Title of Design: Berkeley Autonomous Emergency Responder (BEAR)
Challenge #1: Surface Autonomous Vehicle for Emergency Response (SAVER)

Team Name: Water Bears
Academic Institution: The University of California, Berkeley
Address: 120 Sproul Hall, University of California Berkeley, CA 94720-5404

Faculty Advisor
M. Reza Alam
Associate Professor of Mechanical Engineering
reza.alam@berkeley.edu
+1 (510) 643-2591

____
Faculty Advisor Signature

Team Leaders & Contacts:
Ryan Luna - Team Leader
Junior - Physics
lunar@berkeley.edu
+1 (949) 382-0678

Leon Liu - Team Leader
Junior - Electrical Eng. & Computer Science
leonliu22@berkeley.edu
+1 (858) 729-8612

Team Members:

Mechanical Team

Christian Nisperos
cnisperos@berkeley.edu
Sophomore - Mechanical Engineering

Mathias Guillen
mathias.armenta@berkeley.edu
Junior - Physics

Michael Vronsky
michaelvronsky@berkeley.edu
Junior - Mechanical Engineering

Paulina Umansky
paulinaumansky@berkeley.edu
Senior - Mechanical Engineering

Programming Team

Kevin Wang
kevwang@berkeley.edu
Freshman - Electrical Eng. & Computer Science

Charles Liu
cliu2002@berkeley.edu
Freshman - Computer Science

James Nguyen
jamesnguyen14@berkeley.edu
Junior - Computer Science

Ryan Whittaker
rwhittaker@berkeley.edu
Junior - Electrical Eng. & Computer Science

Chris Lai
chrislai_502@berkeley.edu
Junior - Electrical Eng. & Computer Science

Business Team

Ashok Sundararaman
ashoksun01@berkeley.edu
Sophomore - Data Science

Sultan Dildar
sultandildar@berkeley.edu
Junior - Finance and Accounting

Christopher Carlucci
Carlucci@berkeley.edu
Sophomore - Business Administration

Richard Herrera
hichardxrerrera@berkeley.edu
Sophomore - Business Administration

Rafael Shifren
rafaelshifren@berkeley.edu
Sophomore - Economics and Data Science

Shane Schulte
shaneschulte@berkeley.edu
Sophomore - Business Administration

Education & Outreach Team

Matthew Choy
mwchoy@berkeley.edu
Junior - Public Health and Data Science

Maeve Almos
maevealmos@berkeley.edu
Junior - Interdisciplinary Studies Field

Hema Katta
hkatta@berkeley.edu
Senior - Public Health

Grant Nguyen
grantnguyen@berkeley.edu
Senior - Environmental Science

Brad Villacis
bradvillacis@berkeley.edu
Junior - Computer Science

Team Advisers:

Joshua Salzedo
joshuasalzedo+saver@gmail.com
Programming

Sean Roh
sroh@berkeley.edu
Education & Outreach

Corey Hague
chague@uci.edu
Electrical

1 Technical Section

1.1 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. The BEAR (Berkeley Emergency Autonomous Rescuer) vehicle will deliver necessary supplies to astronauts in distress in the maritime environment. The lightweight vehicle will be capable of detecting 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 Blue Robotics T200 thrusters, Raspberry Pi, Arduino, latches, and hinges are used to increase reliability and achieve a production cost of approximately $1600.

1.2 Design Description

1.2.1 Brainstorming and Down Selection Process

The team considered several designs (see appendix E), with some key features being: closed vs. open hull, self-righting capability (i.e. instability in the inverted orientation), ability to function while inverted, large flotation attachments (such as a catamaran), and an entirely submerged torpedo-like design. A decision matrix is included in appendix D. The design ultimately chosen features self-righting capability due to its simplicity and good hydrodynamic properties which are critical to meeting the 2 m/s cruise speed requirement.

1.2.2 Preliminary Evaluation of Froude Number and Resistance Forces

A ship will experience maximum wave drag at a critical Froude number $\mathrm{Fr}_c = \frac{1}{\sqrt{\pi}} \approx 0.56$ (Fitzpatrick). When the ratio of water depth (h) to length at the waterline (l) exceeds 1, shallow water wash effects may be neglected, and we calculate the "Length Froude Number" (Abdul Ghani & Abdul Rahim 130)

$$\mathrm{Fr} = \frac{u}{\sqrt{gl}} \tag{1}$$

where u is the ship speed, g is the gravitational acceleration. Rearranging, we can find the critical speed for a ship to be $u_c = \sqrt{\frac{gl}{\pi}}$. We are interested in determining whether our vehicle will operate below or above the critical Froude number. To do this, we can calculate the length at which a ship travelling at 2 m/s will be at its critical Froude number (any ship shorter than this will be at a supercritical Froude number). Solving for l_c, we find

$$l_c = \frac{u^2}{g\mathrm{Fr}_c^2} = \frac{\left(2\frac{m}{s}\right)^2}{9.81\frac{m}{s^2}\left(\frac{1}{\pi}\right)} \approx 1.28m \tag{2}$$

The long vessel length required for travel at the desired velocity and low Froude numbers raises the question of what the peak drag force would be to achieve supercritical Froude number. According to Birk (p.299), the resistance is calculated by

$$R_W = \frac{1}{2} C_W \rho u^2 S \tag{3}$$

where R_W is the drag force, ρ is the density of water, S is the wetted area of the hull, and C_W is the dimensionless wave resistance coefficient. Data on the resistance coefficient at the peak Froude number is difficult to find, as power-to-drag ratios of large vessels make travel past the critical Froude number uneconomical.

As an order of magnitude estimate, we take the peak resistance coefficient to be about 0.05 (this is quite conservative for a typical ship hull. For a ship travelling at 2 m/s, with an approximate wetted area of $0.25m^2$, we obtain a peak wave resistance force of about 24 N, or about 2.5 kgf. This order of magnitude is likely achievable with the electrical power constraints. Thus, we conclude that it is feasible to design a vessel of this scale which will travel at a supercritical Froude number.

The Reynolds number of the flow around our vehicle is calculated to be approximately $2 \cdot 10^6$, using vehicle length as the characteristic length. We have neglected viscous drag for this analysis, as it is negligible in comparison to the peak wave resistance. Typical viscous drag coefficients for a ship hull at $\mathrm{Re} = 2 \cdot 10^7$ are on the order of $3 \cdot 10^{-3}$ (Lin et. al.). Naturally, the viscous drag force will prevent our vehicle from accelerating indefinitely, but is less relevant in the analysis of planing carried out above.

1.2.3 Statically Stable Hull Design

After considerable deliberation and manipulation of our decision matrix on hull design, our team has come to the consensus that a self-righting boat hull design is most advantageous for numerous reasons. These reasons include but are not limited to: weight, speed, mechanical complexity, and manufacturability. These qualifications are among the highest ranking in importance that our team deduced throughout the decision making process.
A boat hull's self-righting properties are dictated by certain factors such as center of buoyancy (CB), center of gravity (CG), metacenter (M), and their distance in relation to varying heel angle (GZ) (Akyıldız, Şimşek). In order for a hull design to adhere to self-righting properties, CG must be above and along the same axis vertical as CB and must also be under the metacenter. This can be seen in figure 1.

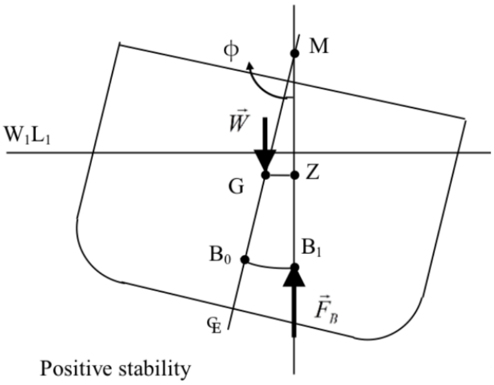


Figure 1: Hull Cross Section for Positive Stability (Akyıldız, Şimşek)

Along with this, it is also necessary that as heel angle varies, in relation to a statically stable orientation, a varying lever arm is exhibited to bring the hull back to a stable orientation. As can be seen in figure 5, the magnitude of this lever arm (GZ) increases along a curve of stability as angle increases ($0° \leq \phi < 90°$) until a maximum value corresponding to an angle of 90° in relation to the vertical center line of the hull is reached. At this point and beyond ($90° \leq \phi \leq 180°$) the hull is considered to be in a capsized state and exhibits decaying stability. With this is mind, generalized calculations can be made in order to get an idea of how we would be designing our hull. The center of buoyancy can be generalized from the following equation (Techet 4):

$$CB_x = \frac{1}{V_{sub}} \iiint_{V_{sub}} x dV \tag{4}$$

$$CB_y = \frac{1}{V_{sub}} \iiint_{V_{sub}} y dV \tag{5}$$

$$CB_z = \frac{1}{V_{sub}} \iiint_{V_{sub}} z dV \tag{6}$$

Where CB_k denotes the CB coordinates in the k axis, V_{sub} denotes the submerged volume of the vehicle, treating its interior as filled. In practice, this is just the volume of the vehicle that is beneath the waterline.
The center of gravity can be generalized by the following equations:

$$CG_k = \frac{\sum M_i \cdot d_{i,k}}{\sum M_i} \quad \text{for } k = x, y, z \tag{7}$$

, where M_i is the mass of the ith component, $d_{i,k}$ is the coordinate of the ith component in the k direction, and CB_k is the CB coordinate in the k direction. which is determined by the mass and location of every component within the vehicle. While the following equations yield the necessary data, computer aided design software such as SolidWorks yields the same data in regards to CG and CB [1]. This tool was utilized in order to hasten the designing process. From this data, we are more accurately able to say how stable our craft will be in water. Given the time constraints of the challenge, the team was unable to carry out a completely rigorous analysis of the vehicle's stability curve, but hopes to do so before manufacturing and testing begin. Computational methods such for such analysis are well-documented by Larson and others. Subscale models are also planned in order to validate the stability curve.

1.2.4 Hull Design

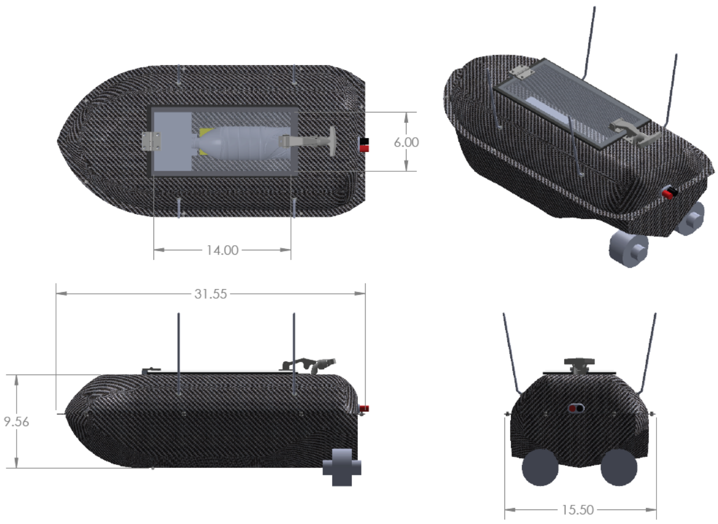


Figure 2: A schematic of the vehicle design.

The length, width, and height of the hull are 31.54 inches, 15.50 inches, and 9.56 inches respectively. The material for both sections of the hull will be manufactured out of carbon fiber. The top and bottom half of the hull both incorporate geometry that aids in self-righting ability. The lower half of the hull utilizes a "shallow vee" shape which is known for being highly stable in comparison to other hull designs, while still being manufacturable with our current capabilities. The rear of the boat transitions to a short section about 3.5 inches long with a sharper angle and flat sides to allow for dual motor mounting. The top half of the hull features circular sides to promote instability in the event of rollover. The two halves will be secured together with a combination of a rubber compression gasket, bolts, and nuts. Other holes for mounting electronic connectors and motor mounts will be sealed with epoxy or gasket screws to ensure a watertight seal.

1.2.5 Internal Support

The internal reinforcement ribbing currently is not shown in the CAD model. However, in the manufactured prototype, the boat will have internal support ribbing to reinforce the initial drop impact on the hull during deployment. The ribs will also incorporate slots to allow for straps that secure the payload and be manufactured out of 6061-T6 aluminum.

[1]Using SolidWorks to obtain the location of the CB is rather tricky. We utilize bespoke parts to model the submerged section of the vehicle, and check that their displaced water weight is equal to vehicle mass. Upon setting a uniform density, CG tool may be used to determine CB.

1.2.6 Hatch

The hatch is a critical component in the operability and function of the vehicle. While the hatch is nominally not submerged, it must be reasonably watertight to allow the vehicle to recover from an inverted orientation. For these reasons, the size of the latch is kept fairly small while still allowing for comfortable access to the interior of the vehicle. The hatch measures 6" by 14", which is more than enough to fit the largest of payloads and a gloved hand. Sealing is achieved by the use of taped sealing foam designed for boat hatches. This foam is easy to install, and while likely not completely watertight, is highly durable and can provide a sufficient seal. A standard hinge is used, and the hatch is retained by a compliant rubber latch. This latch is weather resistant due to its rubber body. This simplifies manufacturing tolerances and ensures reliability after the initial drop into the water.

1.2.7 Payload Selection & Storage

Our current payload contains the following items:

1. ANGEL beacon
2. Orion Systems Daytripper 1st Aid Kit [2]
3. 1 Liter of water stored in a plastic water bottle
4. EAM UXF-35 LIFE VEST/Life Preserver Unit [3]
5. Standard Horizon HX210 Compact Floating 6W Handheld VHF Radio [4]

Other than the specified ANGEL beacon, alternative payloads satisfying the given requirements were chosen due to their smaller size and weight savings. Additionally, the life vest selected allows for two methods of inflation: inflation by a CO2 canister which would be used in environments outside of the NBL and manual inflation through an inflation tube.

The life vest, first aid kit, and handheld radio will be packaged together in a lightweight nylon bag. The nylon bag and water bottle will be secured using polyurethane straps (Voile Straps®) that run through slots in the support ribbing to ensure that the materials don't move during tilting or rollover. The straps prevent slipping and ensure that payloads remain in place even in the inverted orientation.

1.2.8 Battery Selection

To power our boat without the supplied NBL umbilical cord, we will be using a 8400mAH 13.2V 4S2P LiFePO4 battery. The battery can handle a peak draw of 25Amps for approximately 20 minutes. We may use the given specs of a 1 nautical mile range at 2 m/s to obtain a maximum cruise time of

$$t_{\text{cruise}} = \frac{1NM}{2\frac{m}{s}} = \frac{1852m}{2m/s} = 926s = 0.257\text{hours}$$

Since we anticipate at most a peak draw of 25A, a baseline estimate for our battery capacity would be

$$25A \cdot 0.254\text{hours} = 6350\text{mAh}$$

We anticipate our nominal current draw to be around 10A at speeds higher than 2m/s, meaning our battery capacity will be more than sufficient for our mission. The chosen battery achieves a FOS of 1.3 over this conservative estimate which assumes continuous operation at the maximum power (which is in itself unlikely). We avoid choosing a bigger battery due to weight constraints.

1.2.9 Motor Selection

The main factor for our motor selection was the amount of drag force introduced by the hull design of our vehicle. Based on our simulations (see section 1.2.2), we estimate the peak wave resistance force of our vehicle to be about 24N. Therefore, our thrusters should produce a combined force of 24N in order to achieve our target speed.

[2] http://www.orionsignals.com/product-groups/first-aid-kits/product/119.html

[3] https://www.aircraftspruce.com/catalog/pspages/ixf35lifevestwhistle.php?utm_source=google&utm_medium=organic&utm_campaign=shopping&utm_term=13-12679

[4] https://www.jamestowndistributors.com/product/product-detail/64017

Another constraint for the motor selection was the 25A current draw limit from our power source. After allocating 3A to our electronics, there remains 22A to power our thrusters, giving each thruster around 11A of peak current. Other things like size and price are also factors taken into consideration. With these requirements in mind, we chose the BlueRobotics T200 Thruster. Based on BlueRobotics' empirical data sheet on the T200, each motor will only need to draw 3.2A of current from the power source to produce the 24N we require. Also, each thruster can produce a maximum of 30N of thrust when supplied with a 12A of current, giving us a lot of flexibility in the control system.

This Arduino-Pi configuration will allow us to maximize both input-output (using the pins on the Arduino) and compute power (with the Pi) using two well known and reliable systems.

Figure 3: T200 Thruster

1.2.10 Vehicle Control

The T200 is a brushless DC motor that can be controlled with the BlueRobotics Basic ESC (Electronic Speed Controller). These ESCs will be controlled by an Arduino board via PWM (Pulse Width Modulation). The Arduino, along with the various sensors and antennas described in the other sections, will communicate with a Raspberry Pi which will serve as the central computation and decision making hub of the vehicle.

This Arduino-Pi configuration will allow us to maximize both input-output (using the pins on the Arduino) and compute power (with the Pi) using two well known and reliable systems.

1.2.11 Homing Technology

After considering a variety of options proposed by NASA and our advisors, the team has decided on the safest and most reliable homing technology solution. It would come in the form of a commercially purchased Software-Defined Radio (SDR). With safety and reliability in mind, we have chosen to incorporate one of the most battle tested solutions in this sector, the KerberosSDR (figure 6).

Harnessing this quad antenna SDR will not only allow us to take advantage of its commercially bundled software, but allow for additional signal manipulation and processing through our custom software solution. Pairing the SDR with our Raspberry Pi will give us the option to leverage our simplified API and communicate both bearing and direction to our primary software application, where it will seamlessly be converted into corresponding mechanical motion.

Appropriate antenna selection and software tuning will allow our vehicle the ability to precisely home in on the 121.5 MHz emergency recovery frequencies emitted by the Emergency Locator Transmitter. In addition to software, we also must consider that the physical placement of the four antennas in relation to each other is of utmost importance in order to reduce unwanted noise and ensure proper signal tracking.

The optimization of the antenna array requires that the four antennas are to be placed on top of the vehicle and arranged in a circular pattern such that each antenna is equidistant from each other. The distance of each antenna from the center of the array is calculated as follows, based on the signal frequency:

$$f = 121.5 * 10^6 Hz$$

The wavelength λ would be:

$$\lambda = \frac{c}{f} = \frac{300 * 10^6 m/s}{121.5 * 10^6 Hz} = 2.47m$$

The radius of the uniform circular array can be determined by the given equation

$$r = \frac{s * \lambda}{\sqrt{2}} \tag{8}$$

According to the manufacturer RTL-SDR, it is recommended to use an interelement spacing factor s that is between 0.1 and 0.5. Plugging in $s = 0.1$ into equation (3), the smallest is $r = 17.4cm$. Similarly, if $s = 0.5$ then, the the largest is $r = 87.2cm$.

Thus it suffices to say that the workable range in which the radius of the antennas can be set up would be $r = 17.5cm$ to $r = 87.2cm$. It is also worth noting that a spacing factor of $s = 0.33$ is generally used for an uniform circular array. From equation (3), this gives an ideal antenna array radius of $r \approx 58.2cm$.

The above calculations are based on an ideal scenario but conforming to that would place undue restrictions on the vehicle's overall dimensions, which would negatively impact mechanical performance by adding complexity. For that reason, we believe a more realistic s value will fall in the range of 0.10 to 0.20. We plan to test the minimum spacing at which the honing system achieves adequate reliability. Since larger spacing achieves greater precision, final antenna spacing will seek to satisfy the results of the antenna test as well as to fit within the physical footprint of the vehicle. Should the antenna test result in a spacing greater than the footprint, additional mechanical mitigation (such as placing antennas on booms) or electrical mitigation (such as a non-circular array) will be implemented.

1.2.12 GPS Technology (Optional)

Due to limited documentation available on the scope of the mission, we felt it would be wise to at least consider the possibility of including GPS based positioning of our vehicle for a variety of reasons. The most prominent advantage would be the ability to redirect our craft should we lose line of sight with the homing signal. This could be due to the large swells or intermittent loss of signal if perhaps the beacon goes underwater. This additional layer of accuracy however, would only be useful if there is a way to either pre-program the GPS coordinates of the intended target or establish live communication via satellite. Until we are able to clarify with our mentor whether these requirements are practical, we feel that maintaining this option will allow the possibility for a much more robust homing and tracking option for our vehicle.

1.2.13 Ultrasonic Sensor (Optional)

Due to unknown certainty of the accuracy of just homing in on a homing signal, we have an ultrasonic sensor as a backup. In the case homing in on a signal does not provide enough information on when to stop the boat, waterproof ultrasonic sensors will be placed on the exterior of the boat to detect close distance from an astronaut in distress.

1.2.14 Requirement Compliance Matrix

In order to create a design which would meet the intended operational mission, we have created several more top-level requirements which were not listed in the challenge document. These are included below, along with their respective compliance justifications.

Number	Requirement	Compliance Justification
1	The vehicle shall be capable of being dropped from a 10-15 foot height into the maritime environment.	As discussed in the manufacturing plan, the hull will be constructed of a high-strength carbon fiber layup in order to sustain the impact with the water surface. As discussed in the design ideation section, we opted for a design which is self-righting; this will allow the vehicle to operate succesfuly from a wide range of initial conditions.
2	The vehicle shall be capable of being carried on a Group 1 (small) or Group 2 (medium), Close-range UAV.	The DJI MATRICE 600 PRO "Government Edition" has a stated payload capacity of 6kg, or 13.2lbm (https://www.doi.gov/aviation/uas/fleet). From our CAD model, our total vehicle weight is estimated to not exceed 13 pounds. While there is some uncertainty with the final weight of the composite hull, we have chosen conservative estimates of hull thickness, using 4 layers of 8.9 thou carbon cloth.

3	The vehicle shall be capable of transporting (carrying or towing), at a minimum, the following items to the victim: a. Water (1 liter minimum - 2.5 liters max per Human Systems Integration Standard) b. Medical kit (Orion 0.6 lb kit) c. Spare Life Preserver Unit (LPU)* d. Contingency/Spare 406 MHz Second-Generation Beacon (ANGEL) e. Survival Radio Optionally, the following may also be included: f. Inflatable life raft (taking into account size/mass considerations)	The hull is designed to accomodate the volume of all required payloads (see CAD visualization). The optional life raft is not included due to the payload weight limitations of a group 2 UAV.
4	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.	The vehicle will use the KerberosSDR with a 4-antenna array to detect the ANGEL beacon and determine its direction and distance.
5	The vehicle shall be capable of traveling to the person in distress via the most direct route in an autonomous manner, including: a. Unmanned operation (no local or remote human intervention) b. Programmed with mission profiles to address specifics of rescue scenario.	A Raspberry Pi will be on the vehicle, which will interface with the various sensors (SDR, IMU) to determine the route and command an Arduino board that controls the thrusters via Electronic Speed Controllers.
6	The vehicle shall include protections in software/hardware to ensure no harm to the crew upon arrival in their vicinity.	The hazard posed by the fast-spinning propellers is heavily mitigated by their ducted design. All sharp edges will be deburred to minimize cut hazards to personnel and/or lifeboats. The boat will be programmed to stop once we are within 2 feet of the astronaut. To do this, we will be using the homing signal to pinpoint the astronaut in distress. When testing, if the homing signal is not sufficient enough we will place ultrasonic sensors on the exterior of the boat to detect close range distances.
7	The vehicle shall be able to mechanically interface with the NBL electrical power source via an umbilical cable.	The Pomona Electronics P/N 6883 connector is used to provide a watertight and secure mechanical connection to the umbilical cable. It is located at the top-rear of the vehicle to minimize risk of entanglement.
8	The vehicle shall not jettison any parts into the environment.	No parts are jettisoned from the vehicle. This ensures both rapid reuse of the vehicle and operational safety & compliance in the NBL.
9	The vehicle shall be designed to perform nominally in or be easily extensible to perform nominally in rough sea conditions.	The chosen self-righting design is robust and will be able to withstand splashing, resist capsizing, and provide enough power for propulsion in rough conditions thanks to the powerful T200 thrusters.
10	The vehicle structure shall provide sufficient RF transparency to enable reliable communication in all directions.	Antennas are mounted externally to avoid interference by the carbon fiber hull.
11	The vehicle shall attain a velocity of at least 2 m/s in cruise.	Based on our rough calculations in sections 1.2.2 and 1.2.9 we believe this requirement, stated in the FAQ document, will be fulfilled.

12	The vehicle shall be designed to operate for a 1 nautical mile range.	While clearly not a requirement for testing at the NBL, the expected range was mentioned at an infosession. Our calculated battery capacity in section 1.2.8 fulfills this requirement.

1.2.15 Manufacturing Plan

Our team intends to utilize resources offered by our university such as the UC Berkeley Machine Shop and the Jacobs Hall Makerspace. Both offer manufacturing services during the ongoing COVID-19 pandemic; the facilities are implementing a "job shop" model, where we may request parts and pick them up when they are ready. Once we have acquired all of the molds we will individually work on different parts of the assembly. For the two hull components: a coating of water soluble PVA or polyvinyl alcohol release film will be applied to the positive molds of the hulls. After this has dried, a layer of carbon fiber followed by a layer of epoxy will be applied. This process will be repeated three more times, for a total of four layers, and set over a period of time to cure. After curing, holes will be drilled into the hull pieces for mounting hardware. Excess material will be trimmed and sanded/filed down to ensure there are no sharp edges. Also, excess PVA will be thoroughly cleaned off. For further explanation of constituent parts, please refer to the table below. For added safety, all aluminum and ABS plastic will be sanded down to ensure there are no sharp edges or remaining burrs. Furthermore, once all parts are manufactured, they will be sent to an individual on the mechanical subteam to construct the near final assembly. Finally, the UAV will be sent to an individual on the electrical subteam to install the electrical components.

Part name	Material Selection	Justification of Material Selection	Manufacturing Plan
Bottom half of hull	Four layers of 3k 2x2 Twill 5.9oz carbon fiber cloth bonded with Marine Epoxy (such as West Systems 105 Resin/206 Hardener)	Carbon fiber is a composite material which means that it is relatively easy to mold into irregular shapes such as that of the hull. Composites are preferred over vacuum-formed plastic due to its higher strength-to-weight ratio and ability to be cut easily. Carbon fiber offers better rigidity and strength-to-weight ratio than fiberglass.	A custom mold made from a polyurethane foam (such as Last-A-Foam) will be used to construct the composite layup around. The foam will be cut using a CNC mill, or alternatively, a multi-part FDM-printed mold may be used. We intend on using the Mechanical Engineering Student Machine shop and Jacobs Makerspace to manufacture the molds. A drill press will be used to manufacture holes on the flange, hull bodies for electrical components, and for the motors.
Top half of hull	Reference bottom half of hull	Reference bottom half of hull	Identical to the bottom half of the hull. A drill press will be used to manufacture holes on the flange and hatch mount, and a hand drill will be used to manufacture holes on the curved surfaces.
Hatch door	1/16" Carbon Fiber Sheet	Carbon fiber sheets offer superb strength-to-weight ratios and high stiffness, which are critical in reducing vehicle weight and minimizing hatch leaks due to plate flexure. 6061-T6 Aluminum would be acceptable yet a heavier alternative.	The OMAX 2626 abrasive water jet cutting machine located in UC Berkeley's Jacobs Makerspace will be used to cut the overall shape of the hatch, and holes will be drilled using a drill press. Alternatively, a vertical bandsaw may be used to cut the overall shape.

Hatch hinge spacer plate	6061-T6 Aluminum	6061-T6 Aluminum alloy is low-cost and lightweight, The thick geometry of the part precludes many composites. PETG may be used, but given the large moments which may be placed on this part and the difficulty of anisotropic analysis on parts manufactured using FDM makes such alternatives unattractive.	A vertical bandsaw will be used to cut the overall shape, and a drill press will be used to drill all through holes.
Internal Ribbing	6061-T6 Aluminum bonded to the hull with marine epoxy.	See hatch hinge spacer plate.	The OMAX 2626 abrasive water jet cutting machine located in UC Berkeley's Jacobs Makerspace will be used to cut the overall shape of the ribbing. Holes for weight reduction may be later added using a mill.
Electronics Enclosure	ABS plastic	ABS is chosen because it can withstand a large range of temperatures while remaining rigid. It is preferred over other 3D printing materials such as polylactic acid (PLA) because it does not degrade as easily in water.	The enclosure will be 3D-printed in two parts using Fused Deposition Modeling (FDM): the main box and the lid. Parts will be printed at 50% infill to allow for increased strength due to thicker (.25") walls while reducing mass. FDM is preferred over epoxying wall pieces together because it reduces the amount of seals that could break. Threaded inserts will be added to the screw holes within the part by heating the metal inserts so that the plastic around them melts. These inserts will allow for bolts to be used on the part.
Electronics Enclosure Gasket	1/8" Neoprene Rubber	Neoprene rubber is chosen because it does not corrode in water and can be compressed between the enclosure door and main enclosure box, ensuring a seal from water.	The gasket will be laser cut from a sheet of rubber using UC Berkeley's makerspace facilities.
Hull Gasket	Neoprene Rubber	See Electronics Enclosure Gasket	The gasket will be custom-made by an outside supplier. Alternatively, the gasket can be laser cut from a sheet of rubber using UC Berkeley's makerspace facilities.

1.3 Operations Plan

The following describes our plan for operating the vehicle in the NBL.

1. Ensure that all required hardware and tools are obtained
2. Parts
    2.1. Bottom half of hull

2.2. Top half of hull
2.3. Eight #10-24x0.5 316 Stainless Steel Bolts and corresponding nuts
2.4. Payloads (or acceptable boilerplate)
   2.4.1. Water bottle filled with 1.0 kg (-0.0kg, +0.05 kg) of potable water
   2.4.2. Medical kit
   2.4.3. Fully-charged ANGEL beacon
   2.4.4. Water (measured)
   2.4.5. Life Preserver Unit (LPU)
   2.4.6. Fully-charged Survival Radio
2.5. Kerberos SDR and 4 antennas
2.6. Electronics module enclosure and mounting bolts
   2.6.1. Ten #.06-80x1.25x.5 316 or 18-8 Stainless Steel Bolts and corresponding nuts
   2.6.2. Module enclosure
   2.6.3. Module enclosure gasket
   2.6.4. Module enclosure lid

3. Tools
   3.1. Adjustable wrench
   3.2. Hex key set
   3.3. Backup gasket tape
   3.4. Kitchen scale (for measuring water)

4. Install electronics module into hull using the mounting bolts.

5. Clear all personnel and stray parts away from the thrusters.

6. Connecting power supply
   6.1. If using an onboard battery:
      6.1.1. Place the battery at the designated location (as shown in CAD), and connect to the electronics module/electronic speed controller.
   6.2. If using the umbilical power cord at the NBL:
      6.2.1. Connect umbilical power cable to the vehicle using the banana plug connectors.
   6.3. From this moment on, ensure that fingers, bolts, loose papers, and other debris are kept clear of the thrusters.
   6.4. From this moment on, ensure that vehicle is not held by the umbilical cord, but rather by the hull.

7. Place payloads in designated locations and secure using Voile straps (plastic buckles).

8. Inspect sealant ring between top and bottom hull sections for defects or improper placement.
   8.1. If the sealant ring is compromised, replace or reposition to ensure adequate sealing

9. Align top and bottom hull segments, making sure to obtain a good seal and align the holes in the flanges.

10. Connect top and bottom hull segments.

11. Power on external power supply.

12. System checks
   12.1. Switch on the mounted breaker and check for proper feedback from IMU, GNSS, Homing Signal, and motors.
   12.2. Thruster running sequence to visually check thruster control and direction.
   12.3. Sensor checks while moving the vehicle for making sure IMU and homing devices are working and connected to the Raspberry Pi.

12.1. Insert #10 Stainless Steel bolts and hand-tighten nuts.
12.2. Once a proper fit is achieved, use appropriate tools to tighten.

13. Drop from crane

  13.1. If the vehicle is to be dropped by an individual from the crane, proceed with crane loading, positioning, and drop procedures. Otherwise, connect appropriate remote disconnects to vehicle.
  13.2. While the vehicle will be able to operate from any initial drop orientation, an univerted, nose-down attitude is preferred.

14. Upon completion of the test, the vehicle may be either towed manually or remotely piloted to the edge of the pool.

15. Turn off external power supply.

16. Carefully lift vehicle out of the water and place on a suitable work surface.

17. Allow the vehicle to dry somewhat, or pat dry with a towel. This is done to prevent accidentally short-circuiting electrical components inside the hull.

18. Carefully disassemble all of the bolts connecting the hull halves together and place them in a bag.

19. Carefully separate the two halves of the hull.

20. Once the hull halves are separated, begin to disassemble the internal components.

  20.1. Carefully and with dry hands remove the power connection either to the battery or umbilical power cable.
  20.2. Remove any remaining payloads.
  20.3. Remove electronics module fasteners.
  20.4. Remove electronics module.

1.4 Safety

The complete analysis of our risk identification and mitigation is included in the risk matrix below. Below is a brief list of the subset of our tests which will be relevant to safety:

1.4.1 Tests to be Performed

Subscale hydrodynamic testing In order to ensure proper self-righting of the vehicle, we will construct subscale models using FDM 3D-printing. These models will have the same shape as the vehicle and appropriately scaled CG location. By ensuring proper self-righting of the vehicle, we minimize electrical hazards due to leakage caused by prolonged exposure to water, as well as hazards posed by the motors.

Mechanical testing of hull The composite hull will be tested by dropping into a pool with appropriate boilerplate masses. This testing minimizes risk of fracture and exposure of sharp edges, as well as ensuring operational performance.

Submergence test In order to minimize electrical hazards caused by leakage into the hull, we will perform submergence tests to test the performance and integrity of seals between the hull halves as well as the top hatch.

Homing stopping distance test The homing system will be tested to evaluate performance in how far the vehicle stops from the person in distress. This test helps mitigate risk of collision with the individual.

1.4.2 Risk Matrix

The following is a Risk Summary Chart for the BEAR. A corresponding risk matrix is available in the appendix.

ID	Summary	CxL	Trend	Approach	Risk Statement	Status
1	SAVER Overturning	5x1	↓	M, R	Given that: SAVER is meant to operate in the maritime environment, which can be unpredictable and turbulent, the SAVER may flip over while in operation and therefore be unable to operate properly.	The Mechanical Team has oriented SAVER's mass so that it will self-right in the event of rollover. The team is using SolidWorks and will be using custom software to analyze the SAVER's mass and buoyancy distributions. We also plan to conduct subscale testing using 3D-printed models with accurate mass distribution. Once the SAVER is built, it will be tested thoroughly using UC Berkeley's labs to ensure that it has sufficient self-righting properties.
2	Mechanical Component Failure	5x2	→	M, R	Given that: the SAVER is going to be dropped from a height of 10-15 feet and in operation will be exposed to harsh ocean conditions, the hardware could fail (such as hull cracking after drop or during operation)	316 Stainless Steel fasteners will be used to prevent corrosion, which could lead to catastrophic separation of the hull halves. High-strength 6oz. carbon fiber fabric will be used to construct the hull, and will be extensively tested early in the manufacturing cycle.
3	Electrical Component Failure	5x2	→	M, R	Given that: the SAVER is a water vehicle and electronics are not compatible with water, the electronics could fail due to water exposure	The electronics enclosure is designed to be water resistant an enclosed withint the hull, where it will make use of existing waterproofing measures to minimize exposure. External connections will be accomplished with sealing gaskets.
4	Personal Safety (Mechanical Components)	3x1	↓	M	Given that: SAVER is constructed to operate in close proximity to people, the SAVER may cause bodily harm to users from exposed or sharp hardware components	The SAVER will have all edges deburred and sharp corners rounded during manufacturing to eliminate any sharp components.
5	Personal Safety (Electrical Components)	5x1	↓	M	Given that: SAVER is meant to operate in the maritime environment, the electrical components on board may cause electric shock to the person being aided.	The electronics are contained within a water-proof enclosure to prevent any potential harm to the user. The SAVER will be thoroughly tested to ensure that all potentially harmful electronics are contained.

Approach	L = Likelyhood (1-5)
Accept (A); Mitigate (M); Watch (W); Research (R)	1 = not likely; 5 = extremly likely
CxL Trend	**C = Consequence (1-5)**
↓ - Decreasing (improving) ↑ - increasing (worsening) → - unchanged	1 = low consequence; 5 = high consequence

1.5 Technical References

Abdul Ghani, M. P., & Abdul Rahim, M. N. (2008). The Prediction of Wake Wash in the Towing Tank. *Jurnal Mekanikal*, 26, 129-140.

Akyıldız, Hakan, and Şimşek, Cemre. "Self-Righting Boat Design." Istanbul Technical University, 2016, pp. 41–54., doi:https://upload.wikimedia.org/wikipedia/commons/b/b2/Self-righting_boat_design.pdf

Birk, Lothar. "Ship Wave Resistance." *Fundamentals of Ship Hydrodynamics: Fluid Mechanics, Ship Resistance and Propulsion.* John Wiley & Sons, 2019.

Fitzpatrick, Richard. "Wave Drag on Ships." *Oscillations and Waves*, 8 Apr. 2013, farside.ph.utexas.edu /teaching/315/Waveshtml/node69.html.

KerberosSDR Quickstart Guide. (2020, August 28). Retrieved October 26, 2020, from https://www.rtl-sdr.com/ksdr/

Larson, Scott. "Design and Construction of Unmanned Surface Vehicles." (2015).

Read, Douglas. "A drag estimate for concept-stage ship design optimization." (2009).

Techet, Prof. A. H. "13.012 Hydrodynamics for Ocean Engineers." Handouts. 2020, Massachusetts Institute of Technology, WebMIT, doi: http://web.mit.edu/13.012/www/handouts/Reading3.pdf

Tulin, Marshall P. *Ship Wave Resistance-A Survey.* No. TR-7819-1. HYDRONAUTICS INC LAUREL MD, 1978.

2 Outreach Section

Our home, the San Francisco Bay Area, is a massive metropolitan center that houses a vast variety of sociocultural groups from all walks of life. In the representation of our curriculum, we wish to challenge the status quo of our world today–empowering the underserved youth who live in the area around our school and fostering a love of science, discovery, and learning for years to come.

We planned each outreach activity to fit within the 5E Education Model (where students engage, explore, explain, elaborate, and evaluate), with emphasis to ensure each activity represents the team project. To accomplish the said purpose, the team identified and distilled basic technical aspects from our team's Surface Autonomous Vehicle for Emergency Response (SAVER). Through a balance of exploration, discussion, and reflection, the key part of our curriculum is to create a relationship between us and the students. Our hope is that we become approachable enough so that they feel comfortable asking questions and feel confident in communicating their ideas.

Our curriculum is tailored to fourth and fifth grade elementary students in underserved communities throughout the San Francisco Bay Area. Said children are at the age where they can properly comprehend the basics of concepts that tie into our project. We chose fourth and fifth grades as the grade range for our outreach because this is a huge turning point in their educational journey. They question why things are important and why they need to learn things. They are also about to head to middle school, a place where they can really start defining their own personal interests. By choosing to incorporate outreach at this age, we can positively influence their perspective about STEM subjects. A majority of students develop negative relationships with STEM classes because they are under-resourced. We hope to leave them with a positive experience with science, one they can feel confident about.

We base this curriculum on the 5E Education Model, an evidence-based practice. By allowing the kids to explore and interpret at their own pace, we hope to cultivate a positive relationship between the student and the lesson plan. These activities will inspire students to explore science in a way that is hands-on and fun. When a lesson or task is open-ended or creatively fluid, we give the student the academic freedom to personalize their learning method. We showcase this in the way activities intertwine with each other; we focus the design of our curricula on reinforcing similar academic concepts in different ways. This pattern helps the student grasp the curriculum at their own rate, leaving them feeling accomplished and excited about their work. We will be cognizant of the classroom at all times, adapting to their conversational language and educational backgrounds. By being aware of the classroom environment, we can guide students to have a more meaningful experience with our outreach activities. In learning how they express themselves and the dialogue they use, we can better communicate our pedagogy to further will help us communicate our curricula and expand their interest in science.

With Micro-g NExT, NASA's Neutral Buoyancy Laboratory (NBL), and the team's mechanical prototype in mind, we created a curriculum that connects with students and allows them to see themselves working on things like this in their future. With the information we have gathered on both the organization and research for our model, we wanted to provide students resources on how they can get involved and continue to exploring a career in STEM.

Social media links:

- Website: https://oceanbear.org/
- Facebook: https://www.facebook.com/MoonWaterBears
- Instagram: https://www.instagram.com/moonwaterbears/?hl=en

Our team has secured agreements with the following schools:

- Sylvia Mendez Elementary: We contacted Robin Harley, the fourth and fifth grade science teacher, who agreed on October 24th, 2020, to have us present sometime in May - June 2021.
- Cobb Elementary: We contacted Principal Joseph Funk, who agreed on October 26th, 2020, to have us present sometime in May - June 2021.
- Fremont Elementary: We contacted Principal Sylvia Ramirez, who agreed on October 28th, 2020, to have us present sometime in May - June 2021.

2.1 Curriculum Plan

Outreach Estimate: Our outreach will expand to three schools in the Bay Area, with four to five classrooms per school of fourth and fifth graders. Estimating an average of twenty-five kids per classroom, we can expect a total number of 300+ students.

Our curriculum surrounds four main activities that are relevant to our team's project:

- Buoyant Boat Activity
- Density Activity
- Surface Tension Boat Activity
- String Distance Activity

The 5E Education Model: Engage, Explore, Explain, Elaborate, and Evaluate.

2.1.1 Engage

This is a method of introducing the curriculum in a way that sets the student up to feel comfortable in the space. We want to encourage them to pursue their interests and inquiries about the subject. At this point in the lesson plan, there is no "right" answer to any inquiries. You want to put yourself in the student's perspective to make the learning experience more suited to them. Understanding how they think will also help you communicate ideas by using their language.

Educator Guidelines:

- Present a situation.
- Identify a task with instructions.
- Set the limitations and restrictions of the task before engagement.
- Use discussion to reveal the ideas, experiences, and language of the student group.
- Make connections to past lessons, past knowledge, and past learning experiences.

Situation: Astronauts have returned from the moon! They end up having an emergency crash landing in the ocean! Thankfully, our boat is there to help rescue them. What does the boat need to do in order to help these astronauts? During this description, incorporate info about NASA and the challenge (Micro-g NExT, NBL, and the team's vehicle).

Task: Figure out what supplies the boat might need to help the astronauts. I.e.: water, medical kit, radio, live-preserver, as well as delivering them with speed, sturdiness, etc. - Explain how the boat also needs to locate multiple astronauts.
Instructions:

1. Get into groups of three and draw a small boat on a piece of paper.

2. Pick out four different types of supplies to be able to provide to the astronauts. Use your creativity!
3. Within your group, discuss three reasons why you chose the items that you did and how it would be useful in this situation. Note: Discuss why they chose the items they did, and what those items would actually do in this situation. Then guide them to the items that we have in our boat, explain why we chose these things, and explain our limitations.

Instructions for social distancing (have them do the "String Distance Activity"):

1. This will be a quick activity that will get the energy going within the classroom.
2. For this activity, we want to make them very excited right off the bat. So we will have a small challenge for them.
3. Each student will perform this activity themselves, we will hand them a premade paper with dots on them (as well as any other materials they need for this project).
4. The entire class would then compete in a short timed race as to who connects all the dots with the string first (REMINDER: SHORTEST IS BEST).
5. Whichever students have the shortest length of string used would "win."
6. Then have a short discussion with the class as to why this is important.

2.2 String Distance Activity

The mission of this activity is to design a boat that rescues astronauts when the returning craft from the moon malfunctions and astronauts eject out of the spacecraft, landing into the ocean. As time is very important in a rescue scenario, finding the path that reduces the time to rescue all the astronauts is crucial to the functionality of our boat.

Materials Needed:

- Graphing paper
- String/Yarn
- Marker

Instructions:

1. Get a piece of graph that has four randomized dots (representing stranded astronauts) and a randomized starting point.
2. The goal is to locate and help all four dots (representing stranded astronauts) and return to the starting point with the shortest total string.
3. Write three bullet points analyzing why having the shortest string is important for the project.
4. As a class, discuss why the shortest string represents the shortest distance to travel to all points. Since the boat has a max speed, the distance traveled is proportional to the time traveled (distance = speed * time). In minimizing the distance, we minimize the time the mission takes, thus getting the astronaut's help in the shortest time possible.

Explore:

The educator's goal is to encourage the students to find common experiences, so they can communicate with each other and further the exploration. You want to cultivate an autonomous scholarship and fuel a passion for learning. Having them in groups will foster teamwork, teaching them to communicate with each other to work towards a common goal.

Educator Guidelines:

- Facilitate learning
- Allow time for exploration
- Guide students
- Students record and analyze observations of data, construct ideas, or explore solutions.

For this explore section, we will transition into the "Buoyant Boat Activity." Students will get into groups of three to make a boat and explore its properties. Record (on paper) your observations and obstacles of building and using the boat. We will build our own boat as a guidance point for the students, we will also check in with the groups to help them build it.

2.3 Buoyant Boat Activity

Our vehicle must take into account the buoyant force, among many others, to make sure we stay afloat! We need to make sure that our boat can displace enough water to carry the weight of everything on board.
Materials Needed:

- Penny
- Dice
- Paper clip
- Tubs to hold water
- Salt
- Aluminum foil

Instructions:

- Create a boat able to float and carry a certain load (load could comprise of pennies, dice, and paper clips).
- Fold to create a simple boat out of tin foil.
- After creating a boat that successfully floats, make your boat sink by adding more items (hint: the boat will sink when the weight of the load exceeds the weight of the buoyant force).
- Within your group, discuss and write why certain boats sink and others float. Think of what would occur if the boats were in different liquids (less or more dense than water). Predict if the boat would float or sink in each situation.

The buoyant force is the upward push of a liquid or gas on an object. It is caused by increased fluid pressure at greater depth. We know the tendency of objects to float is known as buoyancy.
In the case of a tennis ball, buoyant force is greater than the ball's weight. If the force of gravity is greater than the buoyant force, then an object will sink. If the object floats on the surface, the weight of the object and the buoyant force are equal.

Explain: This is to support the advancement of their models or explanations of the topic at hand. You want to help them achieve their goal for the lesson. Essentially, you identify the tools and environment they need to succeed in their comprehension of the subject. When they share their perspective, it gives the instructor a chance to understand their comprehension of the topic. Once we understand their language, we gain insight into their experiences, unveiling what we may need to adapt in our lesson. We will describe all terms and concepts discussed in the lesson through the use of visuals (whiteboard illustrations, images, other media, and hands-on tools).
Educator Guidelines: This section contains two parts:

- Have the students share their experiences and observations from the previous two phases.

- Provide resources and additional information about the subject in discussion to support the student's exploration.
- Once the students finish exploring the boat and how it works, start a discussion about it based on the observations they recorded.
  - Before beginning discussions, combine the groups into larger groups of six to nine kids (each group would have an educator, one of us).
  - This will make discussion easier, and it will allow students to have more time to talk about their experiences.
- To provide additional resources: explain density.
  - Why did the boat sink at a certain time? What is density? Why does the boat need to be made of strong but lightweight materials?
- To explain density, we can present the "Density Activity" to the class.
  - Each advisor will show the "Density Activity" to their group of six to nine kids. This will let them be close up to the project.
  - This will also be a good time to use the terminology of "surface tension."

Additional Information To Refer To:
What is density?
Density is the measurement of mass per unit volume. It tells us the amount of mass contained in one unit of volume of that substance. This is connected to the idea of how tightly packed an object is. Densities will differ from substance to substance. Solids that float on water have a density less than 1.00 g/mL and those that sink have a density more than 1.00 g/mL.

2.4 Density Activity

When designing a boat, it is important to use materials in the boat that have the least density to strength ratio. If we use any materials that are too dense, there is the possibility of sinking the boat because it may not displace enough water to let the buoyant force be equal and opposite to the gravitational force.
Materials Needed:

- An empty glass/transparent cup of water
- Food coloring (optional)
- Syrup (food syrup/syrup consistency)
- Oil (canola or any cooking oil)
- Objects like a nail, grape, bottle cap, sponge, or even candy. Open-ended, test different objects!

Instructions:

1. Get into groups of six to nine individuals.
2. Pour water into an empty cup (fill 1/4th) and add food coloring if on hand and mix.
3. Add syrup, then oil (1/4th of the plastic/glass cup each).
4. Explain why distinct layers form and why they form in the order they do (goal is to have the students understand that liquids have different densities).
5. Drop nail into liquid and write observations on a piece of paper (the nail should drop right to the bottom, meaning it is denser than all liquids).

6. Drop the grape in (the grape should drop to the bottom of the water layer because it is denser than water and oil, but not syrup).
7. Drop-in plastic bottle cap (the bottle caps should sink to the oil-water layer, meaning it is less dense than water but denser than oil, technically floating on water, but sinking in oil).
8. Drop-in sponge (the sponge should float on top, less dense than all liquids).

Elaborate: It is okay if the student still has misconceptions, guide their exploration so that the solution comes to them. Or listen to them explain their experience and have a meaningful conversation to get you both on the same page. Offer interesting facts or opportunities that they can look to the outside of this learning experience or at home.

Educator Guidelines:

- Assuming they have developed their project...
- Give the students additional/external resources.
- Motivate self-involvement in other scientific experiences.
- Show them tangential topics and related ideas.
- These activities should allow the student to apply their understandings.
- Try having them find similar situations.
- Ask them if they have questions about anything that has happened so far.
- Ask them if they know about surface tension.
- Using the same tubs of water.
- Then go through the steps of the "Surface Tension Activity."
  - But only do the paper clip parts.
  - Have the students' design a cool looking boat out of printer paper, they can make it artistic. I want to let them keep the paper boat as a souvenir since we had floating boats in the beginning.

2.5 Surface Tension Activity

Surface tension is an important concept in two-phase flows, particularly at small scales. The surface tension of water allows the liquid to support objects on the surface. This activity teaches the importance of surface tension in supporting the weight of everyday objects.

Materials Needed:

- One plastic tub
- One paper clip
- One square of toilet paper
- A few drops of liquid soap
- Paper boat (made out of printer paper)

Instructions:

- 1st Activity: Try to make paper clip float in just water and explain observations.
- 2nd Activity: Try to make paper clip float with soap in water and explain observations.
- 3rd Activity: Make paper boats.

1. Put soap in the divot and explain observations.
2. Make this more fun by designing your own boats with your own artwork, be creative!

Principles Used:

- All liquids have surface tension along the surface of a liquid, caused by liquid molecules pulling other liquid molecules together. These are called inter-molecular forces. Liquid surfaces act like skin.
- Isaac Newton's third law of motion says for every action there is an equal and opposite reaction. The movement of the detergent provides a 'pushing force' backward into the water surface as the detergent molecules spread out, sending the boat forward... i.e. an equal and opposite motion. Explain it like this: the soap particles are being pushed out from the backside of the boat which is why the boat is moving forward.

Evaluate: It is okay if reflection and feedback occurs before this segment, but it is the focus of this section. This is the time in which we want the student to reflect on their work to reinforce their understanding of this educational experience. When they reflect, they solidify the terms and concepts they learned, making them more confident when leaving the classroom.

Educator Guidelines:

- This is the "feedback" portion of the learning process and the reflection.
  - The student will assess their understanding and learning process.
    - This has them acknowledge their abilities and identify their future learning goals.
  - The instructor will take this time to evaluate students on a more individual level.
    - It is beneficial to give one-on-one feedback on each student's progress. However, giving summative feedback to the entire group will also leave the students on similar pages.
- Have the students write a small reflection on the whole lesson, but ask them to pick their favorite one as well.
- Have them draw out their favorite.
- In the reflection, make it so they have to write down one to two questions they still have about what we did.
- During this time the educators will walk around to each student and have 1-on-1 conversations with them, let them guide the conversation.
- After the students are done and the educators have walked around, have the educators present a summative reflection of the process.
- Encourage the students to pursue their interests and to explore opportunities.

2.6 Summary

This concludes our lesson plan. The most important goal of this curriculum is to leave the students with a positive relationship concerning their perspective of the STEM field. By keeping them engaged with fun hands-on activities and letting them personalize their learning process, we can hope that they feel empowered in their knowledge of this experience. When using the 5E Education Model, students can personalize the way they intake new information, making the lesson plan adaptive to each student's educational background. This method acknowledges that each student learns in their own way, and at their own speed. We set the lesson up to reinforce the key concepts of our team's project by intertwining each activity and discussion to our project. We intentionally made each step to inform the students about different aspects of our team's project, in addition to dispersing information about the NBL and Micro-g NExT challenge. We want to use the Micro-g NExT Challenge to provide an inspiring educational opportunity for underserved children in our community. Often these students don't receive the motivation or the knowledge to continue their education, so we hope this opportunity can serve as the sign students need to show that they can, in fact, succeed.

3 Administrative Section

3.1 Test Week Preference

The team's top preference for test dates are within the second week of June.

3.2 Mentor Request

The team is not currently collaborating with a technical point of contact at NASA.

3.3 Institutional Letter of Endorsement

UNIVERSITY OF CALIFORNIA, BERKELEY

BERKELEY • DAVIS • IRVINE • LOS ANGELES • MERCED • RIVERSIDE • SAN DIEGO • SAN FRANCISCO SANTA BARBARA • SANTA CRUZ

PROFESSOR KARL VAN BIBBER
SHANKAR SASTRY CHAIR FOR LEADERSHIP & INNOVATION
DEPARTMENT OF NUCLEAR ENGINEERING
UNIVERSITY OF CALIFORNIA, BERKELEY
4107 ETCHEVERRY HALL
BERKELEY, CA 94720-1730

EXECUTIVE ASSOCIATE DEAN
ASSOCIATE DEAN OF RESEARCH
COLLEGE OF ENGINEERING
TELEPHONE: (510) 642 3477
email: karl.van.bibber@berkeley.edu

October 26, 2020

SUBJECT: UNIVERSITY OF CALIFORNIA ENDORSEMENT FOR WATER BEARS TEAM

The Water Bears team of twenty-six University of California Berkeley students have accepted the challenge of building a surface vehicle, the SAVER (surface autonomous vehicle for emergency response), that will aid in emergency response in the case of a launch abort or contingency landing. The SAVER will serve as a force-multiplier in assisting current efforts to attend to survivors in the event of an emergency on the scene by autonomously searching for any isolated victims, allowing on-scene rescuers to immediately attend to survivors in the main life raft. This project is exciting as it creates an opportunity to design and test a solution to an authentic, current space exploration challenge.

In order to achieve the challenge goal, the Water Bears team members are divided into five departments focusing on different aspects of the project: mechanical, electrical, programming, finance, outreach/education. The project leaders, Ryan Luna and Leon Liu, work closely with each of these departments in order to ensure consistency across the team.

I, Karl van Bibber, acknowledge that the University of California, Berkeley has knowledge of the Water Bears interest in participating in this activity and endorses the team's involvement.

Sincerely,

Karl van Bibber

Karl van Bibber
Executive Associate Dean & Associate Dean for Research
College of Engineering, UC Berkeley

3.4 Statement of Supervising Faculty

As the faculty advisor for an experiment entitled "Berkeley Autonomous Emergency Responder (BEAR)" proposed by a team of undergraduate students from The University of California, Berkeley, I concur with the concepts and methods by which this project will be conducted. I will ensure that all reports and deadlines are completed by the student team members in a timely manner. I understand that any default by this team concerning any Program requirements (including submission of final report materials) could adversely affect selection opportunities of future teams from The University of California, Berkeley.

Name: ______________________ Signature: ______________________ Date: ______________________

3.5 Statement of Rights of Use

UC Berkeley's Intellectual Property and Industry Research Alliances (IPIRA) department has barred faculty members from signing the current statement of rights of use. Further communication with IPIRA is required.

3.6 Funding and Budget Statement

3.6.1 Expected Expenditures

Team	Item(s)	Estimated Cost
Mechanical	Carbon Fiber Fabric	$200
	West System 105 Epoxy Resin / 206 Slow Hardener	$60
	6061-T6 Aluminum	$10
	Composite mold materials	$100
	Hatch hinge (McMaster-Carr P/N 1488A130)	$11
	Hatch latch (McMaster-Carr P/N 1685A26)	$15
	Hatch sealing foam	$20
	Fasteners	$50
	Sealing gaskets	$20
	Voile Mounting Straps	$30
	PVA Release Film	$12
Electrical	Rasberry Pi	$35
	Arduino x 2	$52
	Kerberos SDR	$250
	Antennae x 2-4	$120
	Fuse Box	$28
	Battery	$98
	Motor Controller x 2	$54
	Thrusters x 2	$360
	Breaker	$28
	IMU	$20
	Banana plug bulkhead connector (Pomona Electronics P/N 6883)	$4
	Antenna bulkhead connectors (L-Com P/N BA21)	$34
	Shrink Wraps	$10
	Wires	$20
Education	Pennies (40)	$0.45
	Dice (pack of 50)	$7.99
	Paperclips (pack of 450)	$5.99
	Tubs (pack of 4)	$22.99
	Salt	$3.66
	Aluminum Foil	$3.41
	Toilet paper (12 roll)	$5.99
	Liquid soap (12 fl oz)	$4.99
	Printer paper (500 sheets)	$3.87
	Three graphing paper notebooks	$17.61
	Roll of String	$5.87
	Two pack set of transparent plastic cups (200 total)	$24.98
	Food coloring	$3.48
	Canola Oil	$2.48
	Dixie cups	$9.99
	Candy	$10.49
	Maple syrup	$6.88
Travel to NBL	Gas	$750
	Food	$1,300
	Hotel	$2000
	Miscellaneous	$400
	TOTAL	$6,282

3.6.2 Financial Representative

Sultan Dildar - Business Team Lead - sultandildar@berkeley.edu

3.6.3 Potential Sources of Funding

Registered Student Organization (RSO) We plan to become an RSO at Berkeley in the spring semester. By doing this, we will be able to secure funding from the institution for our endeavors and have access to more resources that we otherwise would not have.

Berkeley Engineering Fund The Berkeley Engineering Fund supports students and faculty of Berkeley. They provide the core budgets for student-led organizations, as well as provide funding for projects and research initiatives. We will be applying for a grant from the Berkeley Engineering Fund in February in order to secure some funding.

SICHOP Grant Grant for undergraduate students working on a "hands-on" project, recommended to include an outreach component. Our project aligns nearly identically with the mission of the grant. Requires grant activity photos and final report. This grant is offered on a rolling basis, with funding requests up to $5,000.

Berkeley Rotary Grants The Berkeley Rotary Club offers grants to local groups that promote the ideas of peace and service, and have shown generous support to organizations that seek to enhance community-building and education. The next grant cycle opens February 15 and funding ranges from $500 to $6,000.

Local Business Sponsorships and Promotions We will be connecting with local businesses and hope to secure sponsorships and promotions from them. We hope that they will be able to donate small lump sums of cash in return for us promoting them with their business name on our team shirt or on our boat.

Corporate Sponsors We will be reaching out to the public relations teams of corporations such as SpaceX, Boeing, and other companies to seek funding or a sponsorship.

GoFundMe Our GoFundMe will be used to promote our project and gather donations. We will spread this page through our social media, website, and on LinkedIn to Berkeley Alumni, largely engineering and stem graduates specifically.

3.7 Parental Consent Forms

All members are above the age of 18.

Appendix A Abbreviations

NBL	Neutral Buoyancy Laboratory
SAVER	Surface Autonomous Vehicle for Emergency Rescue
BEAR	Berkeley Emergency Autonomous Responder
FAQ	Frequently Asked Questions
RF	Radio Frequency
P/N	Part Number
SDR	Software-Defined Radio
GPS	Global Positioning System
GNSS	Global Navigation Satellite System
CxL	Conseuqence & Likelihood
CG	Center of Gravity
CB	Center of Buoyancy
CAD	Computer-Aided Drafting
ANGEL	Advanced Next-Generation Emergency Locator
VHF	Very High Frequency
FOS	Factor of Safety

Appendix B Design Risk Matrix

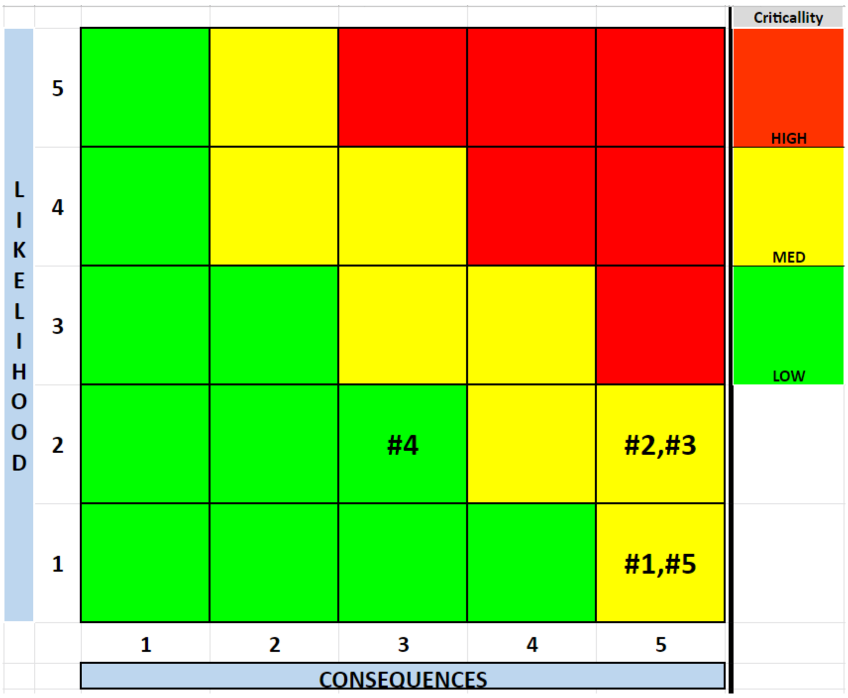


Figure 4: Note: numbers within boxes are the corresponding numbers of the risks identified in the Risk Summary Chart.

Appendix C Static Stability Curve

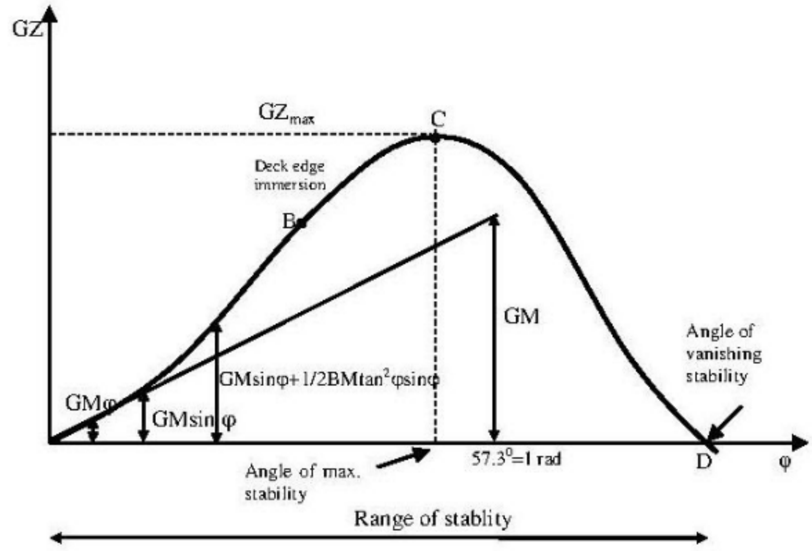


Figure 5: (Akyıldız, Şimşek)

Appendix D Design Decision Matrix

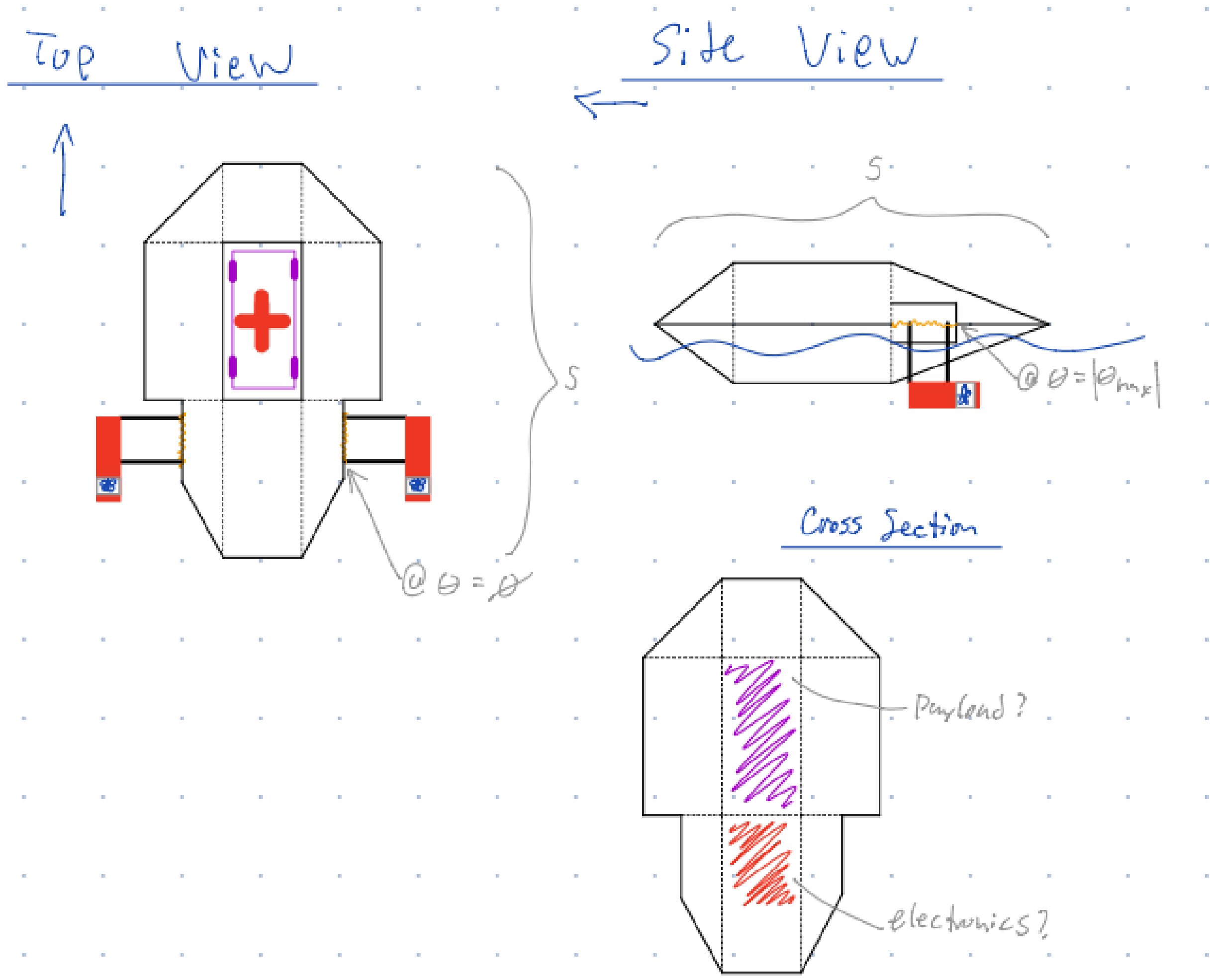
	Using numbers 1-5, 5 being "better'				
	Weighting	**1.5**		**1.5**	
		Mechanical Complexity (higher is less complex)	**Justification**	**Design Complexity**	**Justification**
A	**Closed hull + hinges**	3	Mechanically complex: 1. 100% success rate in orientiation 2. locking mechanism in desired orientation	3	Hinges add design complexity
B	**Closed hull + fixed motors (positive AOA)**	4.5	Not having a hinge eliminates moving parts, reducing mechanical complexity. The closed hull structure is slightly more complex than the catamaran structure, which can be a simple rectangular frame	4	Simple design (no moving/ adjustable part)
C	**Catamaran with fixed aft motors**	5	Fewer parts, no hinges or other complex parts	5	Simple design (no moving/ adjustable part)
D	**Catamaran with hinges**	3.5	Again, hinges add complexity. Catamaran is less mechanically complex than a monohull since the hulls used for floatations can be simpler	3	Hinges must be designed so that they can keep the SAVER orientation agnostic
E	**Torpedo**	5	Simple cylindrical construction	3	Would have to find a way to allow it to be at a certain depth w/ AND w/o load
F	**Self-righting conventional boat**	4	Easier to construct	2	Has to satisfy certain physical conditions to be self-righting. requirement that the vehicle be operational with and without payload makes this trickier to ensure across a range of weight distributions. Self-righting is often achieved with ballast, which is likely prohibitively heavy in this case.

3		1.5		1	
Weight	**Justification**	**Electrical complexity (higher is less complex)**	**Justification**	**Accessability to the cargo**	
5	The hull being both buoyant and structural saves having weight on a separate mechanical frame. Hinges save some weight since we do not require long aft booms	4	Servos are a little complex, but not really.	5	A cargo door hinge with a latch/toggle clamp provides easier access than having to untie/cut open a package. This allows for more flexibility in the packaging of the individual package components, which allows for easier acess by the person in distress
4	See above, but motor booms take some more weight	4.5	This is about as simple as it gets. When compared to a self-righting boat, you need an additional orientation sensor to know "which way is up"	5	Same as closed hull
1	The catamaran design requires a more rigid frame since the hull is not a load-bearing structure. This adds weight to the vessel. Fixed aft motors also need to be mounted significantly far back, which increases the weight of the frame.	4.5	Same as above	3	In a rescue scenario, hard to untie/unclip rather than unlatch
2	See above, but not having booms for aft motors saves some weight	4	Servos are a little complex, but not really.	3	Same as ^
2	saves weight on not having extra boom for motors	2	The possibility of needing control in 2 axes (i.e. yaw and pitch) complicates things. This may require use of additional sensors, servos, and more involved control loops	1	Difficult since it is underwater (would have to worry about removing cargo without it getting wet/swept away)
5	The hull being both buoyant and structural saves having weight on a separate mechanical frame.	5	There are no moving parts besides the use of the motor	5	Same as closed hull

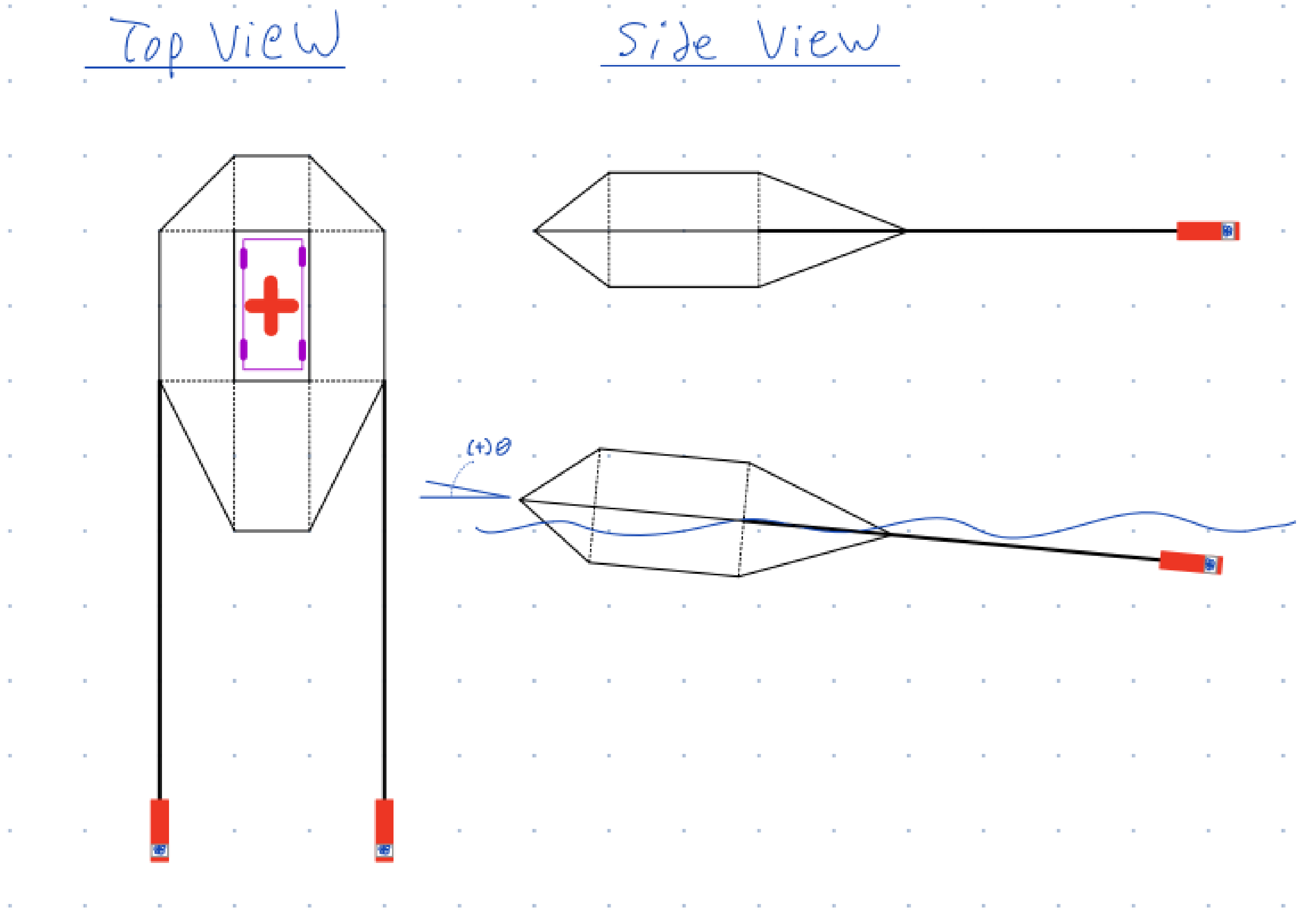
2.5		2		1			
Speed		**Manufacturability**		**Novelty**			**Totals**
4.5	Not under water -> least drag	3	Hinges are more mechanically complex, which leads to slightly more difficult manufacturing of the hinge parts. Also, more parts to worry about when compared to a fixed design	5	Hinges are a novel solution to the problem of orientation-agnosticity	**Closed hull + hinges**	**57.25**
4.5	Same As ^	4	Not as easy as catamarans, but easier than closed hull + hinges. Close hull solutions may require custom layup molds, which can be harder to manufacture (i.e. cnc)	2	This design is essentially a typical boat, which is not very novel	**Closed hull + fixed motors (positive AOA)**	**57.75**
4	more drag due to payload being partially submerged	5	Limited amount of parts to manufacture (generally easy to put together)	2	Not very novel, very similar to COTS solution.	**Catamaran with fixed aft motors**	**49.75**
4	Same As ^	4	Same as above, slightly more difficult since more parts (not counting design difficulty of the hinges)	5	See A. Catamaran is not much more novel than a monohull	**Catamaran with hinges**	**47.75**
2	Completely submerged, water has higher density, viscosity, more drag	5	Either two main parts (top/bottom) or off-the-shelf rocket parts (per Michael)	3	Competition name is Surface ...	**Torpedo**	**40**
5	Not under water -> least drag	4	Similar to closed hull	2	Very similar to obvious solution, but with some more design complexity.	**Self-righting conventional boat**	**59**

Appendix E Unselected Initial Design Concept Sketches

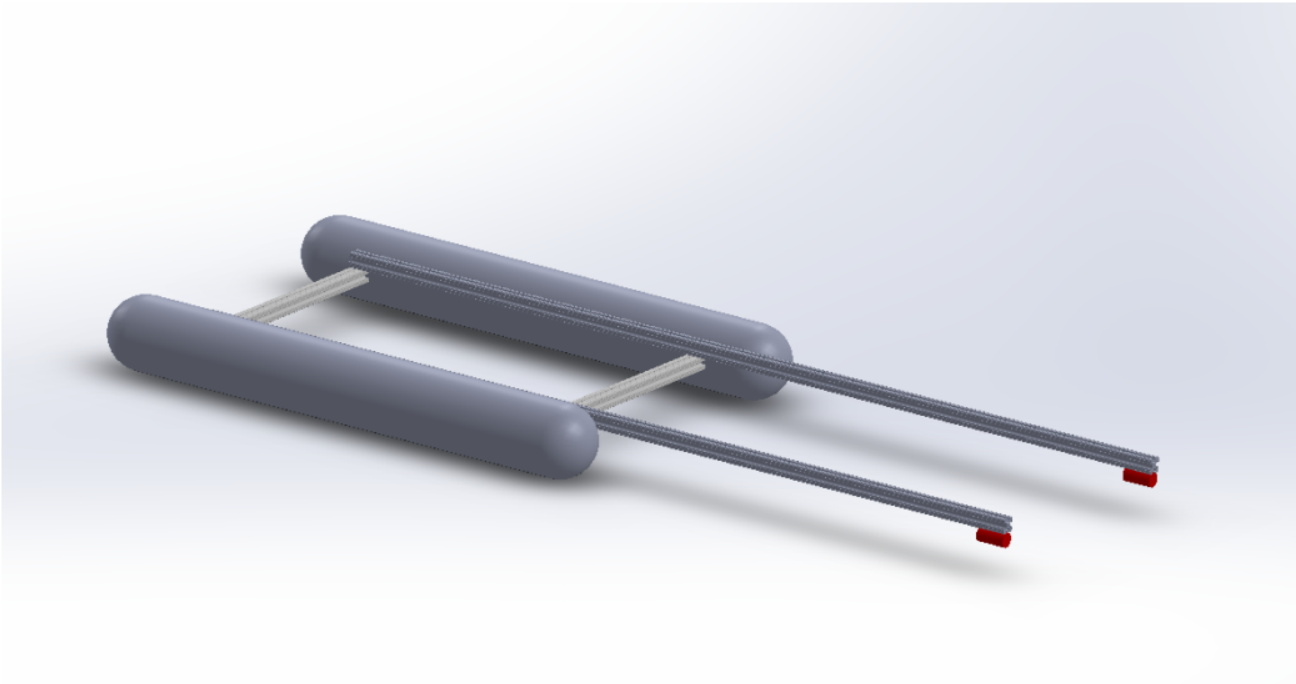
E.1 Closed Hull with Hinged Motors



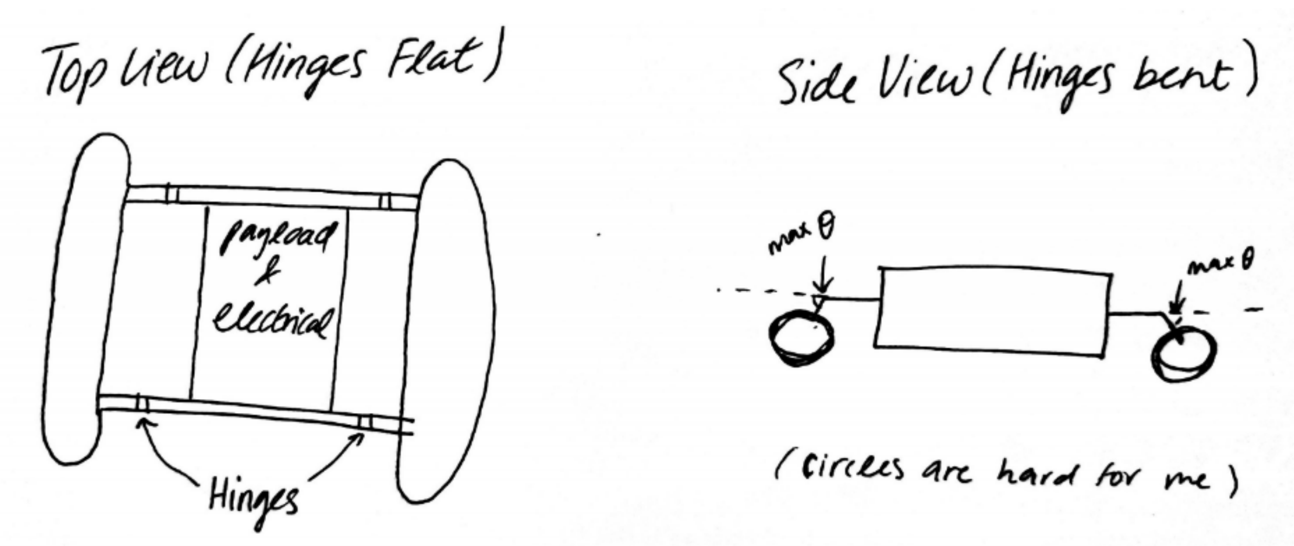
E.2 Closed Hull with Fixed Motors



E.3 Catamaran with Fixed Aft Motors



E.4 Catamaran with Hinged Motors



Appendix F Kerberos SDR

Figure 6: KerberosSDR