Berkeley Emergency Autonomous Responder (BEAR)

Team: Water Bears

Challenge: Surface Autonomous Vehicle for Emergency Response (SAVER)

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1 Abstract

In order to help achieve NASA's goal of returning to the Moon by 2024, an autonomous ocean surface vehicle for emergency rescue is designed. In the event of a launch abort, contingency landing, or other emergency that results in the Orion crew exiting their vehicle into a maritime environment, the BEAR (Berkeley Emergency Autonomous Rescuer) vehicle will deliver necessary supplies to astronauts in distress. Designed to be lightweight, fast, and self-righting, the BEAR will be powered using a raspberry pi, arduino, and battery, all of which are mounted in a watertight electrical box at the rear of the boat. Capable of detecting and locating an astronaut's distress beacon, the BEAR will track the astronaut and provide emergency relief supplies, which can be easily accessed through a hatch on the roof of the vehicle.

2 Background

To track down astronauts potentially separated from the crew, the BEAR uses an array of 4 antennas to locate a 121.5 MHz ANGEL homing signal and navigate towards it autonomously. We will achieve control and propulsion with differential thrust, using dual underwater propellers placed at the stern. For the exterior design, we propose a composite carbon fiber hull to minimize the weight of the vehicle and survive a 10-15 feet drop. The BEAR is designed to be self-righting, eliminating the possibility of capsizing. To allow easy access to the required payloads and electronics, the exterior is designed to be watertight. The design includes several safety features, such as ducted motors, smooth edges, and enclosed electronics. Reliable commercial off-the-shelf parts such as the KerberosSDR, Blue Robotics T200 thrusters, Raspberry Pi, Arduino, LIDAR sensors, latches, and hinges are used to increase reliability and achieve a production cost of approximately $1600.

3 Hardware Design

3.1 Technical Description

The final design is divided into three primary categories: the bottom hull assembly, the top hull assembly, and the electronics bay assembly. This categorization convention is used to more easily segregate the hardware that is unique to each primary structure (i.e. the top hull, bottom hull, and the electronics bay).

The primary structure is composed of two hull halves that form a shell when mounted together. One hull half is fully in contact with the water and the other hull half serves as a cover that fully encloses the interior. These two hull pieces were created through a vacuum bag composite layup process using milled medium-density fiber (MDF) wood panels as the mold, this can be seen in Figure 1. The result was a carbon fiber composite with clear marine grade epoxy resin as the composite matrix, this can be seen in Figure 2. There are three layers of 3k 2x2 twill weave carbon fiber cloth for the top hull and 3k 2x2 woven weave carbon fiber cloth for the bottom hull and three coats of clear marine grade varnish applied to the exterior that serves as a final sealant and waterproofing barrier.

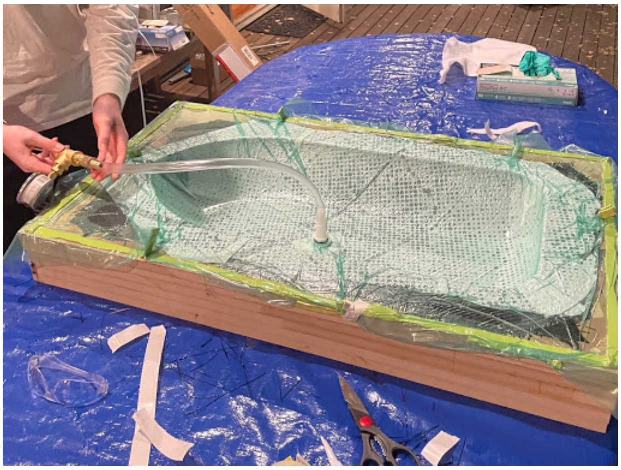

Figure 1: Carbon Fiber Composite Once Cured

Figure 2: Carbon Fiber Composite Mold Under Vacuum

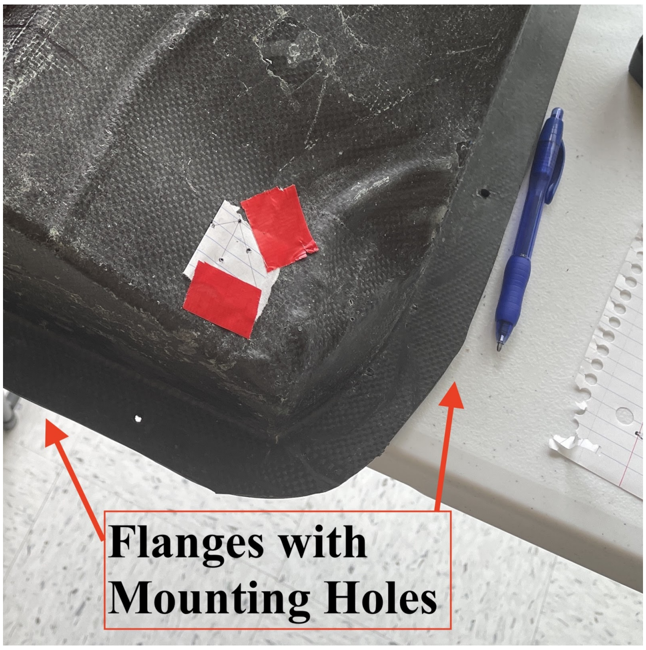

Figure 3: Bottom Hull Flanges With Holes

Each of the two negative molds for the top and bottom hulls were coated with a layer of wax mold release to smooth out the rough wooden surface post CNC and three layers of water soluble PVA mold release as a composite-mold separating agent. Once the composite was separated from the mold, excess mold release material was then washed and wet sanded to ensure there was no residual residue. The top hull resulted in a weight of about 1.4 pounds and the bottom hull resulted in a weight of about 1.7 pounds. (Note: The masses mentioned reflect the current mass with excess material removed, not the mass right after curing.)

An excess of 0.75 inches to 1 inch of composite material remained around the perimeter to provide as a flange for mounting the two halves together, this can be seen in Figure 3. With this, the length and width of both of the hulls are nearly the same with 31 inches in length and 14 inches in width, ± 0.5 inches. The bottom hull has a height of about 7 inches and the top hull has a height of about 5 inches. The two hull halves are bolted together by 13 M5 nuts, bolts and washers. The washers are rather important as they have a wider radius than the bolt/nut heads and thereby distribute the compression load more effectively over the flange surface area. This decreases the probability of fracture in the composite material as there is a comparatively lesser pressure on the flange. In between the two hull halves runs a 1 inch wide by ¼ an inch tall gasket made from medium density foam designed to prevent water from entering the interior through the hull flange interface. A final layer of waterproof silicone calk will be applied to the interior interface between the top and bottom full flanges as an added waterproofing barrier.

3.2 Self Driving Purpose

3.2.1 Top Hull Assembly

There are 4 antennas, a hatch door (with hinges, latch, and their respective shims), the electrical umbilical connector, the electrical umbilical load bearing eye bolt and a lider sensor inside a custom waterproof housing fastened to the top hull. A representation can be seen in figure 4. All but the antennas, electrical umbilical connector, and the electrical umbilical eye bolt are fastened with M4 nuts, bolts, and washers.

Figure 4: Isometric View of Top Hull

The antennas serve as a way to calculate the heading of the emergency frequency being emitted from the distressed astronaut. The antennas all have a weight of about 0.3 pounds each and are individually screwed onto their own antenna wire connector. The wire connectors passed through the hull through a ¼ inch hole where a bolt, a washer, and an O-ring hold them in place. The O-ring is necessary to ensure that water will not enter through the ¼ inch hole made from the antenna connector. The configuration of the antennas are made out to reflect the shape of a square with 13.5 inch sides. Each antenna connector is attached to an interior wire extension with the excess slack fastened to the interior surface of the top hull and screws into four more connections attached to the aft top corners of the electronics bay.

The hatch door's function is to allow access to the interior of the BEAR's payload when open while simultaneously acting as a water barrier when closed. The hatch door is 3D printed 5 inch by 14 inch by inch rectangle made from PLA material. Attached to this are 2 hinges, 2 compression spring draw latches, and the same 1 inch wide by ¼ inch tall gaskets running the parameter of the hatch door, all totalling a weight of about 1.1 pounds. (Note: Previous interactions presented an acrylic hatch door and only one compression spring draw latch. Due to fatigue and subsequent warping, this is no longer being used, but may be shown in presentables.) Compression spring draw latches were chosen as a fastening mechanism due to their compression characteristics. This is preferential in regards to water resistance as compressing the foam gasket will ensure an ideal seal between the hatch door and the 4 inch by 13 inch rectangular hole in the top hull. There are two rail-like shims on either side of the hatch door: one is used as an attachment point for the hinges and the other is used as an attachment point for the compression spring draw latch hooks. These shims are each mounted to the top hull with M4 bolts and fastened on the interior with M4 nuts. There is a layer of waterproof silicone calk on the interface between the top hull and each shim and around the interior nuts for added water proofing security.

The lidar sensor is mounted to the interior of a 3D printed housing designed to be waterproof. An acrylic sheet is used as a window for the lidar sensor to see out of and it is permanently glued into the housing. There is one hole in the bottom that allows the wire leads to enter the interior of the top hull and further mount to the electronics bay. Excess wire is mounted to the interior of the hull. There are two configurations of the lidar sensor housing: one is parallel with the top hull and the other is pivoted downward to compensate for the vehicle pitching up under acceleration.

The electrical umbilical connector is one that is designed to be waterproof, be easily disconnected from the umbilical, and act as a barrier between the exterior and interior. The connector is meant to hold the appropriate gauge wire we chose to supply the BEAR with power through NASA's supplied power source. The connector is held in place by permanent glue and silicone calk and sits in a hole in the rear of the BEAR roughly the same size as the connector itself.

The electrical umbilical load bearing eye bolt is mounted near the electrical umbilical connector and serves as a location to attach the electrical paracord. If the electrical umbilical is pulled from the poolside, the load will be transferred to the eye bolt and not to the electrical connector.

3.2.2 Bottom Hull Assembly

The bottom hull piece has the motors, electronics bay, battery, and payload mounted to the interior and exterior. The bottom hull acts as the primary floatation device and platform for all of the electrical and payload components on the interior. It also is used as a location for the aft motors to be mounted and supported on the exterior.

With the motors being attached to the bottom hull with four M3 bolts each, the wires that supply them power pass through holes right under the bottom flange. These wires are then connected to the electronics bay and are held in place by silicone calk as a fastening measure and a waterproofing measure. 9.5 and 10.5 degree wedges are added as spacers between the motors and bottom hull as a way to point the motors in the same direction. After the composite-mold separation, there seemed to be an error that left our composite slanted, leading us to correct the error in motor direction.

The electronics bay is mounted on the keel of the interior floor by numerous velcro strips rated to carry 10 pound loads. A protective cover is also mounted to the electronics bay that is intended to prevent a false trigger of the breaker switch. Along with this, the battery is mounted to the farthest rear of the BEAR interior, sitting between the electronics bay and bottom hull. This helps with pitch and handling performance. This can be seen in Figure 5. (Note: The figures presented are not final representations of the BEAR. Specifically, there may be excess tape, loose wires, etc. that will not be present in the final iteration sent to the NBL.)

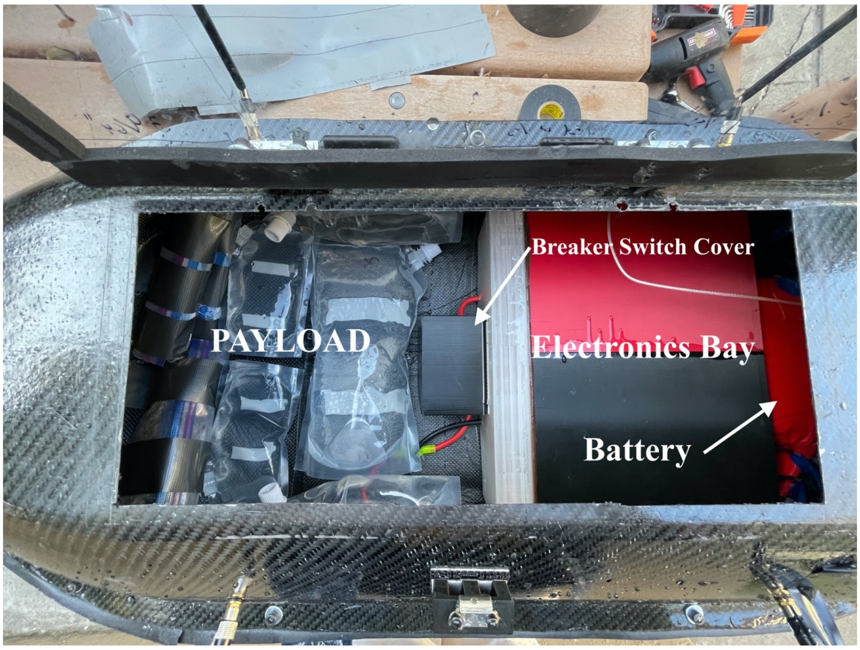

Figure 5: BEAR Interior

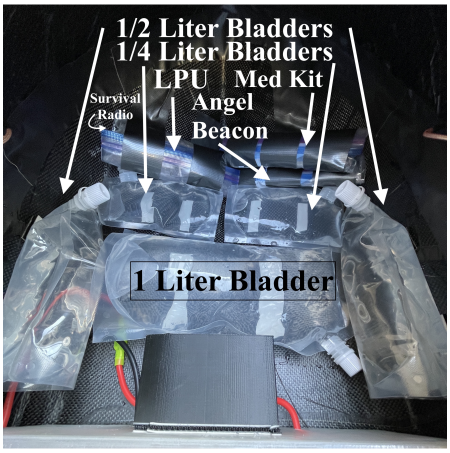

Figure 6: Payload Arrangement

The payload consists of 2.5 liters of water and four sandbags used to simulate the weights of the life preserver unit, the spare angel beacon, the survival radio, and the medical kit. The 2.5 liters are divided up into a single 1 liter bladder weighing in at 2.5 pounds, dual ½ liter bladders each weighing in at about 1 pound, and dual ¼ bladders each weighing in at about 0.5 pounds. The total weight of the water will be 5.5 pounds. The med kit weighs about 0.6 pounds, the life preserver unit weighs about 1.1 pounds, the survival radio weighs about 0.6 pounds, and the angel beacon weighs about 0.3 pounds. The water fill be fixed to the interior floor of the bottom hull by 10 pound capable velcro straps. These serve a lightweight yet easily removable solution to accessing the payload contents inside that are also relatively unaffected by water if splashed.

3.2.3 Electronics Box Assembly

The electronics box was entirely 3D printed from PLA material and consists of two primary components: the door sled and the housing. The door sled serves to enclose the electronics box and as a platform to mount all of the electrical hardware to, as seen below. The electrical hardware is fastened to the sled by means of 10 pound load capable Velcro. (Note: Wire lengths will be shortened and wiring configurations will be fastened and organized in final interaction sent to NBL.) A gasket seal is placed on the ridge interface of the cover which ensures a barrier of water resistance when screwed onto the electronics box with four M4 bolts.

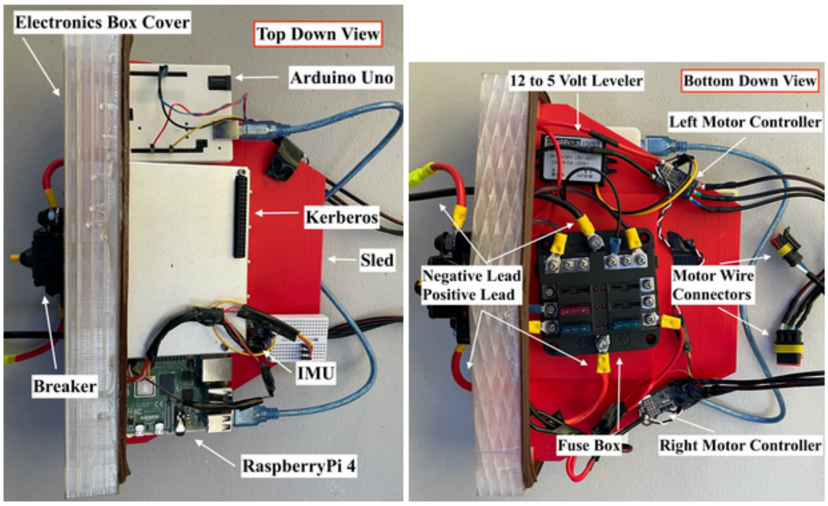

Figure 7: Top and Bottom View Electronics Bay

The electronics box houses an Arduino Uno, RaspberryPi, fuse box, 12 volt to 5 volt potential converter, right and left motor controllers, Kerberos, IMU, and breaker. The cover sled is intended to pull out in one piece leaving only the two motor connections, the four antenna connections, and the lidar sensor wiring connectors. The cover sled was also designed to fit conveniently through the top hatch for ease of maintenance if there was an issue with any electrical equipment and something needed to get services in a timely manner. This can be seen below. (Note: The lidar sensor wiring and board are not shown in these images but they will be present in the final iteration sent to the NBL.) The ground lead coming out of the front cover and the positive lead connected to the breaker can both be connected to either the battery housed in the rear or can be connected to the electrical umbilical connector in the rear of the top hull.

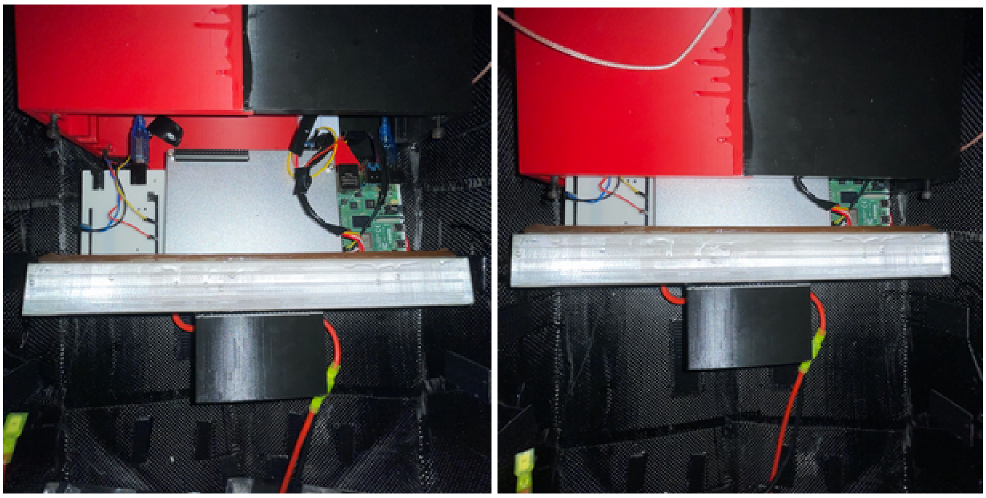

Figure 8: Cover Sled With Hardware Sliding into Electronics Box

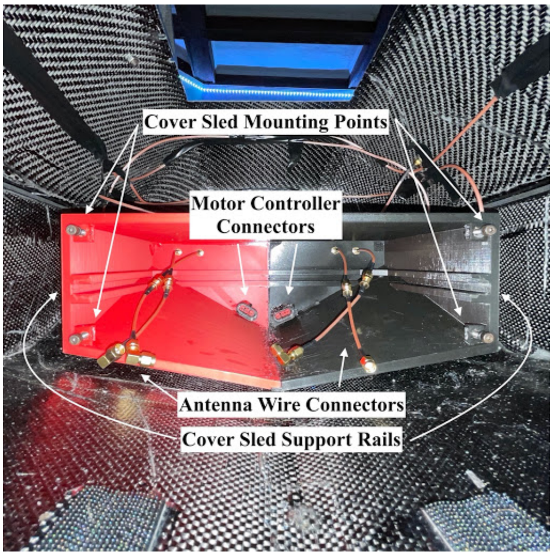

Figure 9: Electronics Box Housing Interior

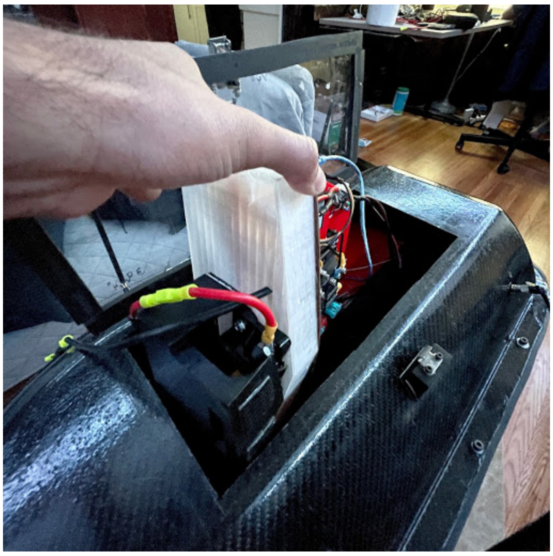

Figure 10: Cover Sled Through Hatch Door

3.3 Functional and Technical Requirements Table

Functional/Technical Requirement	BEAR Requirement Fulfilment
The vehicle shall be capable of being carried on a Group 2 (MTOW 21-55lbs) close-range UAS	BEAR currently weighs about 21.71 pounds, placing it safely within the required weight limit for Group 2 close-range UAS.
The vehicle shall be capable of transporting a minimum of 1 liter of water, a medical kit, a spare LPU, a spare ANGEL Beacon, and survival radio.	The vehicle has been tested to meet this requirement with either the parts themselves or parts of equivalent mass, and has thus shown it is indeed capable of transporting all of the listed payload.
The vehicle shall be capable of using existing equipment to detect the ANGEL beacon 121.5 MHz homing signal in order to guide the vehicle toward the beacon.	We will be using 4 antennas incrementally placed 13.5” apart. The signals will be processed using the KerberosSDR, giving us the direction of the radio emitter. Based on the angle of the direction we will adjust power to thrusters to have the boat face in the correction direction.
The vehicle shall be capable of traveling to the person in distress via the most direct route in an autonomous manner, including: unmanned operation, self-guided operations to move to the GNSS position, and the ability to follow programmed mission profiles to address specifics of a rescue scenario.	The vehicle will be using direction finding based on the signal the Angel beacon transmits. To stop the vehicle we will be using a Lidar sensor to detect the approaching astronaut. Regarding different locations/mission profiles, the vehicle will travel to the location of the radio autonomously and won’t need multiple types of programs for different mission profiles.

The vehicle shall include protections in software/hardware to ensure no harm to the crew upon arrival in their vicinity.	The software is designed to slow the vehicle to slow/stopped speeds by first reversing and then killing the motors at 10m to insure safety of the astronaut . Hardware protections include extensive use of sanding to ensure there are no sharp edges, marine-grade and non-carcinogenic coating materials are used to ensure lubricants aren't in contact with the crew, and use of soft gasketing materials ensure pinch points are minimized. BEAR only has one moving part that needs to be operated by the crew which reduces the chance of injury from loose components.
The vehicle shall be able to operate nominally in both fresh and salt water environments.	Marine-grade epoxy resin and marine-grade composite varnish ensure that there is no corrosion to the BEAR hull in either environment. The use of stainless steel nuts and bolts also ensures this, as well as using waterproof silicone calk to seal entry points to the interior.
The vehicle shall be able to interface with the NBL power outlet via an umbilical cable.	We will be using a 75ft 10awg umbilical cord. Connecting the cord to the boat using water proof connectors and bananclips to the power source.
The vehicle shall not jettison any unrecoverable parts into the environment.	The interior of the vehicle is entirely self-contained beyond one access hatch on the top of the craft. Since BEAR is self-righting, the hatch should never be in a position to cause potential jettison of parts. Even in the case this does occur, the hatch is held in place with a latching mechanism that is strong enough to hold any payload in.
The vehicle must be designed for a range of 1 nautical mile.	The antennas should be able to pick up radio signals farther than 1 nautical mile away. There needs to be more testing for this.

4 Analysis and Testing

4.1 Computation Fluid Dynamics

The unmanned surface vehicle (USV) is designed to be statically stable in open water due to internal righting moments developed by a low center of gravity; however, further simulation is required to robustly design for seakeeping in more dynamic scenarios. Using Numeca's FINE™/Marine CFD solver, the USV's seakeeping ability will be rigorously analyzed to understand the vehicle dynamics considering a free surface and variable wave conditions. Key simulation outcomes include determining range of stability along with evaluating dynamic stability under various theoretical quasi-static loading scenarios. The ultimate goal of this study is to arrive at a hull configuration for physical carbon-fiber composite prototyping that optimizes the seakeeping performance metrics described above.

4.1.1 Model Validation

Not included in this report in the interest of brevity. Elementary test cases were conducted in order to validate the FINE/Marine CFD solver results. These test cases included a sphere in uniform flow and a cone placed at the free surface. Both simulations have extensive data published in literature and confirmed the results derived from the solver.

4.1.2 Mesh Generation

The current hull iteration was placed within a box to define the simulation domain's bounding box. The upper surface of the bounding box is defined as a free surface between the two fluids: water and air. The hull shape was subtracted from the bounding box at a previously calculated water displacement (from weight) and pitch. Due to the computational limitations of the simulation machine, a crouse mesh was used over the entire domain and was locally refined around the hull's contour.

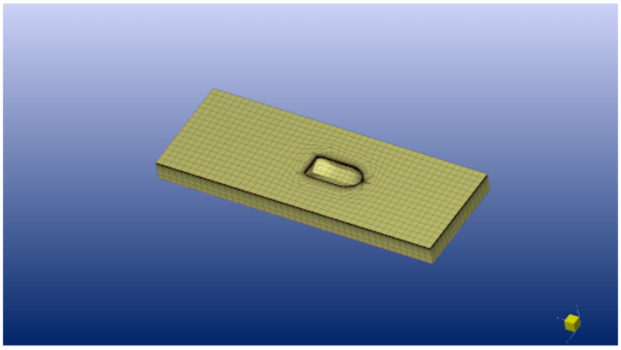

Figure 11: Mesh Generation

4.1.3 Preliminary Results

The parameter of greatest interest for determining hull performance is hydrodynamic pressure along the hull's exterior. As in any iterative design process, we are attempting to reduce weak points, which in the case of CFD, translates to minimizing localized areas of high hydrodynamic pressure along the hull. In addition, we want to decrease the drag experienced by the boat. Areas on the hull that show higher pressure and have a normal vector opposing the direction of flow will generate drag. Points of interest based on these analysis guidelines are highlighted in the below screen captures.

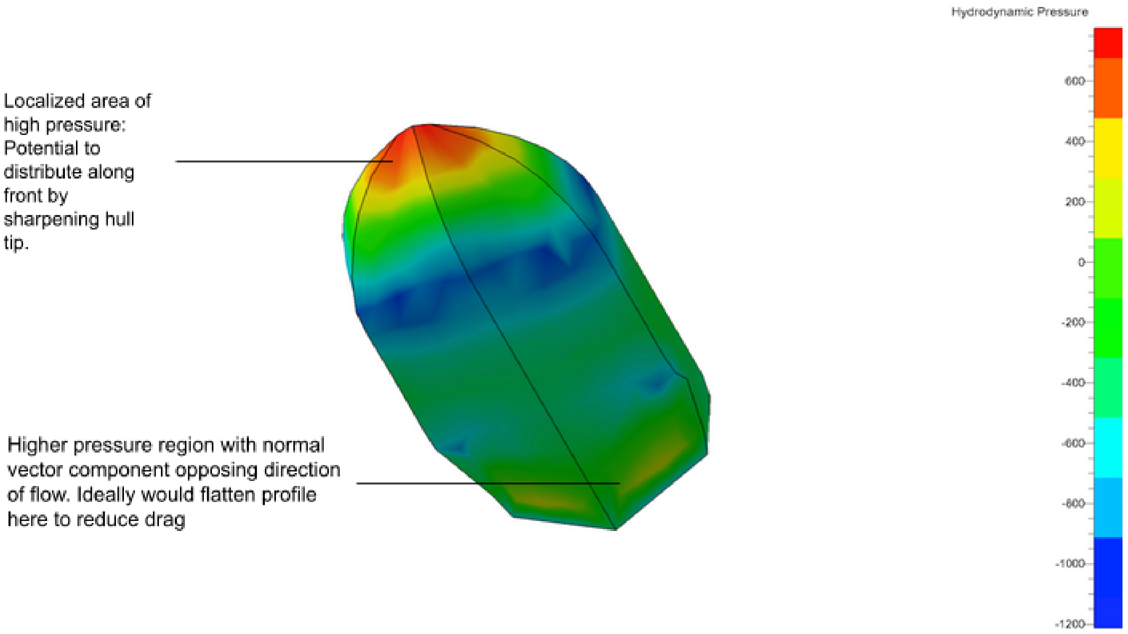

Figure 12: Hydrodynamic Pressure Load Distribution Perspective 1

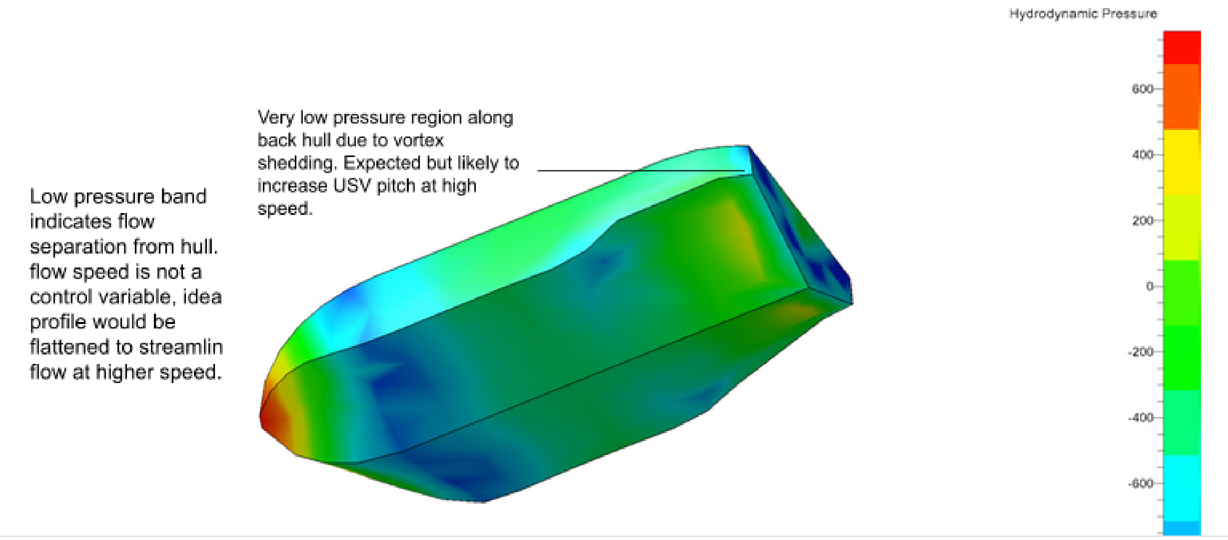

Figure 13: Hydrodynamic Pressure Load Distribution Perspective 2

The supplemental figures below are present to validate the conclusions drawn above.

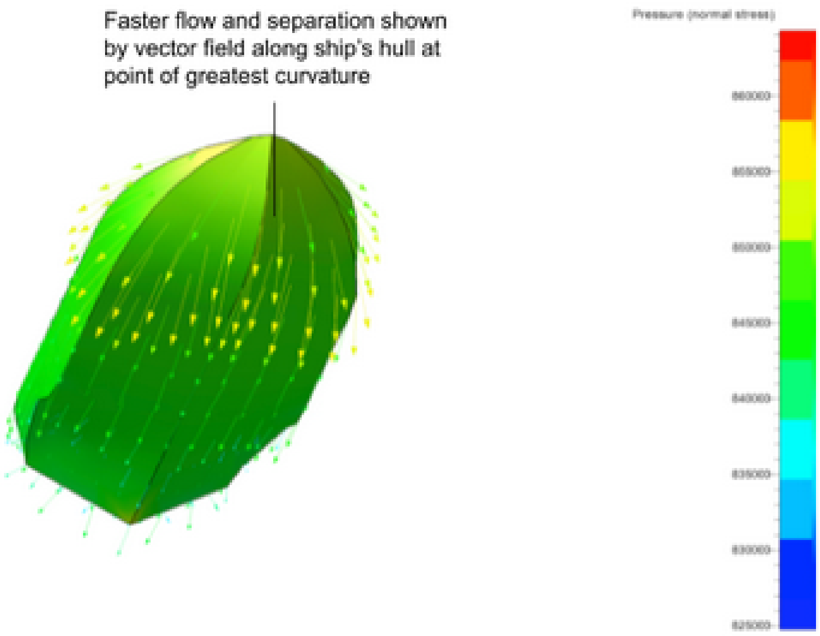

Figure 14: Supplement 1

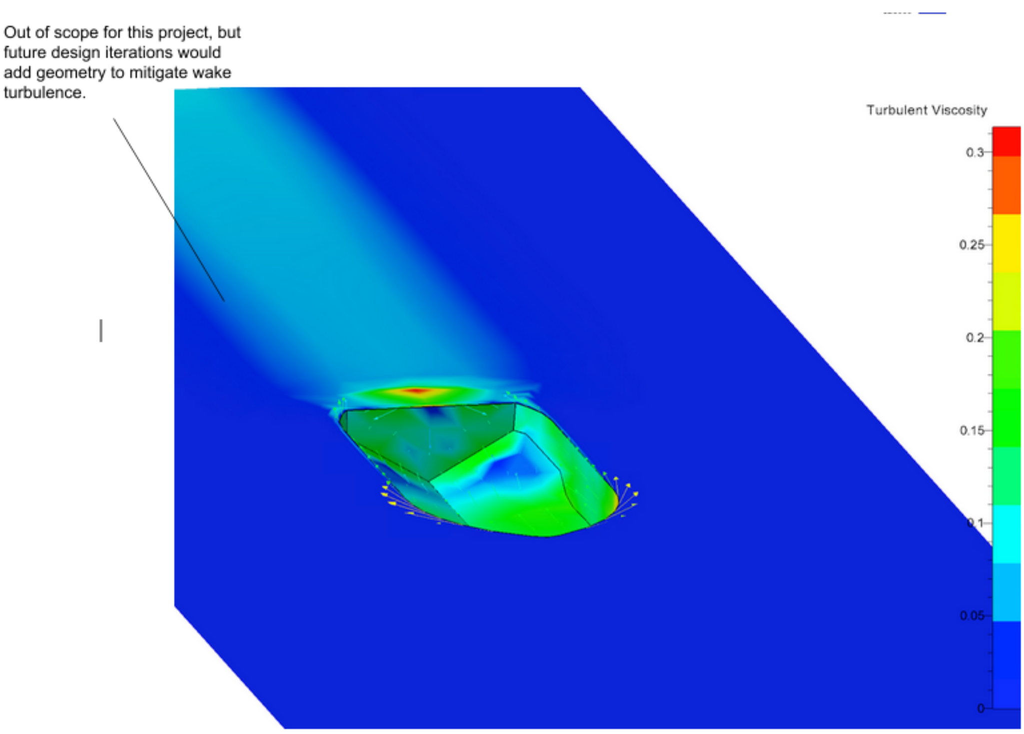

Figure 15: Supplement 2

4.2 Description/Result and Further CFD in ANSYS FLUENT

The hull of the boat has two big pieces, the top half and bottom half of the hull, that are attached together. It uses gaskets and silicon to waterproof the gap between the two pieces. To completely waterproof the carbon fiber hull we applied multiple layers of varnish.

The Electronics are in a waterproof/water resistant bay within the hull. It has gone through testing in the shower but not submerged in water. The boat can currently be controlled to move remotely and is on schedule to have the direction finding ready for testing next weekend on 4/24. The software for the distance sensor is written up and needs to be tested and implemented into the main structure of our code.

Some unexpected results during testing was when thrusters were using the same power it would not go straight, this has to do with the uneven placement of the thrusters on the bottom of the hull. We accounted for the unevenness by powering a single thruster with less power during early april testing.

We rearranged the payload towards the back of the boat more, such as the battery. We wanted the boat to pitch upwards a little bit so that the nose of the boat wouldn't tip down at high speeds, decrease splashing, and increase fluid dynamic.

While the BEAR was designed with the intent to survive at least a 10 foot free fall drop into water, to confirm these capabilities CFD was needed to examine the actual pressure forces the craft would experience in this water entry scenario. Utilizing ANSYS's FLUENT CFD solver, these pressure forces were analyzed, with the maximum among them being used to run FEA on the hull to ensure that the experienced stresses on the hull were beneath the yield point of our material. Specifically, a transient time FLUENT simulation was run using a multiphase volume of fluid method considering six degrees of freedom. Of course, for the subsequent FEA the Von Mises criterion was used to determine our factor of safety for yielding.

4.2.1 Mesh Generation/Simulation Set-Up

The required mesh for this iteration of CFD varied slightly from that in the previous section. Since we are interested here with motion in the z direction, the mesh was created via a boolean subtraction of our bottom hull shape from a large rectangular prism, resulting in a cavity within the prism. Due to limitations with the ANSYS license utilized and the simulation machine, a relatively small mesh was employed (as the number of control volumes was a limiting factor). As such, within the simulation the boat did not free fall from 10 feet, but rather fell from about .03 meters given an initial velocity as if it had already fallen 10 feet.

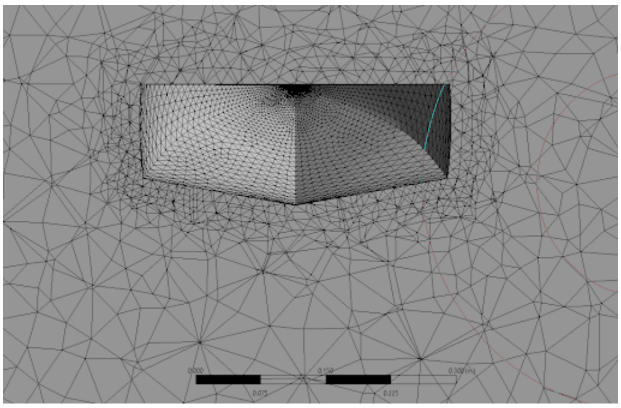

Figure 16: Mesh Generation - Section View

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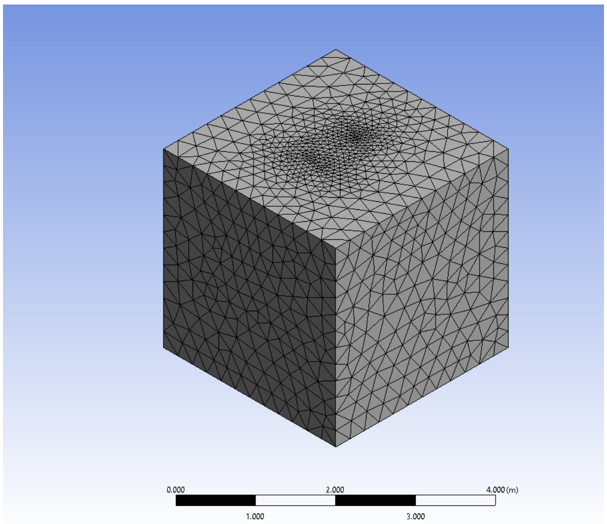

Figure 17: Mesh Generation - Isometric View

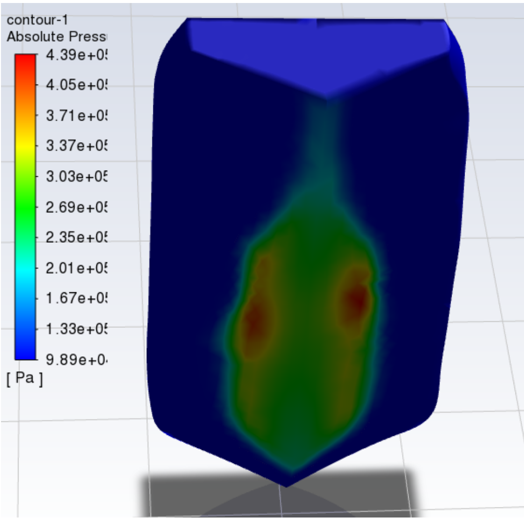

Figure 18: Pressure Contour with Maximum Gauge Pressure

4.2.2 Finite Element Analysis

From figure 18, we can see the maximum gauge pressure the craft experiences in water entry is 338 kPa (to see all generated pressure contours, see the following link: https://imgur.com/a/srw2wAg). While this pressure is only in two small zones on the bottom of the hull, to create a more conservative FEA we apply this along the entire pressurized area, pictured in green/yellow in figure 18. The following picture shows that in this load case, we have a FOS to yielding of around 1.3. Despite being a slim margin, this simulation is fairly conservative (the worst load case is taken over a larger area, when in reality this would never occur and the worst load case happens over a very small time span). We thus conclude that the BEAR craft can indeed withstand water entry from a height of 10 feet. Note that the fixed surface in the center of the craft is representative of a support rib that helps to both strengthen the hull and reduce deformation.

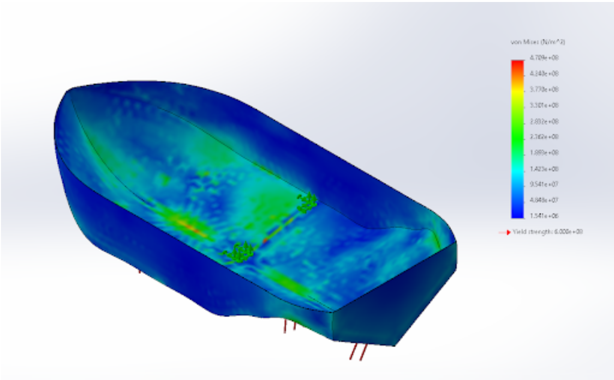

Figure 19: Bottom Hull Structural Stress

4.3 SOLIDWORKS FEA For Mounting Holes

Three mounting points (via eye screws) were placed on the Bear's top hull for the purpose of transport. To ensure the top hull was strong enough to hold its weight (about 18 pounds) through these mounting points, SOLIDWORKS FEA was conducted to verify high FOS for yielding. While more in depth FEA (that further considered the anisotropic behavior of our composite material) could be conducted, the high factor of safety (minimum of 1.5 occurs at unrealistically high zone of stress at bolt holes, FOS is on average 2 or higher) that our FEA displayed in SOLIDWORKS confirmed beyond doubt that our top hull would be able to withstand the stresses it would experience through these holes. The mounting load was applied via a remote load above the center of the top hull to simulate the scenario NASA specified (i.e. 3 cables connected at one point above the boat).

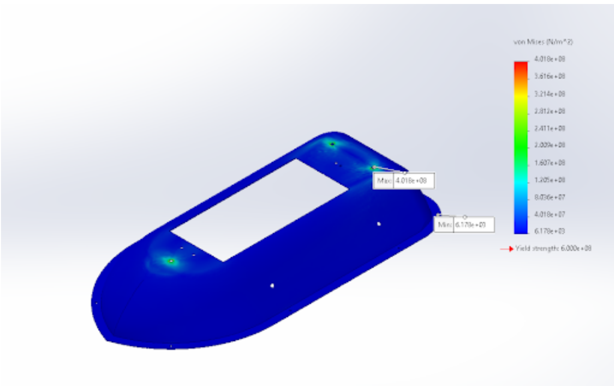

Figure 20: Top Hull Hoist Structural Stress

4.4 KerberosSDR Direction Finding

After considering a variety of options, our team decided that the best solution for signal tracking and homing would be the commercially purchased RTL-SDR KerberosSDR. Testing of the KerberosSDR can be separated into two parts: ensuring its physical functionality of the Kerberos's signal tracking, and retrofitting the Kerberos software to function for our boat.

To individually test the Kerberos's functionality, we utilized commercially available antennas, coaxial cables, and a raspberry pi, mounting the antennas on a wooden board to mimic their placement on our boat. We began by using the KerberosSDR commercial software, which utilized the raspberry pi to connect to a Wifi hotspot and transmit data to a web browser application. After experimenting with a variety of different configurations for values such as antenna gain, sampling frequency, filter bandwidth, FIR tap size, decimation, and direction finding algorithms, we were able to obtain accurate signal direction finding results utilizing a 138.5 Mhz Radio Signal (the closest publicly available signal to our target 121.5 Mhz).

We were originally under the impression that we would need antenna switches in order to disconnect the antennas during calibration; however, after several rounds of testing, we found that calibration could consistently and accurately be performed as long as there was no signal from our target bandwidth transmitting at the time. More importantly, we found that calibration did not need to be redone every single time. By saving the settings values from the previous calibration and direction finding steps, we could safely skip the calibration steps and immediately begin signal tracking, greatly speeding up and simplifying the process.

We also found that the results tended to be rather inaccurate when testing indoors or directly next to large structures, likely due to radio signals bouncing off the surrounding surfaces. However, both the pool's testing environment and an aquatic ocean would be sufficiently empty for this problem to be ignored.

running it locally instead of hotspot
hacking away at the kerberos software

4.5 Motors

We sought to use a combination of python and C++ on the raspberry pi and arduino respectively to control our motors. Because the KerberosSDR would calculate and return the direction of the desired signal, we designed our program to take the direction we wanted our boat to travel in and then convert that into power values for our motors. In order to decrease the amount of computational time and memory needed, we choose to hardcode the motor values for a variety of different direction angles instead of relying on the computationally expensive sine and cosine functions.

One major issue we had was that the python programs on our raspberry pi and the C++ scripts on the arduino were running on different intervals. Because the arduino took much longer to run the necessary calculations and power the motors than the raspberry pi, the direction we wanted to drive in and the values the motor was running at would quickly go out of sync. To fix this, we tested placing sleep functions (intentional delays in a program) at various points in our code, eventually finding a configuration which allowed the two computers to run together consistently. We also had some setbacks regarding the motors shutting off when running at full power for more than several seconds outside of water, likely due to overheating; however, this was easily fixed by simply limiting the speed at which the motors ran to less than 80% of its max speed.

A benefit to the motors is that they are enclosed. The motors being enclosed ensures that foreign objects such as seaweed and other debris will not get entangled within the motors and cause the motors to fail. This is a huge advantage in real world scenarios as this could cause the boat to malfunction altogether. Another benefit to the motors being enclosed is that they protect the crew and keep astronauts as well as other items on the boat safe. This guarantees overall protection in regards to the enclosure of the motors, as safety is a number one priority during the handling and drive of the boat.

4.6 IMU

The IMU will be used to control the stability of the ship. We will be using the orientations sensors from the IMU to make sure the ship is pointed towards the correct angle.

We have implemented a PI controller that controls the angle of the ship along with the thrust. In doing so, this will allow us to correct the angle of the ship should it drift off course. The desired angle will be set by the Kerbrose.

Another plan for the IMU is to use it to detect swells to control the thrust and lidar. Based on the readings of the IMU, we can calculate where the ship is along a wave. We can then optimize thrust for stability and discard noisy lidar readings.

4.7 Lidar

The lidar will be used to slow down and stop the ship once it gets close to the astronaut. The lidar we will be using is:

https://www.adafruit.com/product/4441

It has a range of 10 meters and a beam divergence of 4.77 degrees from the optical aperture of 14.9 mm. The lidar will constantly feedback a distance of detection in the forward direction. In combination with the Kerbrose, which detects the angle of the astronaut relative to the ship, the lidar will slow down and stop once it reads a reading of fewer than 10 meters.

We have two concerns. Large waves interfering with the lidar and the lidar missing the astronaut. We have two solutions that we plan on testing to address the wave solution. The easier to implement solution is to only return a positive reading if the reading is consistent over time. The other solution is to use the IMU to measure when the boat is at the peak of a wave, and reading the lidar's detection there.

The second issue is the detection zone of the lidar. The lidar's beam divergence is relatively low, so we will test our step up in a pool with a person waving their arms to make sure the lidar sufficiently returns a measurement.

5 Operations Plan

5.1 Part A: Configuration

Due to the accessibility of the BEAR, we plan to have our electronics tray test ready during all stages of transportation. We have integrated a circuit breaker into our system in order to power our electronic configuration when desired. This will power our raspberry pi, arduino, thrusters, kerberos, and lidar sensor. The source of power will be connected to a breaker to protect from short circuiting. That will be connected to a fuse box where power will be distributed to a raspberry-pi/arduino slave, thrusters, kerberos, IMU and the Lidar sensor. Overall, the boat will be delivered and fully transported in all stages in its most assembled state.

5.2 Part B: Test Objectives

Using the KerberosSDR for direction finding as well as the BNO055 imu for stability will help the BEAR get to the astronaut in a fast and efficient manner. Once in a close radius to the target, we use a Lidar distance sensor in order to detect proximity and slow down the boat accordingly. We plan on using the sdr to get an accurate reading on the direction of the target in regards to the current direction of the boat, which will help in the change of directions so that the boats path will be directed at the target. During this process, we will use the imu in order to address the stability on the water. Using the three axis orientation data provided from the imu, we will be able to provide control logic to the thrusters depending on the given orientation of the boat at any given moment. Ideally, we would need a couple seconds before starting in order to calibrate the imu and kerberos so that we can be confident in their accuracy throughout the entirety of the mission. Once in an ideal proximity to the target, we will use our lidar sensor in order to slow down the thrusters accordingly so that the boat arrives at the target in a safe manner and for easy convenience as well.

5.3 Part C: Test Plan

First, the hatch will be needed to open so that the breaker switch can be turned on. Once the breaker switch is turned on, the hatch will need to be closed so that the boat will be put in its waterproof state. Once resealed and the breaker is turned into its on state, the boat will be ready to be calibrated. The imu and kerberos will need to be calibrated directly after the breaker gets turned on. This is so that the direction finding feature on the kerberos can be calibrated with the correct frequency, gains, and DOA finding algorithm. The imu sensor needs to be calibrated so that the x,y and z coordinates can be accurate in regards to the stability of the boat and account for other control logistics. Once the boat is fully calibrated, the kerberos tap size and decimation need to be changed accordingly. Now, the physical radio will be able to be turned on, and the boat will start moving towards the target in the most efficient manner.

5.4 Part D: Hardware Procedures

Detailed Steps:

1. Unscrew the antennas.
2. Set the boat in the water and hold it still.
3. Open the hatch and close the breaker to start the electronics, you should hear the motors turn on by its beeps.
4. Close the hatch and hold it still for 40 seconds to let it calibrate.
5. Attach the antennas.
6. Within 2 minutes of closing the breaker, the boat will autonomously navigate to the location of the radio frequency.

Due to the accessibility of the BEAR, we plan to have our electronics tray test ready during all stages of transportation. We have integrated a circuit breaker into our system in order to power our electronic configuration when desired. This will power our raspberry pi, arduino, thrusters, kerberos, and lidar sensor. The source of power will be connected to a breaker to protect from short circuiting. That will be connected to a fuse box where power will be distributed to a raspberry-pi/arduino slave, thrusters, kerberos, IMU and the Lidar sensor. Overall, the boat will be delivered and fully transported in all stages in its most assembled state.

6 Hazard Analysis

6.1 Hazard Analysis Table

Hazard	Cause / Scenario	Consequence / Effect	Controls and Verification	Status
Mechanical				
Structure Failure	Structural Failure of Hull due to inadequate design	Personal injury and/or equipment damage.	Hull material will be constructed out of high-strength 6 oz carbon fiber to provide a maximum factor of safety. Conservative analysis and testing was performed to ensure hull structure is within acceptable safety factors.	Controls in Place
Structure Failure	Hull separation due to corrosion on fasteners	Personal injury and/or equipment damage.	316 Stainless Steel Fastener will be used in order to prevent corrosion.	Control in Place
Rotating Propellers	Contact with propellers while in motion	Slicing causing personal injury and/or equipment damage.	Operation of vehicles does not require close proximity to propellers. Thus, diver training to be mindful of propellers is sufficient.	N/A
Software Failure	Erratic and dangerous movement of vehicle due to software failure	Ramming causing personal injury and/or equipment damage.	Lidar distance sensor for detecting distance to astronaut and slowing down at 10m	In Progress
Electronic bay Water Leakage	Contact with powered on electronics that are in contact with water	Electrical Shock	Electronics will be in a waterproof electronics bay that will not be in contact with water. The power source will be coming in through the back of the boat where the astronaut will not be able to access.	Controls in Place
Hardware Sharp Edges	Contact on sharp edges of Hull and other hardware components	Cutting causing personal injury and/or equipment damage.	Every edge on every external hardware will be deburred and rounded during manufacturing. Organization and layout of hardware is designed to have no protrusions	Controls in Place
Pinch Points	Fingers caught in latches of top hull access door.	Pinching causing personal injury	Diver training for proper use of simple latch operation is adequate to prevent hazard.	N/A

6.2 Hazard Analysis Table

Included in the table above.

6.3 Evidence

This is in our Forward Plan.

7 Forward Plan

7.1 Part A: Remaining Tasks

There are a few deadlines coming up by the end of this month regarding Programming:

1. Strip down and integrate Kerberos for direction finding 4/30
2. Integrate Lidar Distance Sensor for stopping 4/30
3. Possibly use IMU for help in stability. 4/30
4. Thorough testing including distance testing (1 nautical mile) 5/1 - 5/21
5. Different location of radio testing 5/1 - 5/21
6. Shortening and organizing wires 5/1 - 5/21
7. Continuing investigating safety measures during our testing for crew and BEAR interactions in the NBL. 5/1 - 5/21

There are also a few deadlines coming up by the end of this month for Mechanical:

1. 3D Print a new hatch door (with relatively high infill PLA) 4/30
2. 3D Print a final mount for the battery 4/30
3. 3D print another electronics box with stronger mounting points to reduce the chance of fracture 4/30
4. Mount final latch hooks (doubling from one to two, and moving their location) 4/30
5. Add support rib (mentioned in FLUENT section) on the interior to increase hull strength for 10-15 ft impact 4/30
6. Apply silicone to all exposed nuts, bolts, and exterior-to-interior passages 5/21

7.2 Hardware

The vehicle will get to NASA through shipping on or before May 21st. Included in the package will be the 75ft long umbilical cord. We will also send NASA spare parts, such as nuts, bolts, silicone, etc.

7.3 NBL

The only thing needed for testing at the NBL is the vehicle and the connection to the power source through the 75ft long umbilical cord.