1/12/24

EML4551-2

Team 521: NSWC - RoboBoat

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Code of Conduct

This document will serve as the team contract for Team 521 for the duration of the Senior Design period which will last from Fall of 2023 to Spring of 2024.

Mission Statement

To work collaboratively as a team to design, build and operate an Autonomous Surface Vehicle (SVA) that is capable of tackling current challenges faced by the modern maritime industry. The team will aim to employ the members previous course material, knowledge, and experience that has been gained throughout their undergraduate career while also behaving in a professional manner.

Outside Obligations

The team will meet regularly during the senior design class lecture time every Tuesday and Thursday (3:30PM – 7:45PM). The team can schedule additional meetings as deemed necessary; preferably every Monday and Wednesday (7:00PM – 9:00PM) via zoom call. A when2meet schedule will be updated weekly by all members in case an emergency meeting is needed to be scheduled.

Table 1: Team Roles

Team Member	Team Role
Ivanna Caballero	Materials Engineer

Andly Jean	Mechatronic Engineer
Nicholas Norwood	Mechanical Systems Engineer
Makenzie Wiggins	Design Engineer
Sophia Barron	Electrical Systems Engineer
Lucca Meyer	Test Engineer
Michael Fitzsimmons	Electronics Engineer

The materials engineer will be responsible for researching and selecting the materials that are best suited for the development of the RoboBoat. The materials that will be selected will be used to optimize the design. Other responsibilities covered by the materials engineer will be structural integrity, weight and balance, testing and quality control. The materials engineer will also oversee the manufacturing process of these materials to find the safest way of implementing the materials.

The mechatronic engineer is responsible for the programming and the integration of different electronics and subsystems in which they belong to. Working alongside the mechanical systems and electronics engineer, they ensure that each subsystem's programming and physical output operate as planned.

The mechanical systems engineer is responsible for ensuring that all of the interacting systems of the RoboBoat are integrated together. They are also responsible for helping the mechatronic engineer with designing and integrating the mechanical and electrical components of the project.

The design engineer is responsible for the CAD modeling and analysis of the RoboBoat. They ensure that the boat is stable. This will entail designing the boat for stability and making sure the mounting of components is designed in a way to get the most performance/stability out of the RoboBoat. The design engineer will also work closely/help colleagues to make sure the design is optimized.

The electrical systems engineer is responsible for implementing and maintaining the electrical systems of the Roboboat, ensuring that they are efficient and reliant. They are also responsible for creating circuit schematics, electrical block diagrams, and troubleshooting issues in making sure that the different systems functionally operate safely.

The electrical test engineer is tasked with the responsibility of designing and developing diagnostic tests to ensure that anything relating to the electrical components is on the RoboBoat. Working in conjunction with the electrical systems engineer to confirm that the implementation of the schematics and diagrams are functioning properly. In addition to confirmation of design, the electrical test engineer will check the components and ensure that the highest level of quality and safety is being practiced.

The electronics engineer oversees implementation of all electronics onboard the RoboBoat. Main tasks will include ensuring compatibility on various electronics within the overall system, developing and modifying code for communication between electronics, repairing and maintaining circuit boards, as well as creating circuits to connect components.

Communication

All files the team works on will be through Microsoft Teams. Additionally scheduling and formal communication will be conducted through Microsoft Teams. An iMessage group chat should only be used to communicate informally and when a matter concerning the project is urgent. When communicating with Dr. McConomy, sponsors, and other mentors should be done through email, and it is required that all group members be copied. When responding to emails, respond in a professional, polite, and understanding manner. If no response is received within 24 hours for team members and 72 hours for non-team members, a follow-up email should be sent by the original sender of the email.

Meeting notes will be taken by each group member at all the meetings. These meeting minutes must be uploaded to the "Meeting Minutes" folder in Microsoft Teams by every team member. If a member happens to miss a team meeting, it is their responsibility to review and study the recorded notes from the other team members to stay up to date with everything that is occurring within the project.

All team members must read through and review each document before submission. All assignments will be submitted the night before the due date unless extenuating circumstances arise. The submitter will send out a message through iMessage and all the team members must respond with approval to submit before the assignment is submitted. If no response is received prior to an hour before the due date, the submitter has the right to proceed to submit the document.

Dress Code

For any type of event that concerns the project, team members at minimum should be presentable. For general team meetings a specific dress code is not required. For sponsor meetings, advising meetings, either in person or online the team is expected to dress in business casual. For Virtual Design Review presentation team members are expected to dress in the black FAMU-FSU College of Engineering polo with matching black dresspants.On Senior Design Day, all members of the group shall dress in Business Professional.

Attendance Policy

All members are required to attend the Tuesday and Thursday (3:30PM – 7:45PM) weekly meetings. If a member is to miss either an in-class or outside group meeting they should notify the other team members in the iMessage group chat. If a team member missed more than 3 team meetings without prior notice, Dr. McConomy will be notified for guidance on how to handle the matter. Vacations days are to only be used on team assignments upon agreement of all team members. The decision to use a vacation day amongst the team must be made at least 48 hours before the assignment is due.

How to handle any monetary prize

If the team is to place in the RoboBoat competition and win any monetary prize, the prize will be equally divided among all members of the team.

How to Notify Group

The Primary method of communication will be through Teams and through email. Urgent messages can be communicated through text; however, documentation of urgent messages will be uploaded to teams.

How to respond to people in professional meeting

Communication inside and outside of meetings will be done respectfully and politely. During the meeting, one member will be designated as the speaker to ensure no team member is being spoken over.

What do we do before Dr. McConomy or TAs

If there is an issue in the team, it is the responsibility of the parties involved to have it resolved. If the issue has not been resolved after 72 hours, the issue will be brought up at the next team meeting. The team will discuss the problem and make a consensus on how to move forward.

Contacting McConomy

Contact with McConomy and TAs should be made through email or in-person, preferably with all group members present or notified. If the individual meetings and the group meetings have not led to a resolution of the situation, then either Dr. McConomy or the TA's will be notified about the issue. Contact should also be made if our sponsor is currently unavailable or has not given a response for an extended period of time on a matter that is currently halting the progress of the group.

How to amend

This document can be amended at any time during the project. It will require unanimous agreement by all team members. The amendment shall be clearly stated and explained to all team members. Signatures are not required for amendments.

Statement of Understanding

By signing, each person has agreed to the Code of Conduct and will uphold everything that was stated above:

Ivanna Caballero	01/12/2024 Date
Andly Jean	01/12/2024 Date
Nicholas Norwood	01/12/2024 Date
Makenzie Wiggins	01/12/2024 Date
Sophia Barron	01/12/2024 Date
Michael Fitzsimmons	01/12/2024 Date
Lucca Meyer	01/12/2024 Date

Project Scope

Project Description

The objective of this project is to design, build and program an autonomous surface vehicle capable of autonomous movement, object avoidance and having a robust safety system. The ASV will be used to further autonomous marine technology, specifically for the NSWC.

Key Goals

. The primary goal for this semester is to design and develop an autonomous surface vehicle that will serve as a strong foundation for future Roboboat teams. To meet that goal, we aim to achieve the following key goals by the end of the spring semester: having a modular design and code architecture -allowing for easy integration and change in design for future teams. Furthermore, an emphasis will be placed on having a reliable and robust safety system that measures up to competition standards. Waterproofing will be required for some components of our RoboBoat.

Market

There are a variety of groups that would have an interest in our final product. The primary markets for this ASV include future RoboBoat teams, RoboNation and the Naval Sea systems Command, which includes the Naval Surface Warfare Center and Naval Undersea Warfare Center subgroups. The secondary markets include a span of groups from RC boat manufacturers and enthusiasts to the U.S Coast Guard, life size boat manufacturers, and even cargo ship and cruise ship companies. The RoboBoat can serve as reference for future ASV's, spanning both small- and large-scale groups and projects. Its uses can be sought out by RC boat enthusiasts, and it can even go as far as being identified as a prototype that offers insights for future Naval Sea System Command projects.

Assumptions

The assumptions are to have access to the ME design lab for soldering or any tools needed and there will also be access to a COE machine shop. The RoboBoat must comply with previous years rules that we are currently using as a basis for our design until this year's rules are released. The weather conditions at the time of the competition will be beyond our control. There will be a required safety inspection at the competition, and only one task is required to be able to compete. Previous Roboboat evidence manuals will be available as a point of reference. Another assumption is that future FAMU-FSU College of Engineering Roboboat teams will be using our project as a foundation.

Stakeholders

The stakeholders of thivs project include the FAMU/FSU College of Engineering, senior design coordinatorDr. Shayne McConomy, our project sponsor Dr. Damion D. Dunlap – a representative ofNaval Surface Warfare Center and the RoboNation organization in charge of the RoboBoat 2024 competition. Dr.Ordonez and Dr.Clark are also considered as they advise and provide expertise in the development of some motor systems and programing. General readers or other educational institutions could also be stakeholders. This project is being represented by the FAMU/FSU College of Engineers and Dr. Shayne McConomy.

Customer Needs

After discussing and reviewing our project scope and ensuring our objectives and goals aligned with those of our sponsor and event organizers (RoboNation), we decided to develop additional questions for our sponsor, Dr.Dunlap, to further discuss and address the needs and expectations of the company. A phone call meeting was conducted with our sponsor with all members present. During the meeting, we gathered valuable insight that would serve as a way to refine our specifications to better help address the customer's needs. Several of our questions were answered by Roboboat's official website and rule book, and the questions that needed further clarification were discussed in more detail. The statement of responses regarding the questions asked are listed in the following table:

Table 2: Customer Needs

	Questions	Responses	Interpretation
1	How does the RoboBoat project align with the Naval Surface	Allows them to develop and identify talent, it is about skills and interest.	The customer is not looking to gain information from our

	Questions	Responses	Interpretation
	Warfare Center's (NSWC) objectives?	Learn a lot about hardware and software, and get to contribute to what could be a legacy of the FAMU-FSU RoboBoat Team.	project, but rather looking to see if we possess the skills to work with them.
2	What could we add to the project that might help NSWC in a current project they are working on?	We have a substantial challenge already with just the competition. Make use of technical reports from prior teams that were successful. Having expertise in robot operating systems is something the company values.	Focus solely on the requirements already given for the challenge and study previous successful teams' technical reports.
3	Given the limited time frame and resources, what would the ideal end of this project look like to you?	The ideal 'end' of this project is to have an ASV that could drop waypoints and have an appearance of autonomy so that it can also tackle one to two other tasks prior to competition. As for senior design day, it would be interesting to see if our team could accomplish at least one other task and work from there.	Prioritize getting the drop waypoint system to function properly and have one other task prior to competition. Have another task completed by senior design day.
4	What might be some of the technical limitations that we may	One of the challenges that many teams struggle	The primary challenges involve choosing a

	Questions	Responses	Interpretation
	run into that you have seen from previous competitors?	with is making the right choices that would give you more time to test on the water. To ensure that the time on the water is not cut short it is imperative that the battery we are using has enough power to last longer than 30 minutes. It is also helpful to have the boat be large enough so that more than one person can work on it at a time.	high-capacity battery system to sustain operations for over 30 minutes on the water. A bigger and organized boat design is suggested so that more people can work on it at once.
5	What are some specific design preferences you may have? (i.e., bigger or smaller boat, weigh less or more)	He does not have any preferences. It is up to our discretion. One dilemma that he has seen teams make is making the boat optimizable, but not getting easy weight and thrust points. Teams in the top 3 are never the lightest or most powerful boats. Having a larger boat gives us more flexibility and more options (more sensors, batteries, and room)	Design a boat that we make a boat that is not too big or too small but allows for flexibility and complies with the rules.
6	What are the specific targets that you want us to strive to achieve?	Weight is not a great target. Have a target with respect to stability. The cameras looking at the	Weight, stability, and waypoint recognition are targets that need to be included and

	Questions	Responses	Interpretation
		sky aren't helpful. Also, waypoint navigation accuracy is important.	prioritized over the weight.
7	Are there certain things for the Roboboat that you would want well documented for reuse or other purposes within NSWC?	Good documentation of the operational procedures is very important. Without us being present, someone must be able to operate it. Hopefully this will be a foundation that future teams can build off.	Document operational procedures in as much detail as possible. Make sure to compose a detailed operational manual and make everything so that it can be understood by others.
8	What would an ideal speed and power range be for the Roboboat?	Look at the results table from previous technical reports (Top 5 teams). Try to stay in the range of the numbers that were provided by those teams to be more successful.	We will refer to previous result tables from the previous top 5 teams, to get a better understanding of speed and power and base our ranges from there.
9	What is the expected operational duration of the Roboboat?	Competition-wise testing is usually conducted in a 30-minute time slot. This is an all-day event that lasts over the course of about 4 days. Teams have the option of picking their time slot and may also gain the opportunity to remain on the water for longer periods.	Be able to operate for an extended amount of time anywhere from 30 to hour long time frames.

	Questions	Responses	Interpretation
10	What is our expected budget for this project?	$2000 to be mainly used for materials. Increasing the budget will be taken into consideration as the need arises.	Plan for budget to be under $2,000. Account for unexpected costs when creating an initial budget.
11	Are there any chemicals that you would like us to avoid from using for environmental purposes outside of the hull?	None that he is aware of.	Double check with the competition guidelines but no current restriction on chemicals for outside of hull.
12	The timelines for our class assignments and the competition dates are not aligned. We are going to try to get as many of the competition tasks completed as we can but are there certain tasks you would like us to focus on?	Definitely focus on safety as our first task. The system must be able to completely stop when asked to and stay that way to prevent any fires or other complications.	Focus on the safety system – remote, signal, and physical kill switch.
13	What are some failures from past experiences that we should be aware of?	To not necessarily go for the easiest points for example, the lightest boat and fast thrust because the boat will be unstable. To focus on making a stable and efficient system to be able to collect good data and have a good imagery system.	Focus on making a well-rounded reliable design to accurately collect good visual and environmental data.
14	What are the goals wanted to be achieved by partaking in this	For us as students to be able to pick up some	Project is meant to foster the technical

	Questions	Responses	Interpretation
	project and competition? (Personal or company goals)	valuable skills and wants each of us to be able to walk away with something that we were able to contribute to.	growth of participating members.
15	What materials have other previous teams used for the boat structure?	He recommends checking the previous competition reports. He has seen everything from foam hulls with a box on top to carbon fiber automotive grade hulls.	Review and learn from previous top teams' technical reports.
16	What materials do you have already that we might be able to incorporate into our project?	He might be able to get a lidar, a jetson Xavier, a lot of thrusters, small navigation buoys, and some different boat hulls.	There is material already on hand that could be implemented within the final product or used during the testing stage.
17	What should the safety system consist of?	The system must always fail safe. Hitting an off button needs to disconnect power to all motors (relay chain), needs a physical kill switch, a remote/signal kill switch where if the RC transmitter is no longer transmitting the power will be shut down. The device should also have a noise signal that can be listened to to then disable power.	Design will consist of a physical and remote kill switch.

	Questions	Responses	Interpretation
18	What are the maximum overall dimensions that the Roboboat can be?	3 feet in width, 3 feet in height, and six feet in length.	Design Roboboat to fit into size restraints of 3 ft wide x 3 ft high x 6 ft long.
19	What are the weight restraints for the Roboboat?	The whole design should weigh less than 140 lbs. The lighter the Roboboat is the more points you receive.	Design Roboboat so that it is at least lighter than 140 lbs. while still having stability.

The information we gained from this meeting with our sponsor helped our team develop a deeper understanding of the goals and customer needs. Given the list of questions, the needs can be interpreted as seen on the above table. Dr.Dunlap who is part of the NSWC outreach program, is an individual who has had a lot of experience not only with the Roboboat competition (as a judge), but also as a mentor for past Roboboat teams. The meeting further emphasized the priority of making a safety system that properly functions, a navigation system that allows for waypoint detection, and working on completing an additional competition task. The size and weight restraints of the Roboboat are 3 feet wide, 3 feet tall, and 6 feet long and at least under 140 lbs.

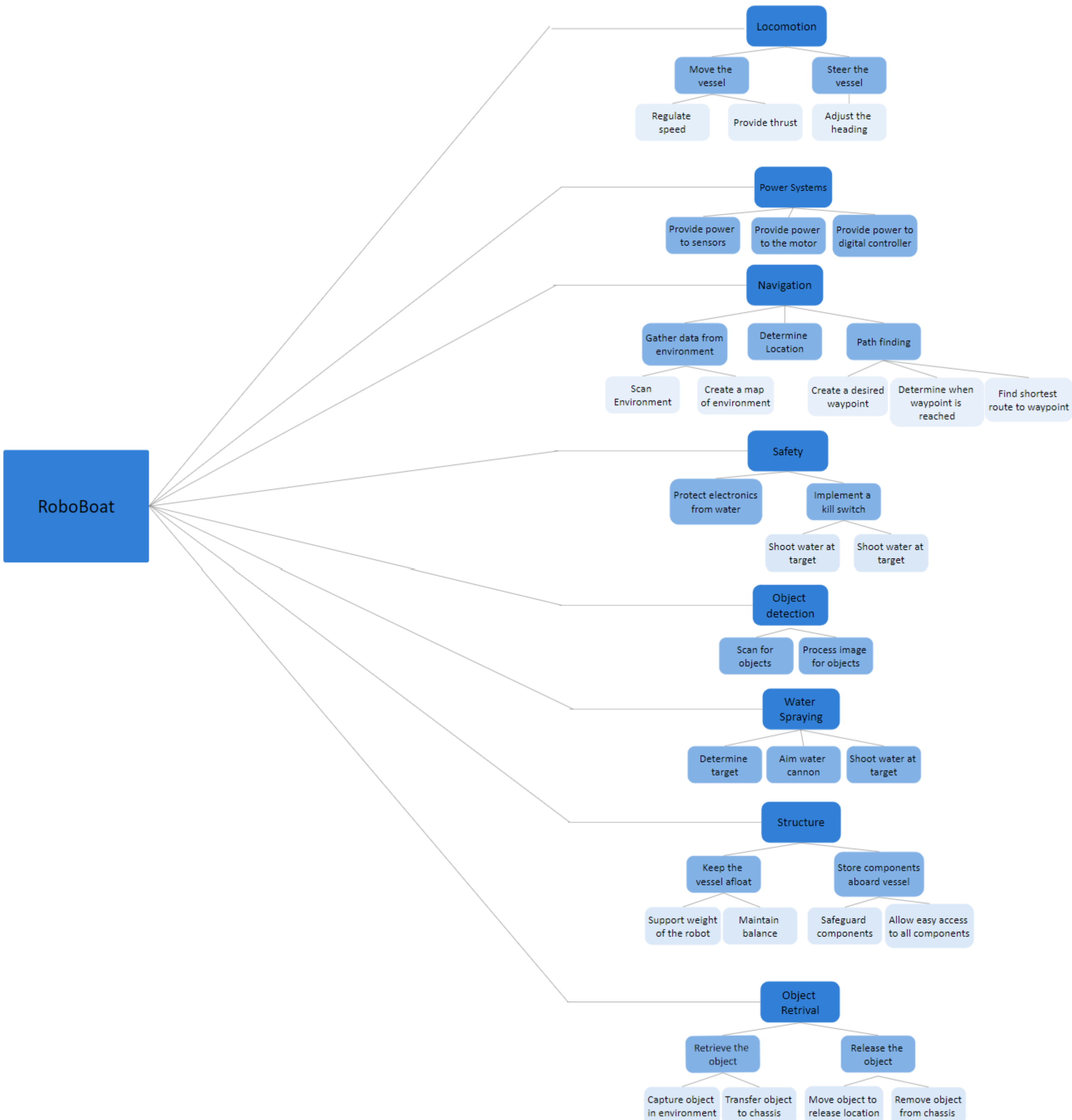
Functional Decomposition

Introduction

Through the functional decomposition, the required actions and outcomes of the project developed in the customer needs are split into the required broad systems. Within each of these broad systems, more specific functions and recognized and organized into their appropriate categories. For the sake of this project, we identified eight necessary system and their sub-functions. In order of no importance, they are locomotion, navigation, object recognition, structure, safety, power systems, and object retrieval, and water spraying. To properly organize our systems and their sub-functions, a hierarchy chart was created. To further compare and determine the relationships between each system, a cross reference chart was created.

The primary goal of this project is to design, build, and program an autonomous surface vehicle (ASV) capable of completing a set of tasks in the following categories: Navigation, detection, object delivery, object avoidance, station keeping, and two-step behavior. With these tasks in mind, we came up with the aforementioned systems that would individually and collectively be able to accomplish the given objectives.

Figure 1: Functional Hierarchy Chart



Connection to Systems

The overall goal of RoboBoat is to design a vessel which can autonomously navigate itself through a system of buoys, and complete various tasks given by the project manual. Based on the customer needs we developed, we have determined the following eight subtasks to be the most crucial pieces of our design:

The locomotion function is responsible for the physical movements of the boat, including steering and varying the velocity of the vehicle.

The Navigation system will use collected information about the vessel's surroundings, process said information, and make decisions on how to control the boat based on this data. The collection will be comprised of collecting information on buoys, obstacles, waypoints, and location of the boat. After this information has been collected, the processor will make and implement informed decisions on where to move the boat.

The structure system has 2 main functions: which focuses on having a stable and buoyant design that keeps our vehicle afloat and on protecting critical components while ensuring easy accessibility. This consists of having a strategic placement of electrical and mechanical components that will be easily accessible without compromising its protection against hazards.

The object retrieval system, much like the locomotion system is also another purely mechanical system. It is responsible for the physical act of grabbing/retrieving the required items. As designed by the competition task this system should be able to grab a variety of small items.

The power system's function is to ensure adequate and lasting power to the boat. The power is provided by the battery(s) for the electronic components encased inside of the boat. These components will consist of motors, sensors, and the digital controller.

The safety system primarily will revolve around two aspects which are incorporating a remote signal-based power removal system which will allow the operators of the vessel to be able to quickly cut off the vessels power system, when necessary, which will improve overall safety and control over the vessel. Another feature of the safety system will be a button which will also be designated as a kill switch to remove all power from the vessel.

The object detection system acts as the eyes of our system, using cameras and sensors this system is responsible for the visualization and processing of the various objects in the environment. This system works hand-in-hand with the navigation, object retrieval, and the water spraying system.

The water spraying system is another one of our mostly mechanical systems. This will involve our detection systems determining the location of the target, aiming the onboard water cannon, and sending the necessary information to the water spraying system that will allow it to fire and accurately hit the target.

Functional Relationships

Table 3: Functional Cross Reference

Subtask	Locomotion	Navigation	Structure	Object Retrieval	Object Detection	Power Systems	Safety	Water Spraying
Provide power to the motor(s)						**X**		
Provide power to sensors						**X**		
Provide power to digital controller						**X**		
Adjust the heading	**X**							
Regulate speed	**X**							
Provide thrust	**X**							
Allow easy access to components			**X**					
Safeguard components			**X**					
Maintain balance			**X**					
Support weight of the robot			**X**					
Determine when waypoint is reached		**X**						

Find shortest route to waypoint		**X**						
Create desired waypoint		**X**						
Create map of environment		**X**						
Scan Environment		**X**						
Remove power using a remote signal							**X**	
Remove power from vessel using a button							**X**	
Remove object from the chassis				**X**				
Move object to release location				**X**				
Transfer object to chassis				**X**				

Capture object in environmen t				X				
Process image for Objects					X			
Scan for objects					X			
Determine Target								X
Aim water cannon								X
Shoot water at Target								X

The table above provides insight into each function for the RoboBoat. We have eight system functions: locomotion, navigation, structure, object retrieval, object detection, power systems, safety, and water spraying. They all have a number of tasks, as indicated with X's, within each function to be achieved by the end of the project as they were interpreted from the customer needs.

<u>Targets and Metrics</u>

Each functions and subfunctions mentioned in the functional decomposition were assigned a target and metric. The targets and metrics given to each function correspond to a quantified goal that the RoboBoat system must meet to complete a desired task and pass the necessary inspections for competition. The need of targets and metrics for functions within the system ensures that the RoboBoat performs its intended tasks efficiently and safely, especially in the cases where system failure could result in hazardous environments. The targets and metrics also serve to best optimize our design by setting objectives and constraints. The critical targets and metrics can be seen in the following section.

Critical Targets and Metrics

Table 4: Critical Targets and Metrics

System	Function	Target	Metric
Structure	The boat has a length constraint	3.94 m	Size
	The boat has a width constraint	2.58 m	Size
	The boat has a height constraint	2.445 m	Size
	Fits within the weight constraint	63.25 lbs	Weight
Locomotion	Regulate speed	At least 1.515 m/s	Measured with an accelerometer
	Has an acceleration of	0.25 m/s^2	Acceleration, Velocity
	Can achieve of minimum turn radius	0 m	Length
	The manual kill switch has a response time of	0.25 s	Time

Safety	The manual kill switch is integrated into the boat	True	Boolean
	The remote kill switch has a response time of	0.25 s	Time
	The remote kill switch is integrated into the boat	True	Boolean
Navigation	The cross-track error of navigating to a destination is at most	2 m	Length
	The error in localizing the position of the boat is at most	5 m	Length
Power Systems	Have a big enough battery to be able to power all components.	13200 mAh	Capacity
	Have a high enough battery life for the duration of the course	1 hour	Time
	Has a way to keep track of battery life	True	Boolean
Object Detection	The camera used for object detection has a resolution of at least	1920x1080 pixels	Number of Pixels
	The boat can detect objects from a range.	25 m	Length
	The accuracy of detecting color in the objects detected is	95 %	Percent Error

	The boat is capable of identifying different types of objects.	Minimum of 6 types of objects	Number of objects
Object Retrieval	The boat can retrieve objects of up to	50 g	Mass
	The mechanism used to retrieve the objects has a Degree of Freedom of	2	Mobility
Water Spraying	The boat can spray water a distance of up to	6.56m	Length
	The pressure of the nozzle needs to be able to reach the above distance	293kpa	Pressure
	The nozzle needs to be accurate to hit a target	12.7 cm	Accuracy

The critical targets are determined based on the minimum functions the RoboBoat needs to accomplish to be able to compete in the February competition, as mentioned above. The critical targets can be seen above in table 4 and are required for our RoboBoat to run and function properly. There are mandatory weight and size requirements as well as safety and navigation requirements listed in the RoboBoat rule book, so it is required that we meet these targets and metrics. The targets associated with the vehicle's waterborne motion are essential for the boat's operational readiness. The RoboBoat must also successfully clear a safety inspection, making the targets related to the kill switches imperative for passing the inspection and preventing a hazardous situation. Similarly, for the RoboBoat to navigate the course effectively and pass the mandatory navigation channel, the navigation-related targets are of utmost importance.

Method of Validation

Structural Design Targets and Metrics

The testing of these metrics is relatively straight forward, using a tape measure and scale, the measured dimensional values will be compared to the chosen metric values. To test and validate our deflection angle, an accelerometer will be used to compute the deflection angle during operation. Using the resistance equation and established metric values theoretical resistance values will be computed and compared to the actual resistance values of the final design iteration.

Navigation Targets and Metrics

Testing of the navigation metrics will be done in stages to ensure the quality of the system. During the first stage the goal will be to navigate to a single way point and track and factor in error in position and heading angle. On the second stage of testing, the goal will be upgraded to being able to accurately follow multiple waypoints as well as further improving our PID controller outputs. For the third stage, the course complexity will ramp up to match the competition environment, during this stage tracking and ensuring cohesion between the navigation and the object detection system will be critical. Throughout the testing process it will be important to add and remove sensors as needed as well as modifying the use of sensor inputs and internal navigation logics along the way, to receive the best outcome. These results will be measured in a T/f manner – it either works or it does not. It is a process that will just need to be troubleshooted as each stage is tested.

Safety Target and Metrics

The safety target is assigned to both the manual and remote kill switch of the entire RoboBoat system. Referencing previous teams' safety targets and metrics, both kill switches operate in a T/F manner. To test the kill switch capabilities, the manual and remote kill switch system will first be tested outside of the integrated RoboBoat system. An onboard push button and a remote RC transmitter will be used to functionally test both kill switch capabilities. This functional testing will test whether the remote and physical kill switches will or will not successfully power off every component per the safety guidelines of the competition. Later, as the kill switches are integrated within the complete RoboBoat system, an oscilloscope will be used to validate observed response times and the voltage drops after activation.

Water Spraying Targets and Metrics

Accuracy:

The assessment of accuracy involves the following equation:

Minimum Accuracy (in cm) = 0.5 * (Diameter of Larger Circle - Diameter of Target Circle). According to the RoboBoat 2022 team handbook, the target comprises a larger circle ranging from 20 to 30 inches in diameter and a smaller circle inside it, measuring 6 inches in diameter. To successfully lift a ball above the required line, a precise accuracy of 12.7 cm is necessary.

Reach:

Achieving the desired reach is crucial for hitting the target accurately. The calculation of reach uses the equation: Horizontal Reach = (velocity^2 * sin(2θ)) / gravity (with θ being the launch angle). However, without the specified distance from the target, the launch angle is inconclusive as it can vary depending on the distance. The RoboNation Handbook specifies the target's height, which ranges from 1 to 3 feet above the water's surface. By averaging this height range to approximately two feet (or 6.56 meters), the required reach can be determined.

Nozzle Pressure:

Adequate nozzle pressure is vital for propelling the water effectively. The 2022 Massachusetts Institute of Technology's (MIT) RoboBoat team employed a water cannon capable of 70 PSI, but they found that only 15 PSI was needed to complete the task. By averaging these two values and converting them to pascals, the metric for the necessary nozzle pressure ranges from 103,421 to 482,633 pascals.

Outside Targets and Metrics

Some targets and metrics were identified outside of the main functions of RoboBoat. Table 2 in the appendix, shows the targets and metrics that address more than just the functions. These targets are not required for our system to operate but would be good targets and metrics to meet for safety reasons as well as serving a purpose of making some of our targets easier to achieve. These outside targets and metrics have to deal with: the arm servo torque, arm servo speed, battery state indicator, buoyancy, fluid resistance, deflection, generated thrust, heat dissipation time, temperature kill switch integration, manual kill switch diameter, transmitter communication range, and the camera resolution. These are needs in order to keep our system durable and able to function more adequately.

Targets/Metric Derivation

The targets for this project will act as a quantifiable goal by which the proper function of the project can be measured against and verified. The metrics are how the targets will be validated for the final design. The RoboBoat was simplified into seven main functions from our functional decomposition which includes: locomotion, power systems, navigation, safety, object avoidance, water spraying, and object retrieval. These were further simplified into corresponding subsystems, then simplified even more with subsystems of these subsystems. For each system function, targets and metrics were established to verify if the end design for the RoboBoat meets its specific function. The targets and metrics were established for this project by using previous winning RoboBoat teams' competition scoring rubric values to determine the best fit targets and metrics to reach our goal of placing in the RoboBoat competition. These metric values were averaged between multiple placing groups and used as the base value for most of the function metrics mentioned. Other values outside of our functions were collected based on the parameters given by the product, for example the battery size and capacity.

The RoboBoat needs to reflect the provided weight and size restrictions provided by the 2024 RoboBoat Handbook. As per their rules, the entire maritime system must weigh less than 140 lbs. The vehicle must also fit within six feet, by three feet, by three-foot box. The metrics for the structure function and its subfunctions were determined by using the top 3 placing groups from the 2022 RoboBoat competition. Because the weight and size restrictions were the same, the measurements provided in previous technical reports were averaged. These measurements were calculated by the winning team to provide a design that reduces wave disturbance. The weight was also determined by assuming that similar equipment and technology from previous winning teams would be used within our RoboBoat. The length, width, and height were calculated roughly in the same manner to ensure sufficient component space and allow team members to comfortably service the system.

The targets and metrics for the navigation function were determined by researching how well the top teams did in the navigation tasks and the tools and specs used by such teams to compete. A list was acquired of the common devices used for navigation by the different teams the competed within the last three years and will be expected to be used in the RoboBoat system.

The technical reports from old winning/top teams were examined and evaluated. The integration of a safety switch was determined by looking at the circuit diagrams from other teams. Per the RoboBoat rule book, the boat is required to meet all safety requirements which include an emergency stop system (location of switches, on-board and remote functionality). This includes a demonstration of the correct function of the Emergency stop system. Figure 2 shows a preliminary circuit diagram for how the safety system might look like based on some of the previous top teams' technical report.

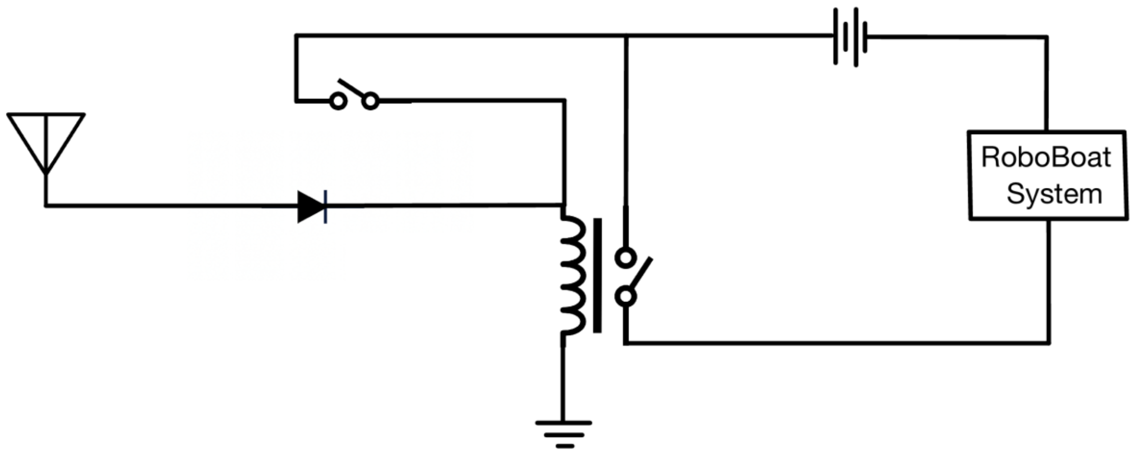


Figure 2: Safety System Circuit

Summary and Catalog

We were able to determine the targets and metrics by reviewing and averaging previous top RoboBoat teams' technical reports. The critical targets were determined by what is required to have a functional RoboBoat at the competition. Our critical targets mainly have to do with the navigation, safety, and structure of the boat. We picked these top three critical targets to explain based on what our customer wanted completed, we listed more critical targets in the event we can complete what our customer wants and can do more. Our customer wanted the final RoboBoat to have an autonomous navigation system, safety system that would pass competition inspection, and one other task which we decided to combine two tasks with water spraying and object detection. The targets that interest our customer the most result in the targets associated with navigation, safety, object detection, and water spraying. This project is outlined to be a foundation for the next RoboBoat team to compete in the next RoboBoat competition in 2025.

Concept Generation

Below, you will find one hundred different concepts our team created to meet our customers' needs. Concept generation supports creative thinking and allows for the designer to think outside of the box. Even if the concept is not feasible, certain aspects can be picked and pulled from the idea and applied to improve the final design. To generate the one hundred concepts, our team used the processes of biomimicry, anti-problem, "crap shoot", forced analogy, and morphological charts.

Initial Random Ideas, No Specific Tools Used

The initial concepts were generated simply through ideas we had, rather than specific techniques. During the project scope process, we had some ideas of what our device would look like, which translated into this category.

Biomimicry

Biomimicry is a generation method that utilizes nature to produce problem solutions. When the group used this method, different animals were researched to find inspiration for possible solutions. Some of the animals that were researched were those that are involved in swimming/moving efficiently in the water and echolocation. These animals are especially relative as they have evolved to be able to detect objects and other animals and also swim away from prey in a fast and efficient manner.

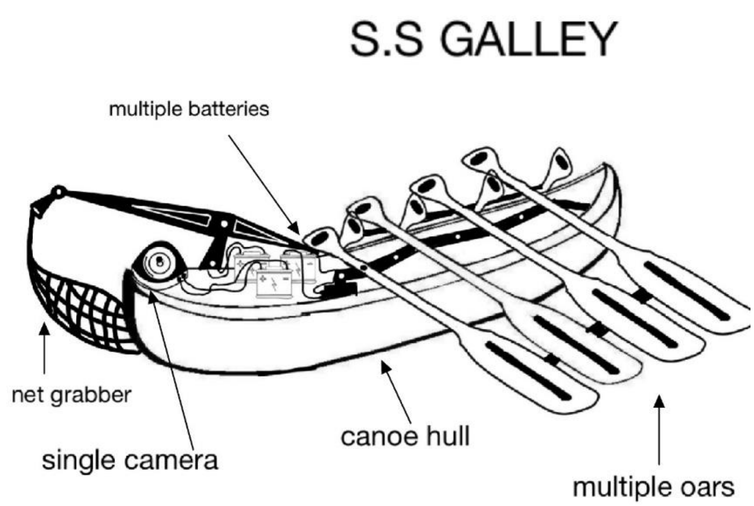
“Crap Shoot”

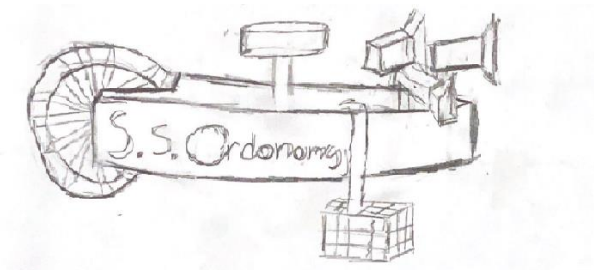
To use the method of “Crap Shoot”, our team listed six random items under each category: people involved, common activities, and potential resources. We then rolled a dice for each category to randomly select combinations. For each of these combinations, we generated concepts that included those three items to design and build our RoboBoat.

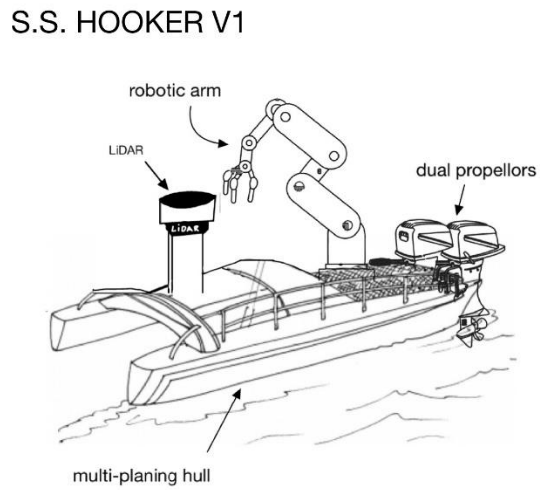
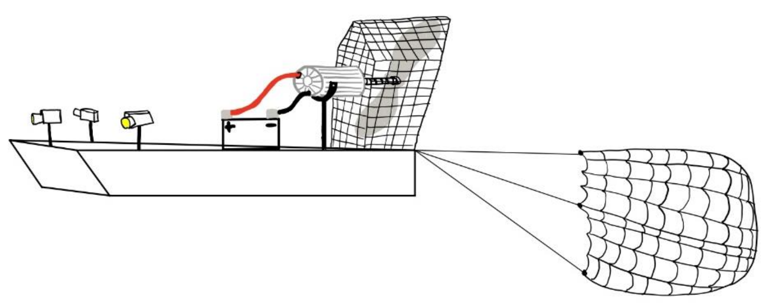
Morphological Charts

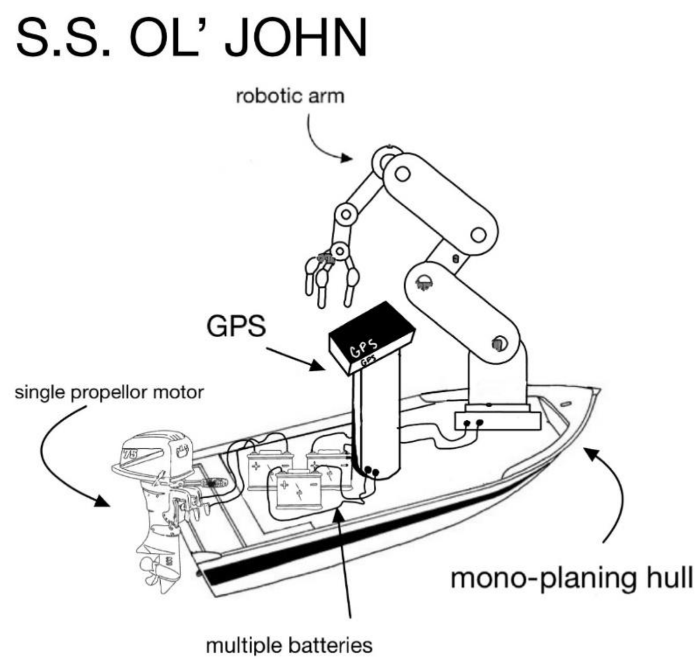
Our team then used the morphological chart where we “cherry picked” the best concepts from our 100 concepts listed in the appendix for each task we will need to complete. We used this morphological chart to generate our best 8 concepts that we will use in the next section for the concept selection process. We discussed with our academic advisor and chose to do it this way because our boat is divided up into different systems to complete different tasks, so to make a boat that accomplishes most of the tasks, we needed to generate these different concepts and then combine them to create our high and medium fidelity concepts. From these eight concepts, we identified five medium fidelity concepts and three high fidelity concepts which met our project objective and key goals.

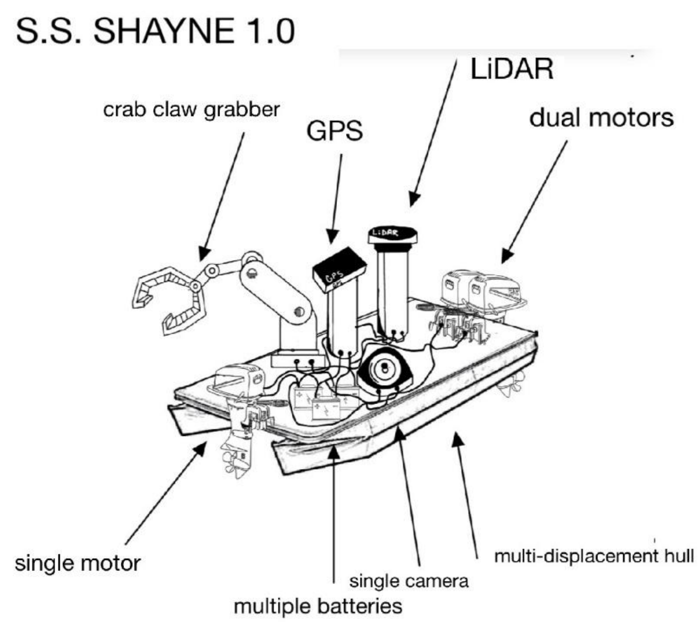
Table 5: Fidelity Concepts

Medium Fidelity Concepts	
Concept #1	<u>S.S. Galley</u> A canoe hull with many small motors attached to oars that are in sync and propel the boat forward, the boat would have multiple batteries to power the motors and has a net to grab the objects out of the water. The boat would have a single camera in the front of the hull and the boat would navigate by aligning the camera between the marker buoys. The canoe hull would allow the boat to have a small profile and lightweight, and not having a propeller would reduce the chance that the hull flips from the unstable hull of the canoe. 
Concept #2	<u>S.S. OrdoNomy</u> Mono-displacement hull, with a paddle wheel at the rear to propel the boat. An IMU, Lidar, and multiple cameras would be used to locate, avoid, and navigate throughout the course. Using an IMU would require us to keep track of the placement of soft and hard metals throughout the boat to account for the offset in the magnetic field of the

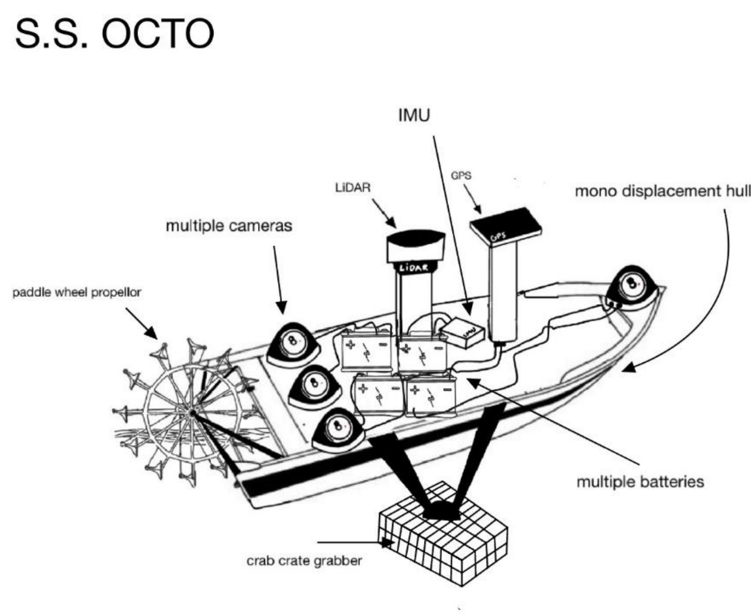
	magnetometer. Multiple batteries would be used to facilitate the prioritizing of higher voltage/current as needed by the system, and a crab crate would be used to collect and deliver objects. 
Concept #3	<u>S.S. Hooker V1</u> A Multi-planing hull, with dual propellers, a lidar sensing system, multiple batteries, and a robotic arm. The multi-planing hull, along with twin rear propellers, would be modeled after a speedboat to create a high-performance, high-speed boat. The multi-planing hull would offer greater efficiency in terms of speed than a displacement hull, while also offering greater stability than a mono-planing hull. A lidar sensing system would implement advanced technology for the boat to understand its surroundings and make choices on how to navigate. Finally, the robotic arm would provide a mechanism for collecting ducks, that could be tucked away in the boat for aerodynamic purposes.

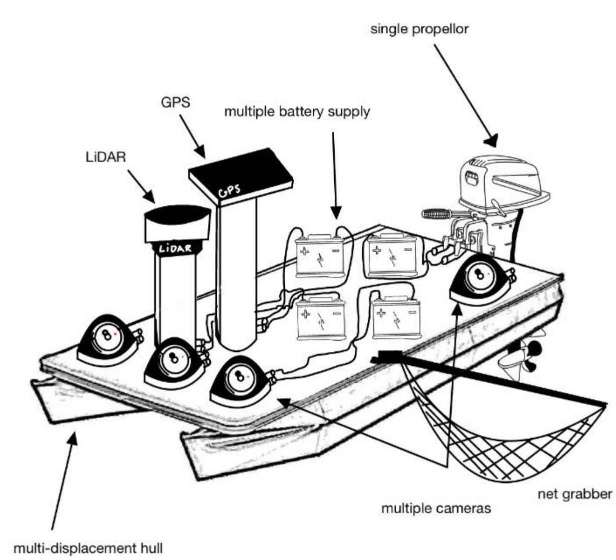
	
Concept #4	S.S. Air Goose A mono-planing hull, with a large fan on the stern to propel the boat. Multiple cameras attached to the hull facing in each direction, along with a GPS system, will allow for object detection and navigation. In order to capture ducks, the boat will drag a net behind it for which the fan will blow ducks into. We will use a single battery to allow for easy and streamlined changeability. The unique feature of fan propulsion would allow for the ability to have an extremely tight turning radius, as well as eliminate the risk of anything in the water becoming caught in propellors or blocking the boat from moving. 
	S.S. Ol' John

Concept #5	A mono-planing hull will be used to create speed for the boat since it will glide over the water and not displace the water. A single propeller will be used to keep the boat stable enough while also providing some speed. The GPS system will contain a GPS module to control the movements and paths of the boat through the courses. Multiple small batteries will be used instead of a single large battery because the multiple single batteries can offer a higher voltage reading if put in a series configuration. A robotic arm will be used instead of a net or claw because a robotic arm can pick up objects safer and it has a high rate of success. 
High Fidelity Concepts	
	S.S. Shayne 1.0 Multi-displacement hull, with dual rear propellers and a single front propeller, and a GPS, Lidar, and camera working in tandem to navigate, identify and avoid objects throughout the course. As a final attachment a crab claw like end effector will be used to retrieve and deliver objects. Using a crab claw like end effector would require us to keep track of the center

Concept #6	of gravity of the object and appropriately place a counterbalance to negate the effects of the arm. A multi-displacement Hull would allow for greater stability and a wider deck width but increase the required turned radius of the boat, but adding a single front propeller would allow us to decrease that turn radius and achieve point turns. The stability of the multi displacement hull allows us to capture data/images more accurately without sacrificing too much speed. The thrusters themselves will be used to propel and steer the boat. Multiple batteries would allow us to prioritize higher voltage/current as needed by the system. 
Concept #7	<u>S.S. Octo</u> Mono-displacement hull, with a paddle wheel at the rear to propel the boat. An IMU, Lidar, and multiple cameras would be used to locate, avoid, and navigate throughout the course. Using an IMU would require us to keep track of the placement of soft and hard metals throughout the boat to account for the offset in the magnetic field of the magnetometer. Multiple batteries would be used to facilitate

<table>
<tr><td></td><td>the prioritizing of higher voltage/current as needed by the system, and a crab crate would be used to collect and deliver objects.


</td></tr>
<tr><td>Concept #8</td><td><u>S.S. Slow N’ Steady</u>
The multi-displacement hull of the boat is designed to enhance stability and adaptability across different water conditions. This hull configuration is made to maximize efficiency for data collection. The open space spanning from the bow to the stern will allow for sensors to pinpoint waypoints with higher precision because the boat can directly traverse over the waypoints within a more extensive area, thereby reducing potential errors. This boat will have multiple cameras, GPS, and LiDAR to ensure precise waypoint navigation. The boat is equipped with a single propeller, a deliberate choice to underscore its reduced emphasis on power and a heightened focus on deliberate and accurate waypoint detection. This design prioritizes methodical and precise waypoint identification rather than rapid propulsion. Multiple batteries are integrated into the boat's electrical system, each assigned to power specific</td></tr>
</table>

	components. This redundancy is a strategic measure to ensure uninterrupted operation and mitigate the risk of power failures during critical tasks. Having multiple batteries will reduce the amount of single point failures in the boat. Additionally, the boat employs a retrieval net for object recovery, a feature that optimizes energy efficiency and provides a larger net surface area to enhance the accuracy of object retrieval. Overall, this boat places a strong emphasis on autonomy and precise waypoint navigation, de-emphasizing the pursuit of high speed and raw power. S.S SLOW AND STEADY 

Concept Selection

After completing our concept generation process, we used Binary Pairwise, House of Quality, Pugh Charts, Consistency checks, and Analytical Hierarchy Process (AHP) to evaluate our high and medium fidelity concepts. These tools took qualitative information and transformed it into quantitative values to eliminate any bias and serve as a tool in choosing the best design concept.

Binary Pairwise

Binary Pairwise Comparison	1	2	3	4	5	6	7	8	9	10	Total
1. Navigation	-	1	0	0	1	0	1	1	1	0	5
2. Retrieving objects	0	-	0	0	0	0	0	0	0	0	0
3. Size within 3 ft wide x 3 ft high x 6 ft long	1	1	-	0	1	0	1	0	1	0	5
4. Weight less than 140 lbs	1	1	1	-	1	0	1	0	1	0	6
5. Enough power for 30 minute minimum run time	0	1	0	0	-	0	1	0	1	0	3
6. Stability	1	1	1	1	1	-	1	1	1	1	9
7. Autonomy	0	1	0	0	0	0	-	0	0	0	1
8. Modular components	0	1	1	1	1	0	1	-	1	0	6
9. Object detection	0	1	0	0	0	0	1	0	-	0	2
10. Costs under $2000	1	1	1	1	1	0	1	1	1	-	8
Total	4	9	4	3	6	0	8	3	7	1	n-1 =9
Check	9	9	9	9	9	9	9	9	9	9	

Figure 3: Binary Pairwise Comparison

In Figure 3, we used a binary pairwise matrix to figure out which customer needs should take precedence in our final design selection. We compared each customer need in one row to the needs listed in the columns, giving a rating of 1 if it was more important, 0 if less important, or a dash if they were the same/equally important. We repeated this process for each row until we had a completed binary matrix. We then added up the values in each row and selected the customer need with the highest total as the most important one. As a result, the most crucial customer needs required for our device to fulfill were determined to be stability, cost, weight, and modular components.

House of Quality

House Of Quality														
	Engineering Characteristics													
	Improvement Direction													
	Units	m	lbs.	Newtons	degrees	m	m/s	m	mAh	ft	grams	pixels	milliseconds	
Customer Needs	Priority	Size	Weight	Buoyancy	Deflection Angle	Turn Radius	Velocity	Calculate distance from objects	Battery Power	Cross-track error	Arm Capacity	Sensor Resolution	Response time	
1. Navigation	5				3	9	9	9	3	9		9	3	
2. Retrieving objects	0	3						9	3		9	3	1	
3. Size within 3 ft wide x 3 ft high x 6 ft long	5	9	3	9	3	3	3		1					
4. Weight less than 140 lbs	6	3	9	9	3		3		9		1			
5. Enough power for 30 minute minimum run time	3	9	9				1		9			3	1	
6. Stability	9	3	3	9	9	3	3	1		1	3	1		
7. Autonomy	1				3	3	3	9	9	9	1	9	3	
8. Modular components	6	3	1						9		1	3	3	
9. Object detection	2				3	1	3	9	3	1		9	3	
10. Costs under $2000	8	3	3	1			3	3	9		1	9	3	
Raw Score		159	153	188	138	92	141	105	242	65	48	180	69	Average
Relative Weight Percent		10.06%	9.68%	11.90%	8.73%	5.82%	8.92%	6.65%	15.32%	4.11%	3.04%	11.39%	4.37%	8.33%
Rank Order		4	5	2	7	9	6	8	1	11	12	3	10	

Figure 4: House of Quality

Figure 4 displays our House of Quality, which serves the purpose of listing all the customer needs and linking them to specific engineering characteristics derived from our functional decomposition. To decide which engineering characteristics should be included in the Pugh chart, we calculated the average of the relative weights. Any characteristic with a weight below this average was excluded from consideration. We determined the most important engineering characteristics to be battery power, buoyancy, sensor resolution, and size. The characteristics that were deemed to be least important from the house of quality were arm capacity, cross track error, response time, and turns radius. House of Quality matrices hold significance as they enable us to establish a prioritized hierarchy of our key characteristics while maintaining objectivity. The most critical characteristics identified through this process are slated for inclusion in both our Pugh chart and the analytical hierarchy process.

Pugh Chart

			Concepts							
Selection Criteria	**Criteria Weight**	**Tel Aviv 2022 RoboBoat Team**	S.S. Galley	S.S. OrdoNomy	S.S. Hooker V1	S.S. Air Goose	S.S. Ol' John	S.S. Shayne 1.0	S.S. Octo	S.S. Slow N' Steady
Battery Power	15.32%	Datum	S	S	S	-	S	S	S	S
Buoyancy	11.90%		-	-	S	+	-	S	-	+
Sensor resolution	11.39%		-	S	-	-	-	S	S	+
Size	10.06%		-	+	-	-	S	S	-	-
Weight	9.68%		+	S	-	-	+	-	-	-
Velocity	8.92%		-	-	+	+	-	+	-	-
Deflection Angle	8.73%		-	-	-	+	-	-	-	+
# of pluses			1	1	1	3	1	1	0	3
# of minuses			5	3	4	4	4	2	5	3

Figure 5: Pugh Chart (Iteration 1)

Figure 5 presents the first iteration of the Pugh chart, which utilizes essential selection criteria to evaluate both the medium-fidelity and high-fidelity concepts generated during the concept generation phase. Two Pugh charts were created: the first compared our concepts to an existing product in the market, demonstrating the need our device would address in the market, while the second assisted in refining the best concept from our list. In each row of the chart, a different engineering characteristic is listed, and each column represents a unique concept. The leftmost column showcases the best current solution available in the market for our problem, serving as the reference point for comparing our concepts. The cells in the matrix contain either a plus, minus, or S. A plus indicates that the concept is superior to the reference at the relevant selection criteria, while minus and S indicate that the concept is inferior or equal, respectively. The bottom two rows present the sums of pluses and minuses for each concept. In our first Pugh chart, the reference was the Tel Aviv RoboBoat team, a finalist in the 2022 RoboBoat competition. The grayed-out concepts were deemed unsuitable for further consideration as they received the most minuses and were notably less favorable than our reference when compared to the other concepts. Based on the Pugh chart comparison, our "S.S. Slow N' Steady" concept was chosen as the neutral reference for our second Pugh chart.

			Concepts			
Selection Criteria	**Criteria Weight**	**S.S. Slow N' Steady**	S.S. Air Goose	S.S. Ol' John	S.S. Shayne 1.0	S.S. Ordonomy
Battery Power	15.32%	Datum	-	S	S	S
Buoyancy	11.90%		-	-	S	-
Sensor resolution	11.39%		-	-	-	S
Size	10.06%		+	+	S	-
Weight	9.68%		+	+	+	-
Velocity	8.92%		+	+	+	-
Deflection Angle	8.73%		-	-	S	S
# of pluses			3	3	2	0
# of minuses			4	3	1	4

Figure 6: Pugh Chart (Iteration 2)

In the second Pugh chart, we established our most balanced concept as the reference point for comparing the other concepts. The decision was made to exclude the S.S. Ordonomy concept because it exhibited the highest number of minuses and the fewest pluses, indicating it was notably less favorable than our reference concept. Drawing from the findings in Figure 6, our top three concepts were determined to be: “S.S. AIR GOOSE”, “S.S. OL’ JOHN”, and “S.S. SHAYNE 1.0”.

Analytical Hierarchy Process

Criteria Comparison Matrix [C]						
Selection Criteria	#1	#2	#3	#4	#5	#6
1. Battery Power	1.00	0.33	0.33	0.20	0.14	0.33
2. Buoyancy	3.00	1.00	0.33	0.33	0.20	1.00
3. Sensor Resolution	3.00	3.00	1.00	0.20	0.14	3.00
4. Size	5.00	3.00	5.00	1.00	0.33	5.00
5. Velocity	7.00	5.00	7.00	3.00	1.00	7.00
6. Deflection Angle	3.00	1.00	0.33	0.20	0.14	1.00
SUM	22.00	13.33	14.00	4.93	1.96	17.33

Figure 7: Criteria Comparison Matrix

Figure 7 presents a matrix that serves to compare the significance of various selection criteria for our device. This matrix was constructed through the collective effort of our project team as we assigned values below the main diagonal. Each column corresponds to a specific selection criterion. As an example, consider column "#1," where the values in each row express the importance of "Battery Power" in relation to other criteria. To illustrate, in column "#1" and row "4," a value of 5.00 implies that the boat's size is 5 times more crucial than battery power. We then totaled the values within each column to normalize the matrix for further analysis.

Normalized Criteria Comparison Matrix [NormC]							
Selection Criteria	#1	#2	#3	#4	#5	#6	Criteria Weights {W}
1. Battery Power	0.045	0.025	0.024	0.041	0.073	0.019	0.038
2. Buoyancy	0.136	0.075	0.024	0.068	0.102	0.058	0.077
3. Sensor Resolution	0.136	0.225	0.071	0.041	0.073	0.173	0.120
4. Size	0.227	0.225	0.357	0.203	0.170	0.288	0.245
5. Velocity	0.318	0.375	0.500	0.608	0.510	0.404	0.452
6. Deflection Angle	0.136	0.075	0.024	0.041	0.073	0.058	0.068
SUM	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Figure 8: Normalized Criteria Comparison Matrix

In Figure 8, we present the normalized version of the criteria comparison matrix. Using this updated set of values, we determined the criteria weights ({W}) by computing the average value for each row. We also conducted additional calculations to generate a table for evaluating the consistency of our group's chosen values and to identify any potential bias in our selections.

Consistency Check		
{Ws} = [C]{W}	{W}	Cons = {Ws}./{W}
Weighted Sum Vector	Criteria Weights	Consistency Vector
0.240	0.038	6.339
0.470	0.077	6.103
0.781	0.120	6.517
1.754	0.245	7.157
3.151	0.452	6.963
0.412	0.068	6.082
	Random Index Values (RI)	
	LAMBDA	6.527
	RI	1.250
	CI	0.105
	CR	0.084

Figure 9: Consistency Chart

In Figure 9, we created a consistency check table by computing the weighted sum vector ({Ws}). This vector was obtained by multiplying the criteria comparison matrix ([C]) by the criteria weights ({W}) calculated from the normalized matrix in Figure 8.

Subsequently, we determined the consistency vector by dividing the weighted sum vector by the criteria weights. We then found the average consistency value, known as lambda. To assess consistency, we referred to an established Random Index (RI) Values for the consistency check table, locating the RI value that corresponded to the number of criteria we had (in our case, 6 criteria). The consistency index (CI) was then calculated using the formula CI = (lambda-n)/(n-1), with 'n' representing the number of selection criteria from Figure 8. Finally, the consistency ratio was determined by dividing the consistency index by the random index value. A consistency ratio less than 0.1 indicated that our prior selection process in the preceding charts was conducted without bias.

We carried out a similar procedure on a more specific scale, involving the ranking of our top three concepts: "S.S. AIR GOOSE," "S.S. OL' JOHN," and "S.S. SHAYNE 1.0," against each of our selection criteria. You can find these charts in the Appendix. This scaled-down process encompassed the creation of a criteria comparison matrix, a normalized criteria comparison matrix, and a consistency check for each selection criterion. The computed values from this process were then utilized to construct our final rating matrix in Figure 10.

Final Rating Matrix			
Selection Criteria	S.S. Air Goose	S.S Ol' John	S.S Shayne 1.0
Batter Power	0.091	0.455	0.455
Buoyancy	0.633	0.106	0.260
Sensor Resolution	0.261	0.106	0.633
Size	0.106	0.633	0.260
Velocity	0.261	0.106	0.633
Deflection Angle	0.200	0.200	0.600

Concept	Alternative Value
S.S. Air Goose	0.241
S.S. Ol' John	0.255
S.S. Shayne 1.0	0.504

Figure 10: Final Rating Tables

Figure 10 displays the final rating matrix, outlining the design alternative priorities for each concept (columns) and selection criteria (rows) on a more specific level. These specific values are detailed in the Appendix. To compute the alternative value, we transposed the final rating matrix and then multiplied it by the criteria weights initially obtained from the criteria comparison matrix in Figure 7. The concept with the highest alternative value signifies the optimal design choice that most closely aligns with the engineering characteristics and customer needs, in this instance, the S.S. SHAYNE 1.0.

Final Selection

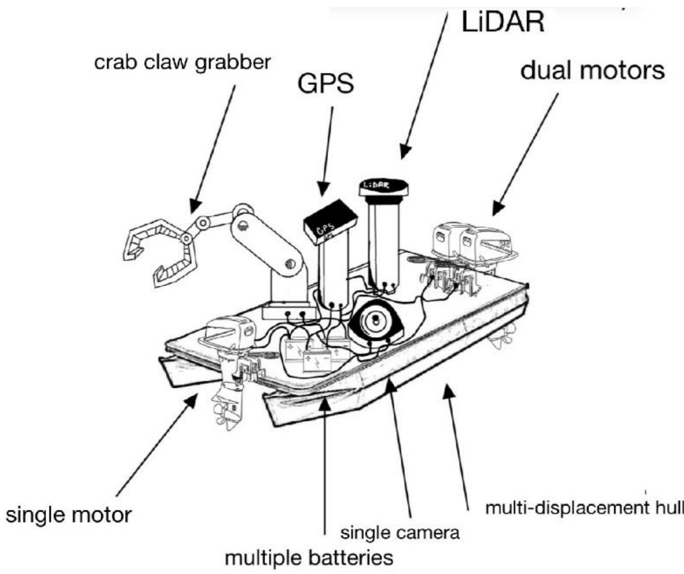


Figure 11: Drawing of S.S. SHAYNE 1.0

Our final selection was determined to be the S.S. SHAYNE 1.0 shown above in Figure 11. This design will feature a multi-displacement hull, allowing for a superior deflection angle when compared to our other hull shapes. A three-part propellor system will move the boat through the water with a greater velocity than many other methods. Using a combination of GPS, a camera, and a Lidar system will deliver the highest quality of autonomy possible within the means of the project. Along with these key characteristics, an arm modeled after a crab claw will offer the most accurate method of retrieving and collecting objects from the water. Each of the engineering characteristics listed are shown through our final concept selection charts, which define the S.S. SHAYNE 1.0 as the leader in each area. Looking at the Pugh charts and the final rating tables, the S.S. SHAYNE stands alone as a clear winner against our seven other plausible concepts. Please refer to the concept generation table for a diagram of how we have envisioned this design.

As a final attachment a crab claw like end effector will be used to retrieve and deliver objects. Using a crab claw like end effector would require us to keep track of the center of gravity of the object and appropriately place a counterbalance to negate the effects of the arm. A multi-displacement Hull would allow for greater stability and a wider deck width but increase the required turned radius of the boat, but adding a single front propeller would allow us to decrease that turn radius and achieve point turns. The stability of the multi-displacement hull allows us to capture data/images more accurately without sacrificing too much speed. The thrusters themselves will be used to propel and steer the boat. Multiple batteries would allow us to prioritize higher voltage/current as needed by the system.

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https://www.cruisersyachts.com/

Appendix

Table 1: Targets and Metrics

System	Function	Target	Metric
Structure	The boat has a length constraint	3.94 ft	Size
	The boat has a width constraint	2.58 ft	Size
	The boat has a height constraint	2.445 ft	Size
	Fits within the weight constraint	63.25 lbs	Weight
	Needs a buoyancy to be able to float while supporting weight	300 N	Force
	Has a resistance of	-19 N	Force
	Limit deflection angle to	15 degrees	Angle
Locomotion	Regulate speed	At least 1.515 m/s	Measured with an accelerometer
	Has an acceleration of	0.25 m/s^2	Acceleration, Velocity
	Can achieve of minimum turn radius	0 m	Length
	Provide thrust	14.6 lbs	Force
Safety	The manual kill switch has a response time of	0.25 s	Time
	The manual kill switch is integrated into the boat	True	Boolean
	The remote kill switch has a response time of	0.25 s	Time

	System experiences a voltage drop time of	0.5 s	Time
	The manual kill switch has a diameter of	1.5 in	Length
	The transmitter must have a communication range of at least	1220 m	Length
	Maintain a maximum internal temperature of	82 ˚F	Temperature
	A temperature kill switch is integrated into the system	True	Boolean
	The remote kill switch is integrated into the boat	True	Boolean
Navigation	The cross track error of navigating to a destination is at most	2 m	Length
	The error in localizing the position of the boat is at most	5 m	Length
	GPS system has an accuracy of at least	5m	Length
Power Systems	Have a big enough battery to be able to power all components.	13200 mAh	Capacity
	Have a high enough battery life for the duration of the course	1 hour	Time

	Has a way to keep track of battery life	True	Boolean
Object Detection	The camera used for object detection has a resolution of at least	1920x1080 pixels	Number of Pixels
	The boat can detect objects from a range.	25 m	Length
	The accuracy of detecting color in the objects detected is	95 %	Percent Error
	The boat is capable of identifying different types of objects.	Minimum of 6 types of objects	Number of objects
Object Retrieval	The boat can retrieve objects of up to	50 g	Mass
	The mechanism used to retrieve the objects has a Degree of Freedom of	2	Mobility
Water Spraying	The boat can spray water a distance of up to	6.56 m	Length
	The pressure of the nozzle needs to be able to reach the above distance	293 kpa	Pressure
	The nozzle needs to be accurate to hit a target	12.7 cm	Accuracy

Table 2: Outside Targets and Metrics

Type	Target
Arm Servo Torque (oz-in)	208.3
Arm Servo Speed (rpm)	100
Battery State Indicator	True
Buoyancy (N)	334
Fluid Resistance (N)	-19.008
Deflection (Degrees)	15
Generated Thrust (lbs)	14.6
Heat Dissipation Time (min)	4
Temperature Kill Switch Integration	True
Manual Kill Switch Diameter (cm)	3.81
Transmitter Communication Range (m)	1220
Camera Resolution (Pixels)	1920x1080

Concept Generation

100 Concepts

1. The boat could use a single large battery to provide power.
2. The boat could use multiple small batteries to better distribute weight.
3. Plastic box with two robotic arms to propel itself.
4. Boat with suspension system that allows it to lift itself above obstacles.
5. Noodle arm like body design that spins around its axis to propel itself.
6. The boat could be a bag that floats and encases the components, with thrusters for control.
7. The vessel could be a submarine type underwater vessel with a scope sticking out of the water for navigation.
8. The boat could have an air drive fan allowing for less draft in the water.
9. The electrical components are encased in a waterproof box so that the components are in one space together.
10. Make a transformer boat that transforms depending on the obstacle/tasks
11. The electrical components are sprayed with a waterproof sealant so they can be spread out over an area of the boat.

12. Multi Hull boat with a differential drive system and a “swivel” thruster at the front.
13. Mono Hull with two floaters on each side.
14. Outboard engine configuration, mounted on the outside of the hull with the engine serving as both power and steering.
15. Inboard Engines located inside the boat hull with rudders added by propeller to steer.
16. Stern drive engine mounted at the inside back of the boat, drive unit powers and steers the boat.
17. Differential drive, with two thrusters at the back, varying the velocity difference in thrusters would turn the boat.
18. We could use a small dirt bike with skis under the tires to skid across the water.
19. A boat that uses a laser pointer to navigate through the course.
20. A floating Beyblade that spins through the course
21. A boat made from an inflatable slide out of an airplane.
22. A boat that skips along the water, throughout the course.
23. Water balloon launcher to spray ducks.
24. Differential drive, with two thrusters at the back, and one thruster at the front of the boat. Front thruster would facilitate point turns around boat axis.
25. The boat has its batteries laid out flat with the to take up more area.
26. The boat has a CPU and processor without a coolant system.
27. Catapult like arms that deliver ducks to destinations.
28. The boat could use a sail with lines controlled by motors to propel throughout the course.
29. The boat has its CPU and processor with its coolant system being airflow throughout the body of the boat.
30. The boat has its electrical/power system held down physically by tape because it is cheaper.
31. The boat has its electrical/power system held down physically by glue because it is more secure.
32. Using a gimbal stabilizing tool to allow for the sensors not to be interfered with when the boat is moving around in the water with a wake.
33. Using pontoon logs resembles a pontoon boat.
34. Using a fiberglass hull with a single propeller and Lidar
35. Implementing splash guards to ensure that the boat does not take on excessive water.

36. Using thrusters as opposed to a rudder to be able to have more mobility.
37. Purchasing an RC boat from a local hobby shop and implementing the use of LiDAR and sensors to ensure complete autonomy.
38. Using water from the body of water in which the competition is taking place for the water blasting activity to ensure that the weight of the boat is minimized.
39. Storing a water tank on the vessel to use during the water blasting task.
40. Research the fully autonomous cargo ship known as Prism Courage that was able to navigate from Texas to the Panama Canal
41. Draw inspiration on the hull design based on a Naval Warship given that is who is sponsoring our project.
42. Using a similar motor to a trolling motor used for powering small canoes such as a Minn Kota
43. Enclosing the electronics in a water-tight box to ensure that the electronics do not get damaged.
44. Employing autonomy through the storing of data points after a test trial through the course provided
45. Rowboat with motors attached to the oars.
46. Boat drops anchor to maintain its current position.
47. Solar powered boat.
48. Raft with a sail attached and uses wind to traverse the course.
49. Ballons attached to the bottom of hull and a fan attached to the back.
50. Nuclear powered submarine that uses sonar to find the buoys.
51. Electromagnet boat that is propelled by magnets in waypoints on the course.
52. Bumper car boat that navigates by crashing into buoys and remembering where they are.
53. Mock Titanic powered by a steam engine.
54. Tactile sensors added to the front of the boat.
55. Steal another team's boat at the RoboBoat Competition.
56. Pirate boat that harpoons other boats and follows them through the course.
57. Boat lasso to buoys and propels through the course.
58. Air mattress boat with a propeller
59. Using a catapult arm to launch itself around the course.
60. Hamster wheel boat design
61. Tractor beam from Star Wars to get objects out of water
62. Jet engine strapped to the top of the boat to minimize coarse time.
63. Paddle boat that drives over objects to collect them.

64. Raft that drifts through the course.
65. The whole boat being encompassed in a hamster wheel.
66. Styrofoam box with motors and propellers attached.
67. Add a “T-top” to shade the electrical components to prevent overheating.
68. Add a power pole to anchor down the vessel while performing competition tasks.
69. A hover boat that contains fans on the bottom to levitate and transverse over the water.
70. A leaf blower moves the boat instead of thrusters.
71. System that records competitor movements and mimic it to complete course.
72. Sea Xtreme Seabrecher
73. The boat is wound up like a winded up toy to go around the course before competing.
74. Use Find My and attach apple watch to boat for navigation.
75. Boat uses a pre-mapped course given the measurements from the task ideas.
76. A drone flying above the boat pulls it around the obstacle course.
77. Jam the other boats signals using an EMP and we win by default.
78. A boat that can navigate and avoid objects by generating waves that bounce off of obstacles.
79. Like Michigan football, we are going to steal the signals/code from the other boats so that we eliminate the competition.

Idea Generation with Biomimicry

80. Owl like cameras that would give the RoboBoat 360-degree views of the course.
81. Paddle on the back of the boat that would move like a fish to propel to boat.
82. A boat that has legs like a water bug to move throughout the water.
83. The boat has a protective coating to prevent water from getting into it like a frog.
84. The boat has a claw like structure to grab things out of the water like a crab claw.
85. The electric equipment has a waterproof coating on it to protect it from getting damaged from water like a duck.
86. The boat sees the buoys like how a snakes detects things like heat with the LIDAR camera.
87. Floating robot snake that slithers through the water and captures objects by eating them.
88. The boat has a tongue like a frog that shoots out and sticks to objects.

89. Beluga whale echolocation for boat to avoid obstacles and detect objects in its path.
90. The bow of the vessel will be pointed similar to the nose of a dolphin and the boat will also have a rudder that is similar to the tail of a dolphin.
91. Objects are picked up by suction like an octopus.
92. Claws have individual suction cups on them like the arm of an octopus to pick up objects.
93. Implementing a “blow hole” similar to one a whale would have to be able to shoot water as well as use as a cooling system.
94. The boat has a long alligator type tail where it can propel itself out of the water to avoid the obstacle.

“Crap Shoot” Method

95. Implementing the coast guard system of spraying into our boat to have a better water spraying system.
96. Boat makes different sounds depending on how close it is to the waypoint and which tasks it is approaching.
97. A mayday button that sends the last known location to the controller before failing or sinking.
98. ASME designs the relay power system in our boat based from the power system in an RC boat
99. Use a Styrofoam hull with a flex seal type coating to keep boat afloat
100. Coast guard uses remote control to collect debris (rubber ducks)

Table 4: Morphological Chart

Subfunction	Hull	Propeller	Sensor	Power system	Grabber
1	Mono Planning Hull	Single Propeller	GPS	Single large battery	Crab Crate

2	Multi-Displacement Hull	Dual Propellers	Single Camera	Multiple small batteries	Robotic Arm
3	Mono Displacement Hull with Floaters attached	Dual Rear propeller w/ Single front propeller	Lidar	Series configuration batteries	Net
4	Round-Bottom Hull	Fan	Sextant	Parallel configuration batteries	Suction
5	V-Shaped Hull	Sails	Multiple Cameras	Series/Parallel configuration batteries	Bowl

Concept Selection

Figure 3: Binary Pairwise Chart

Binary Pairwise Comparison	1	2	3	4	5	6	7	8	9	10	Total
1. Navigation	-	1	0	0	1	0	1	1	1	0	5
2. Retrieving objects	0	-	0	0	0	0	0	0	0	0	0
3. Size within 3 ft wide x 3 ft high x 6 ft long	1	1	-	0	1	0	1	0	1	0	5
4. Weight less than 140 lbs	1	1	1	-	1	0	1	0	1	0	6
5. Enough power for 30 minute minimum run time	0	1	0	0	-	0	1	0	1	0	3
6. Stability	1	1	1	1	1	-	1	1	1	1	9
7. Autonomy	0	1	0	0	0	0	-	0	0	0	1
8. Modular components	0	1	1	1	1	0	1	-	1	0	6
9. Object detection	0	1	0	0	0	0	1	0	-	0	2
10. Costs under $2000	1	1	1	1	1	0	1	1	1	-	8
Total	4	9	4	3	6	0	8	3	7	1	n-1 =9
Check	9	9	9	9	9	9	9	9	9	9	

Figure 4: House of Quality

House Of Quality														
	Engineering Characteristics													
	Improvement Direction													
	Units	m	lbs.	Newtons	degrees	m	m/s	m	mAh	ft	grams	pixels	milliseconds	
Customer Needs	Priority	Size	Weight	Buoyancy	Deflection Angle	Turn Radius	Velocity	Calculate distance from objects	Battery Power	Cross-track error	Arm Capacity	Sensor Resolution	Response time	
1. Navigation	5				3	9	9	9	3	9		9	3	
2. Retrieving objects	0	3						9	3		9	3	1	
3. Size within 3 ft wide x 3 ft high x 6 ft long	5	9	3	9	3	3	3		1					
4. Weight less than 140 lbs	6	3	9	9	3		3		9		1			
5. Enough power for 30 minute minimum run time	3	9	9				1		9			3	1	
6. Stability	9	3	3	9	9	3	3	1		1	3	1		
7. Autonomy	1				3	3	3	9	9	9	1	9	3	
8. Modular components	6	3	1						9		1	3	3	
9. Object detection	2				3	1	3	9	3	1		9	3	
10. Costs under $2000	8	3	3	1			3	3	9		1	9	3	
Raw Score		159	153	188	138	92	141	105	242	65	48	180	69	Average
Relative Weight Percent		10.06%	9.68%	11.90%	8.73%	5.82%	8.92%	6.65%	15.32%	4.11%	3.04%	11.39%	4.37%	8.33%
Rank Order		4	5	2	7	9	6	8	1	11	12	3	10	

Figure 5: Pugh Chart (Iteration 1)

			Concepts							
Selection Criteria	**Criteria Weight**	**Tel Aviv 2022 RoboBoat Team**	S.S. Galley	S.S. OrdoNomy	S.S. Hooker V1	S.S. Air Goose	S.S. Ol' John	S.S. Shayne 1.0	S.S. Octo	S.S. Slow N' Steady
Battery Power	15.32%	Datum	S	S	S	-	S	S	S	S
Buoyancy	11.90%		-	-	S	+	-	S	-	+
Sensor resolution	11.39%		-	S	-	-	-	S	S	+
Size	10.06%		-	+	-	-	S	S	-	-
Weight	9.68%		+	S	-	-	+	-	-	-
Velocity	8.92%		-	-	+	+	-	+	-	-
Deflection Angle	8.73%		-	-	-	+	-	-	-	+
# of pluses			1	1	1	3	1	1	0	3
# of minuses			5	3	4	4	4	2	5	3

Figure 6: Pugh Chart (Iteration 2)

			Concepts			
Selection Criteria	**Criteria Weight**	**S.S. Slow N' Steady**	S.S. Air Goose	S.S. Ol' John	S.S. Shayne 1.0	S.S. Ordonomy
Battery Power	15.32%	Datum	-	S	S	S
Buoyancy	11.90%		-	-	S	-
Sensor resolution	11.39%		-	-	-	S
Size	10.06%		+	+	S	-
Weight	9.68%		+	+	+	-
Velocity	8.92%		+	+	+	-
Deflection Angle	8.73%		-	-	S	S
# of pluses			3	3	2	0
# of minuses			4	3	1	4

Figure 7: Criteria comparison Matrix

Criteria Comparison Matrix [C]						
Selection Criteria	#1	#2	#3	#4	#5	#6
1. Battery Power	1.00	0.33	0.33	0.20	0.14	0.33
2. Buoyancy	3.00	1.00	0.33	0.33	0.20	1.00
3. Sensor Resolution	3.00	3.00	1.00	0.20	0.14	3.00
4. Size	5.00	3.00	5.00	1.00	0.33	5.00
5. Velocity	7.00	5.00	7.00	3.00	1.00	7.00
6. Deflection Angle	3.00	1.00	0.33	0.20	0.14	1.00
SUM	22.00	13.33	14.00	4.93	1.96	17.33

Figure 8: Normalized Criteria Comparison Matrix

Normalized Criteria Comparison Matrix [NormC]							
Selection Criteria	#1	#2	#3	#4	#5	#6	Criteria Weights {W}
1. Battery Power	0.045	0.025	0.024	0.041	0.073	0.019	0.038
2. Buoyancy	0.136	0.075	0.024	0.068	0.102	0.058	0.077
3. Sensor Resolution	0.136	0.225	0.071	0.041	0.073	0.173	0.120
4. Size	0.227	0.225	0.357	0.203	0.170	0.288	0.245
5. Velocity	0.318	0.375	0.500	0.608	0.510	0.404	0.452
6. Deflection Angle	0.136	0.075	0.024	0.041	0.073	0.058	0.068
SUM	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Figure 9: Consistency Chart

Consistency Check		
{Ws} = [C]{W}	{W}	Cons = {Ws}./{W}
Weighted Sum Vector	Criteria Weights	Consistency Vector
0.240	0.038	6.339
0.470	0.077	6.103
0.781	0.120	6.517
1.754	0.245	7.157
3.151	0.452	6.963
0.412	0.068	6.082
	Random Index Values (RI)	
	LAMBDA	6.527
	RI	1.250
	CI	0.105
	CR	0.084

Figure 10: Final Rating Tables

Final Rating Matrix			
Selection Criteria	S.S. Air Goose	S.S Ol' John	S.S Shayne 1.0
Batter Power	0.091	0.455	0.455
Buoyancy	0.633	0.106	0.260
Sensor Resolution	0.261	0.106	0.633
Size	0.106	0.633	0.260
Velocity	0.261	0.106	0.633
Deflection Angle	0.200	0.200	0.600

Concept	Alternative Value
S.S. Air Goose	0.241
S.S. Ol' John	0.255
S.S. Shayne 1.0	0.504

Figure 11: Battery Power Matrix

Battery Power [C]			
Selection Criteria	#1	#2	#3
1. S.S. Air Goose	1.00	0.20	0.20
2. S.S. Ol' John	5.00	1.00	1.00
3. S.S. Shayne 1.0	5.00	1.00	1.00
SUM	11.00	2.20	2.20

Battery Power [NormC]				
Selection Criteria	#1	#2	#3	Design Alternative Priorities {Pi}
1. S.S. Air Goose	0.091	0.091	0.091	0.091
2. S.S. Ol' John	0.455	0.455	0.455	0.455
3. S.S. Shayne 1.0	0.455	0.455	0.455	0.455
SUM	1.000	1.000	1.000	1.000

Consistency Check		
{Ws} = [C]{Pi}	{Pi}	Cons = {Ws}./{Pi}
Weighted Sum Vector	Criteria Weights	Consistency Vector
0.273	0.091	3.000
1.364	0.455	3.000
1.364	0.455	3.000

Random Index Values (RI)	
LAMBDA	3.000
RI	0.520
CI	0.453
CR	0.870

Figure 12: Buoyancy Matrix

Buoyancy [C]			
Selection Criteria	#1	#2	#3
1. S.S. Air Goose	1.00	5.00	3.00
2. S.S. Ol' John	0.20	1.00	0.33
3. S.S. Shayne 1.0	0.33	3.00	1.00
SUM	1.53	9.00	4.34

Buoyancy [NormC]				
Selection Criteria	#1	#2	#3	Design Alternative Priorities {Pi}
1. S.S. Air Goose	0.652	0.556	0.693	0.633
2. S.S. Ol' John	0.130	0.111	0.077	0.106
3. S.S. Shayne 1.0	0.217	0.333	0.231	0.260
SUM	1.000	1.000	1.000	1.000

Consistency Check		
{Ws} = [C]{Pi}	{Pi}	Cons = {Ws}./{Pi}
Weighted Sum Vector	Criteria Weights	Consistency Vector
1.946	0.633	3.072
0.320	0.106	3.011
0.790	0.260	3.033

Random Index Values (RI)	
LAMBDA	3.039
RI	0.520
CI	0.460
CR	0.884

Figure 13: Sensor Resolution Matrix

Sensor Resolution [C]			
Selection Criteria	#1	#2	#3
1. S.S. Air Goose	1.00	3.00	0.33
2. S.S. Ol' John	0.33	1.00	0.20
3. S.S. Shayne 1.0	3.00	5.00	1.00
SUM	4.33	9.00	1.53

Sensor Resolution [NormC]				
Selection Criteria	#1	#2	#3	Design Alternative Priorities {Pi}
1. S.S. Air Goose	0.231	0.334	0.217	0.261
2. S.S. Ol' John	0.077	0.111	0.130	0.106
3. S.S. Shayne 1.0	0.692	0.555	0.652	0.633
SUM	1.000	1.000	1.000	1.000

Consistency Check		
{Ws} = [C]{Pi}	{Pi}	Cons = {Ws}./{Pi}
Weighted Sum Vector	Criteria Weights	Consistency Vector
0.790	0.261	3.033
0.320	0.106	3.011
1.946	0.633	3.072

Random Index Values (RI)	
LAMBDA	3.039
RI	0.520
CI	0.460
CR	0.884

Figure 14: Velocity Matrix

Velocity [C]			
Selection Criteria	#1	#2	#3
1. S.S. Air Goose	1.00	3.00	0.33
2. S.S. Ol' John	0.33	1.00	0.20
3. S.S. Shayne 1.0	3.00	5.00	1.00
SUM	4.33	9.00	1.53

Velocity [NormC]				
Selection Criteria	#1	#2	#3	Design Alternative Priorities {Pi}
1. S.S. Air Goose	0.231	0.334	0.217	0.261
2. S.S. Ol' John	0.077	0.111	0.130	0.106
3. S.S. Shayne 1.0	0.692	0.555	0.652	0.633
SUM	1.000	1.000	1.000	1.000

Consistency Check		
{Ws} = [C]{Pi}	{Pi}	Cons = {Ws}./{Pi}
Weighted Sum Vector	Criteria Weights	Consistency Vector
0.790	0.261	3.033
0.320	0.106	3.011
1.946	0.633	3.072

Random Index Values (RI)	
LAMBDA	3.039
RI	0.520
CI	0.460
CR	0.884

Figure 15: Size Matrix

Size [C]			
Selection Criteria	#1	#2	#3
1. S.S. Air Goose	1.00	0.20	0.33
2. S.S. Ol' John	5.00	1.00	3.00
3. S.S. Shayne 1.0	3.00	0.33	1.00
SUM	9.00	1.53	4.34

Size [NormC]				
Selection Criteria	#1	#2	#3	Design Alternative Priorities {Pi}
1. S.S. Air Goose	0.111	0.130	0.077	0.106
2. S.S. Ol' John	0.556	0.652	0.693	0.633
3. S.S. Shayne 1.0	0.333	0.217	0.231	0.260
SUM	1.000	1.000	1.000	1.000

Consistency Check		
{Ws} = [C]{Pi}	{Pi}	Cons = {Ws}./{Pi}
Weighted Sum Vector	Criteria Weights	Consistency Vector
0.320	0.106	3.011
1.946	0.633	3.072
0.790	0.260	3.033

Random Index Values (RI)	
LAMBDA	3.039
RI	0.520
CI	0.460
CR	0.884

Figure 16: Deflection Angle

Deflection Angle [C]			
Selection Criteria	#1	#2	#3
1. S.S. Air Goose	1.00	1.00	0.33
2. S.S. Ol' John	1.00	1.00	0.33
3. S.S. Shayne 1.0	3.00	3.00	1.00
SUM	5.00	5.00	1.67

Deflection Angle [NormC]				
Selection Criteria	#1	#2	#3	Design Alternative Priorities {Pi}
1. S.S. Air Goose	0.200	0.200	0.200	0.200
2. S.S. Ol' John	0.200	0.200	0.200	0.200
3. S.S. Shayne 1.0	0.600	0.600	0.600	0.600
SUM	1.000	1.000	1.000	1.000

Consistency Check		
{Ws} = [C]{Pi}	{Pi}	Cons = {Ws}./{Pi}
Weighted Sum Vector	Criteria Weights	Consistency Vector
0.600	0.200	3.000
0.600	0.200	3.000
1.800	0.600	3.000

Random Index Values (RI)	
LAMBDA	3.000
RI	0.520
CI	0.453
CR	0.870