustic Monitoring research cruise. For this cruise my team was scheduled to go out on the ship for two days, the first on November 7th to do a 90m deployment at the location of NOAA’s MB05 buoy in the Monterey Bay National Marine Sanctuary and the second on November 8th to do a 1km deployment in the Wind Energy Are (WEA) off the coast of Morro Bay.
Set up for these deployments began on November 6th, where my team completed lander preparations and purchased additional supplies necessary for our deployments. We began by fixing one of the light filter caps as we found it broken upon returning to our project room that day. Thankfully it was a rather simple fix to super glue one of the legs back on where it had snapped off but was an unexpected addition to our list. Next, we soldered on new burn wires and prepared additional burn wires, chain, and weights for the second day of deployments to bring with us on the ship. We charged all of the batteries before assembling the lander. Lastly, now that the glue on the light filter cap had finished drying, we replaced the light filter caps with red-filters. Finally, I completed an over-night check-out on the machine shop’s soldering iron and related tools we would need for replacing burn wires on the ship between deployments. With all the tools and vacuum pump packed, we were able to load up our cars. We then went to purchase the last supplies we needed for going to sea: additional silicone grease since we had run out and a 7-gallon plastic crate to help transport additional tools and supplies. We were then informed that due to poor weather conditions predicted the next day, both our deployments would be pushed back by a day.

The next day, while it wasn’t safe to go to sea, we were able to meet the NOAA crew to load the ship. Additionally, after loading the ship, we were invited to join them all for a group barbeque to bond and get to know everyone aboard the ship. This was a phenomenal experience and I really enjoyed getting to bond with the crew more and learn all about their different research projects. After dinner, we went home to rest before returning to the ship to depart at sunrise. On the way to the ship we realized we forgot to buy bait the night before, so Maya and Danika ran to a nearby bait shop which was scheduled to be open according to their website. However, this turned out not to be true. Thankfully though, the crew had some extra squid bait in the freezer we were able to use instead. Once everyone was on board, due to colder waters this time of year, everyone on board needed to be trained on how to put on a full-body immersion suit (basically an oversized wetsuit to keep you warm and floating if immersed in the water) in case of an emergency like the
ship going down. We each had 2.5 minutes to take out the suit and fully put it on as part of our training, which we all completed successfully!

![Figure Y-16: Full-Body Immersion Suit Test](image)

Once this training was completed, the ship left port and began its transit to MB05. My team worked to set up the lander during the hour and a half transit. This proved to be challenging since not only were we going over consistent 4-5ft swells but had occasional 8ft swells as well which lead to both Maya and Danika struggling with sea sickness. Thankfully though, we were able to get everything together before we arrived, so only had to attach the weight and bait before deploying. We deployed the lander at 35.765991, -121.430313 which had a depth of 90 meters, and was programmed for a 60-minute bottom time. For the deployment operations, I manned quick release while Danika and Emma Beretta (fellow Cal Poly student and NOAA intern filling in for Maya who was too sea-sick to assist) manned the tag lines to steady the lander while in the air and the NOAA crew-controlled the A-frame/winch.

While the lander was underwater, the NOAA team recovered their MB05 buoy and completed their buoy turnaround. We then returned to the lander drop point where we had all hands-on deck on lookout for the lander. Captain Zac spotted it behind the ship where it had drifted 500ft from
where we dropped it. The crew then repositioned the ship to approach from the down swell where I then used the Shearwater’s carabiner boat hook to latch onto the lander’s recovery bale while Danika spotted me to make sure I didn’t fall overboard. Once the lander was back on deck, we washed it off with fresh water to prevent saltwater build up on its components.

![Image](image1.jpg)

*Figure Y-17: DOV Seastang Recovery at MB05*

After NOAA redeployed their MB05 buoy, we transited back to port. While at sea we spotted lots of sea lions, otters, and sea birds, but most excitingly were 3 baby and 1 young adult Mola Mola. While in transit, we disassembled the lander’s spheres and began recharging its batteries since they take several hours to charge. Once in port, while we waited for the batteries to finish charging, I soldered on new burn wires while Maya and Danika acquired mackerel bait for the next day’s WEA deployment. Before leaving the ship, I took out the SD card in order to take it home and get a preliminary look at the videos from that day’s deployments. At home, I skimmed through the videos where I saw: lots of flat fish (sand dabs/flounders), a shark, 2 octopi, lots of crabs, and several other fish species as well. It took 2 hours for each video to upload, so before going to bed with another long day to come, I only had time to upload the first two videos to the drive that night. I planned to upload the rest along with the WEA deployment videos in the coming days after the cruise.
The next day, on November 9th, Maya unfortunately woke up sick and was unable to join us at sea that day. Danika, myself, and the rest of the NOAA crew departed once more at first light and began our transit to the WEA. While in transit, we once again prepared the lander while traversing 4-5ft swells with occasional 8ft waves. Unfortunately, today was my turn to battle some sea sickness in the process. We ended up deploying the lander just outside the WEA at 35.311600, -121.585457 which had a 900-m depth. After calculating ascent and descent times for the lander, the entire deployment was scheduled as follows: (1) 33 minutes to descend, (2) 60 minutes of bottom time, (3) 20 minutes for burn wires to burn, and (4) 36 minutes for the lander to ascend. This meant that when the lander went in the water at 9:04 AM, its burn-wire timers were set to go off at 10:36 AM, and the lander should surface around 11:32am.
The ship then transited to a location 400m away to NRS-13 drop sight for NOAA's operations. During their deployment operations, we heard a massive explosion but couldn't figure out what it was. It sounded like it came from the sky and further out to sea rather than shore and our best guess based on the sounds was a rocket or missile explosion. After a pause to assess the situation and ensure the ships safety, NOAA was able to complete their NRS-13 deployment.

After this was completed, we return to the lander drop point to keep a look out for its return. At 11:15 AM, we began having all hands-on deck keep a look out. At 11:30 AM, I started checking the SPOT Trace app, but it only showed location of the lander from when we dropped it with last signal at 8:51 AM. At 11:45 AM, I began to worry some but thought maybe there had been low salinity and the burn wires were taking longer to burn as this had happened in a past deployment off the Cal Poly pier during senior project. At 12:00 PM, we returned to collect NRS-13 while those not doing ops continue keeping an eye out for Seastang and I continued to check the SPOT Trace. Figures depicting the drop point of the lander as recorded by the SPOT Trace and the Shearwater’s navigation system can be seen below.

During these operations, my worry-filled brain began trying to think of explanations for the lander’s late arrival. I wondered if my ascent/descent calculations were off. I had based them off
the times recorded on video of the 200ft deployment from my senior project, and while I had originally remembered it being 100ft, my team all confirmed to me it was 200ft so I used their number. If I had been correct though and it was only 100ft it could double the time it took the lander to ascend/descend. I additionally began to wonder if I forgot something during deployment set up, but no – Danika and I were thorough and checked each other at every step. We made sure not to plug in burn wire batteries until after the timers were set to prevent prematurely draining the batteries. The only thing I noticed was a slight residue of salt build up on the burn wire electrode from the MB05 deployment which I had thought about cleaning off but don’t remember if I did. Even if I didn’t clean it though, while it might slow down burn times, it would not stop it from corroding entirely. Next, I wondered if the explosion sound during the NRS-13 deployment was related to the lander imploding or landing on an old military mine/bomb since, after doing the math in my head, I realized it occurred right as the lander was supposed to hit the bottom. The NOAA crew, however, all confirm this couldn’t be the case due to where we heard the explosion come from and attested that even if it did implode, we could not have heard it from that depth. The explosion sound didn’t come from underwater; it was definitely in air.

At 1:30 PM, there was still no sign of Seastang and NRS-13 operations were completed, so after discussing with the crew we began to conduct a final area visual search to look for Seastang with all hands-on deck. The search pattern followed can be seen in the image on the next page. At 2:00 PM, there was still no sign of DOV Seastang, and I was left to make the call to return to shore. On our way back, I confirmed with the crew through their sensors that the sea floor at the drop location was extremely soft/silty, meaning there is a chance the lander could have gotten stuck in the mud from its momentum upon touch down.
I officially deemed the lander lost at sea, and then began the process of notifying everyone involved in the project. I began of course with a message to Dr. White and Maya, followed by the rest of my committee, Kevin Hardy at Global Ocean Design, and the new interdisciplinary senior project team Maya and Danika were mentoring. I let them all know where things stood and our best guesses for what may have happened. In his response, Kevin mentioned that the lander could also have gotten stuck on some jetsam, like a ghost net or abandoned fishing line, and to wait for a local fisherman to find it and contact us in the next week. One of the NOAA crew told me about how in college her teams frequently had burn wires fail in past with them taking hours, days, or even months to burn. I also recounted one of Kevin’s stories of a lost lander showing up 4-5 years after it was dropped. On this deployment, the lander in question didn’t have it’s burn wire timers set so they had to wait for them to naturally corrode. It was deployed off the coast of San Diego and washed up on Catalina where a tourist found it and called the recovery phone.
number on its “If Found Please Recover” sticker. I was also told about some equipment NOAA lost just washing up in Japan 10-12 years after they went missing.

Overall, the NOAA team was very sweet about the whole situation, sharing horror stories of all the expensive high-tech equipment they had lost at sea. They said it happened to everyone in this field at least once, and while they were sorry it happened to me so early in my career, they welcomed me to the club. Saying I’m officially one of them and offering me chocolate on the ride back to shore. While talking with everyone more, I learned all of those on board wanted to tune in for my defense the following week, so I gave Lindsey the flyer for it to pass around. On the cruise that day we had lots of sightings most excitingly were harbor porpoises, humpback whales, and even a pod of Baird’s beaked whales which came right up to our ship!

![Figure Y-22: NOAA Crew + Visiting Scientists Group Photo (Courtesy of Lindsey Peavey)](image)

APPENDIX Y-2.2: Cal Poly Deployments

While we had wanted to complete another deployment off the Cal Poly boat over the summer, each attempt we made at scheduling it was unfortunately met with either scheduling conflicts or weather delays. Because of this, we began exploring other options including using a third-party
boat rental. When we had been talking with Lindsey, she mentioned meeting a ship captain in Morro Bay who did work in the WEA and would be interested in helping with scientific research. Lindsey then gave me the contact information for Captain Shawn Stamback, who I called to discuss our options with. While Shawn was incredibly willing to take us out to the WEA and assist in our lander deployments, unfortunately the cost to operate his vessel daily was more than we could fit into our budget at the time. The quote provided by Shawn was for one day and one deployment in the WEA at a price of $3,000 as can be seen in Appendix I. This combined with concerns about Cal Poly allowing students to use a third-party vessel for liability reasons, led to us unfortunately having to deem this option a dead end.