

[ARBWCI]

Conceptual Design Report

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DISCLAIMER

This report was prepared by students as part of a university course requirement. While considerable effort has been put into the project, it is not the work of licensed engineers and has not undergone the extensive verification that is common in the profession. The information, data, conclusions, and content of this report should not be relied on or utilized without thorough, independent testing and verification. University faculty members may have been associated with this project as advisors, sponsors, or course instructors, but as such they are not responsible for the accuracy of results or conclusions.

EXECUTIVE SUMMARY

This project focuses on the design and development of an autonomous unmanned surface vehicle (USV) for inspecting concrete canal systems in the Salt River Valley of Arizona. These canals are critical to water distribution in the region, but current inspection methods are limited to dry-up cycles that only occur every 5–10 years. As a result, damage such as sediment buildup can go undetected for long periods. The objective of this project is to create a compact, reliable system that can perform more frequent inspections using onboard sensors like sonars while also improving upon the limitations observed in a previous prototype.

The current design uses a catamaran-style configuration with two pontoons connected by a structural frame. This layout provides stability and allows space between the hulls for mounting sensors and other components. The propulsion system consists of two stern-mounted thrusters for forward motion and a centrally located lateral thruster for maintaining position within the canal and correcting cross-track error. One of the main design challenges has been the placement of the sonar system. To avoid signal interference, it must extend below the pontoons, but this also increases the risk of damage during deployment and recovery. However, after some prototype and extensive testing, we found that the sonar system is able to sit behind and above the pontoons just as it was originally designed. The system is controlled using a CubePilot flight controller running ArduPilot, enabling waypoint navigation and providing flexibility for implementing custom control strategies.

At this stage of the project, significant progress has been made in both design and analysis. Preliminary hydrodynamic calculations have been performed to estimate drag forces and required thrust, and MATLAB tools have been developed to evaluate performance under different conditions. Major components have been selected, and a bill of materials has been created within the project's budget constraints. In addition, simulation testing has been conducted to explore control strategies, particularly the use of the lateral thruster for maintaining alignment in the canal. While the simulation environment has some limitations, the results support the feasibility of the current approach.

Overall, the project is progressing toward a practical and field-ready system that can improve the frequency and quality of canal inspections while reducing the time and effort required for maintenance.

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1 BACKGROUND - Christian

This section builds off what the team introduced in Report 1, but now it includes the progress we've made through Presentations 2 and 3. At the start of the project, everything was mostly conceptual and based on CAD models and calculations. Since then, we've started moving toward actual implementation, including early prototyping and testing different subsystems. The goal here is to give an updated overview of what the project is, what we are delivering, and how we now define success based on both our original design and the progress we've made so far.

1.1 Project Description

The ARBWCi project focuses on designing a small, portable robotic boat that can detect cracks or damage in Phoenix saltwater canals. As explained in Report 1, the main issue is that the canals are too dirty to visually inspect and draining them is not realistic in terms of time or cost. This project aims to provide a faster and more efficient solution using onboard sensors. Since the initial report, the project has started to move beyond just planning. We've refined our design based on calculations and begun thinking more seriously about how everything will come together in a real system. For example, we've looked more closely at buoyancy, propulsion, and how we will house and protect the electronics. Presentation 3 especially pushed us toward considering how a working prototype would function, not just how it looks in CAD. The boat still needs to meet the same core requirements: it must be portable enough to fit in an SUV, strong enough to move through current, and durable enough to handle harsh canal conditions. Budget wise, we are still working within roughly the same range (\$1000–\$2000), with some flexibility depending on funding.

1.2 Deliverables

Compared to Report 1, our deliverables have become more focused on actual performance rather than simply completing assignments. The final goal is still the same, which is to develop a working robotic boat that can scan canals and collect useful data. However, based on our progress in Presentations 2 and 3, we now have clearer milestones leading up to that goal. The first prototype, shown in Presentation 3, is intended to demonstrate that at least one major subsystem, such as propulsion or flotation, works properly. At this stage, the focus is not on having a fully complete system, but on confirming that our design choices and calculations are valid. The second prototype will build on the first version by integrating multiple subsystems together and improving any issues identified in the first version. In addition to prototyping, system development is ongoing, including setting up the sensor system, ensuring data can be properly recorded and accessed, and working toward a reliable power setup. We are also continuing to develop our project website and documentation, which will include CAD models, testing results, and overall progress. Overall, the deliverables have shifted from simply completing tasks to demonstrating that the system can function effectively in a real-world environment.

1.3 Success Metrics

In Report 1, success was mainly defined as building a boat that works and ideally performs better than a previous graduate team's design. That idea still applies, but now we have a clearer and more

practical way of measuring success. At a basic level, the project can be considered successful if the boat is able to float properly while supporting its full weight, move effectively through the water, and successfully collect and store sensor data. Beyond these fundamentals, we now evaluate success using more specific performance targets. These include being able to deploy and recover the system in under five minutes, maintaining navigation accuracy within about 0.5 meters of the intended path, achieving a battery life that aligns with our calculated range of roughly 30 to 40 minutes, and ensuring the system is portable and easy to handle. Another important factor is how the design performs during testing. If issues arise but are identified and improved upon, that still represents meaningful progress. At this stage of the project, success is not just about having a perfect working system, but about showing that the design is functional, improving, and moving in the right direction.

2 REQUIREMENTS - Rikki

This section provides a brief description of each requirement given to our team by the clients, Dr. Razavian and SRP. These customer requirements establish constraints that define the scope of the project, allowing the team to focus on the primary function of the autonomous boat: collecting and relaying data from canal scans. The customer requirements are then used to develop engineering requirements, which translate the client's needs into specific, measurable targets. Finally, a Quality Function Deployment (QFD) is used to compare customer requirements to engineering requirements, creating a rating system that helps the team prioritize which design aspects are more important.

2.1 Customer Requirements (CRs)

The following customer requirements define the needs and expectations provided by the clients for the autonomous canal-scanning boat.

| |
|---|
| CR1: Quick and safe deployment and recovery Description: The system must be capable of being deployed and recovered efficiently across a steep 60° canal without causing damage. |
| CR2: Float upstream Description: The system must be capable of maintaining controlled upstream movement against canal flow conditions. |
| CR3: Accurate autonomous navigation Description: The system must navigate a defined path with high accuracy without manual intervention. |
| CR4: Long operation per usage Description: The system must operate continuously for extended durations to complete missions without frequent recharging or intervention. |
| CR5: Hands off operation Description: The system must function autonomously with minimal operator input during normal operation |
| CR6: Waterproof Description: The system must be fully sealed to prevent water entry and ensure reliable operation in wet environments. |
| CR7: Withstand Phoenix weather Description: The system must operate reliably under extreme environmental conditions, including high temperature and sun exposure. |
| CR8: Fail-safe recovery Description: The system must include mechanisms to ensure safe retrieval or recovery in the event of failure or loss of control. |
| CR9: Easy data logging and transfer Description: The system must efficiently record and enable accessible transfer of collected data for |

| |
|--|
| analysis. |
| CR10: Portable Description: The system must be lightweight and compact enough to allow convenient transport and handling by the user. |

2.2 Engineering Requirements (ERs)

The following engineering requirements define the technical and measurable specifications to meet the client's needs for the autonomous canal-scanning boat.

| | Target / Units: |
|--|----------------------|
| ER1: Deployment and recovery time Description: The total time required to complete deployment and recovery of the system. | 5 min. |
| ER2: Overheating Description: The maximum allowable temperature increase of the system above the ambient. | 20° C |
| ER3: Scan speed Description: The speed at which the system performs its scans along the canal. | 3 m/s |
| ER4: Turning speed Description: The angular acceleration of the system during direction changes. | 1 rad/s ² |
| ER5: Float ability Description: The maximum weight the system can support while remaining buoyant. | 60 lbs. |
| ER6: Navigation accuracy Description: The maximum deviation from the defined path or position during scanning operations. | 0.5 m. |
| ER7: Range Description: The maximum distance the system can travel during a single deployment. | 5 km. |
| ER8: Size Description: The dimensions the system is constrained to for easier transport and operation. | 0.5 m. |
| ER9: Material Description: The total mass of the system is based on material selection and construction. | 15 kg. |

3 Research Within Your Design Space - Everyone

3.1 Benchmarking

For the project we looked at three systems regarding it that we consider state-of-the-art. The first one is regarding the launch and recovery of a similar type of project that we used in our design project. The second one is a whole textbook about sensors and how they sense which we used to pick the sensor for our boat. The final source was a YouTube video showing a similar boat to the one we were tasked with making which we used to determine the navigation system for our boat.

[1] “Zhao, C., Thies, P., Lars, J., & Cowles, J. (2021). ROV launch and recovery from an unmanned autonomous surface vessel – Hydrodynamic modelling and system integration. *Ocean Engineering*, 232, 109019. <https://doi.org/10.1016/j.oceaneng.2021.109019>

[2] HANDBOOK OF MODERN SENSORS cited. [Online]. Available: <https://uodiyala.edu.iq/uploads/PDF%20ELIBRARY%20UODIYALA/EL95/Handbook%20of%20Modern%20Sensors%20%20Physics.%20Designs.%20and%20Applicatio.pdf>

[3] Teledyne Oceanscience. (2015, March 30). *Teledyne Oceanscience Z Boat with eBee Drone Surveying - Newfields LLC* [Video]. YouTube. <https://www.youtube.com/watch?v=3FoXxacB6Ro>

3.2 Literature Review

3.2.1 Rikki Bandera Mendoza Sources

[1]

This report reviews current USV capabilities and their applications in real-world missions. It focuses on key performance factors such as endurance, payload capacity, and autonomy, along with common use cases like surveillance and environmental monitoring. It also identifies limitations, including communication and control challenges. This source is useful for the project because it helps define realistic mission requirements and highlights important design trade-offs for a canal-scanning USV. These requirements align closely with the project goals, particularly in terms of range, navigation accuracy, and system reliability. Overall, this source supports establishing realistic expectations for the USV.

[2]

The source provides a detailed overview of lithium-ion battery system design, including energy capacity, discharge characteristics, and thermal management. It also explains the role of battery management systems in maintaining safety and performance. The emphasis on system-level design is important, as it considers how all components interact. This is directly applicable to the project for selecting and sizing a battery system that can support the USV's power demands safely and efficiently. In addition, the concepts of energy density and discharge behavior are important when estimating total mission runtime. These factors directly impact how long the USV can operate before requiring recharge or battery replacement.

[3]

This paper examines materials that combine structural strength with energy storage capabilities. It discusses trade-offs between weight, strength, and energy density, along with current limitations in durability and safety. This is relevant to the project because reducing overall system weight can improve efficiency and runtime, which are critical factors for USV performance. This is especially important when considering the trade-off between added components and overall system weight. A lighter system can improve propulsion efficiency and reduce power consumption. These considerations are useful when optimizing the overall design of the USV.

[4]

This dissertation focuses on modeling and control of USV's, including both nonlinear and simplified dynamic models. It presents control strategies such as PD control and backstepping for trajectory tracking under varying conditions. The work also highlights the role of onboard sensors in maintaining accurate navigation. This source is highly relevant to the project because it supports the development of reliable navigation and control systems for the USV. The modeling approaches presented also provide a foundation for predicting how the USV will respond to external disturbances such as water currents. This is important for maintaining stable operation in a canal environment. These concepts can be applied when validating control strategies for the project.

[5]

This paper introduces a simulation platform designed for testing USV systems in realistic marine environments. It includes modules for vessel dynamics, environmental conditions, and multiple sensor types such as cameras and LiDAR. The platform also supports data generation for training and testing control algorithms. This is useful for the project because it demonstrates how simulation can be used to validate system performance before real-world deployment. The ability to simulate different environmental conditions is particularly useful for testing system performance under varying scenarios. This reduces risk during physical testing and improves overall system reliability. It also allows for early validation of sensor integration and navigation algorithms.

[6]

This source provides examples of commercially available USV's and their capabilities. It highlights design features such as modular construction, stability, and integrated sensor systems for data collection and monitoring. This is relevant to the project because it offers a practical reference for how real-world USV's are designed and deployed, helping guide overall system design decisions. The examples provided also highlight how stability and modularity are prioritized in real systems. This reinforces the importance of designing a platform that can support multiple sensors while maintaining balance. These insights can be directly applied to the physical design of the USV.

[7]

This textbook covers fundamental fluid mechanics concepts, including buoyancy and fluid statics. It explains how buoyant force is determined by displaced fluid volume and introduces key principles such as Archimedes' principle. This is important for the project because it provides the basis for calculating whether the USV can float and support its total weight. These principles are used to calculate the required displacement needed for the USV to remain afloat. This is critical when determining hull size and material selection. Applying these equations ensures the design meets buoyancy requirements.

[8]

This reference focuses on ship design principles, including hull geometry, stability, and weight distribution. It explains how these factors affect how a vessel behaves in water. This is directly applicable to the project because it supports designing a hull that can maintain stability while carrying the required payload. The discussion of stability is particularly important for preventing excessive roll or tipping during operation. This is critical when the USV is carrying sensors and electronics. These concepts help ensure safe and stable performance in real conditions.

[9]

This manual explains the operation of the Lowrance transducer, including CHIRP sonar, SideScan, and DownScan imaging. It describes how sonar signals are used to generate images of underwater features and how installation and environmental conditions impact performance. This is directly relevant to the project because it supports proper use of the sonar system for detecting debris and scanning the canal bottom. It also provides insight into how data is displayed and interpreted in real-time. This is important for understanding how collected sonar data can be used for decision-making. These details support effective integration of the sensing system into the USV.

[10]

This book explains the fundamentals of sonar systems, including sound propagation, signal processing, and object detection. It also discusses limitations such as noise and environmental interference. This is relevant to the project because it helps improve understanding of how sonar data is collected and interpreted, which is important for reliable detection in real conditions. Understanding these limitations is for improving detection accuracy and reducing false readings. This is especially relevant in environments with turbulence or debris. These concepts help ensure more reliable interpretation of sonar data.

3.2.2 Norah Cooley Sources

[11]

This paper examines the challenges of launching and recovering a remotely operated vehicle from an unmanned surface vessel, with a focus on hydrodynamic effects and system integration. The authors analyze how environmental factors such as currents and vehicle motion influence stability during deployment and recovery. This is directly relevant to the project since the USV must operate in canal flows up to 2 m/s while still allowing reliable recovery. The findings help inform design decisions related to recovery mechanisms, sonar placement, and ensuring the system remains stable and functional under real operating conditions.

[12]

This engineering resource provides practical formulas for calculating the forces, torque, and power required in winch systems. It is useful for estimating the effort needed to pull or lift loads, especially in inclined or vertical scenarios. For this project, it supports the analysis of how the USV could be retrieved from steep canal walls and whether manual recovery is feasible. Even if a winch is not used in the final

design, this reference helps validate force requirements and supports the design of a quick and efficient recovery system.

[13]

This paper presents a system where an autonomous surface vehicle uses computer vision to align itself and load onto a trailer in dynamic environments. It focuses on real-time perception and control to maintain accuracy despite disturbances such as motion or misalignment. This is relevant to the project's need for precise navigation and positioning, particularly during recovery. The concepts presented can be applied to improve alignment or docking strategies, supporting the requirement for accurate and autonomous operation.

[14]

This work describes a fully automated system where a USV deploys and retrieves an autonomous underwater vehicle, emphasizing mechanical design and operational reliability. The paper explores different recovery approaches and highlights the importance of alignment, robustness, and simplicity in real-world conditions. This is highly applicable to the project, as it provides insight into designing an effective launch and recovery system for a USV operating in constrained environments like canals.

[15]

This book provides foundational knowledge on hydrodynamic behavior, including drag, lift, and hull performance. Although it focuses on planing hulls, the principles are still applicable to understanding resistance and fluid interaction for the current catamaran design. This reference supports the theoretical basis for drag calculations and helps justify assumptions used in performance modeling, particularly when validating results from simulations or analytical methods.

[16]

This textbook presents the governing equations and control strategies for marine vehicles, including both surface and underwater systems. It is particularly useful for modeling vehicle motion and designing control systems for autonomous operation. In this project, it supports the development of navigation and control logic, including waypoint tracking and lateral thruster use, and provides a strong theoretical foundation for MATLAB-based modeling and system behavior.

[17]

This reference provides a detailed theoretical treatment of fluid flow around marine bodies, including resistance, wave effects, and pressure distributions. It is useful for validating drag force calculations and understanding how hull geometry influences performance. For this project, it strengthens the accuracy of hydrodynamic modeling and supports comparisons between analytical calculations and simulation results.

[18]

The ITTC guidelines provide standardized methods for evaluating ship resistance and propulsion performance. These guidelines are widely accepted in the marine engineering field and offer validated

approaches for estimating drag coefficients and scaling results. This reference helps justify the assumptions used in the project's calculations and ensures that the modeling approach follows recognized engineering practices.

[19]

This manufacturer-provided documentation includes performance data such as thrust output, efficiency, and power consumption for the T200 thruster. It is directly applicable to the project, as it allows for accurate sizing of the propulsion system and evaluation of whether the selected thrusters meet performance requirements. It also supports calculations related to power usage and helps determine if the thrusters are appropriately sized for upstream operation.

[20]

This book focuses on propeller performance, thrust generation, and propulsion system design. It provides detailed explanations of how thrust, efficiency, and power are related, as well as how different configurations affect performance. This is especially relevant to the project's propulsion system, as it helps justify decisions regarding ducted thrusters, placement between pontoons, and the amount of thrust required to overcome drag and current.

3.2.3 William Britt Sources

[21]

This work presents a STEM-based educational activity focused on understanding boat stability. It explains how buoyancy, center of gravity, and center of buoyancy affect whether a boat tips or remains upright. The paper emphasizes hands-on learning to help students visualize stability concepts. It is useful for foundational understanding of naval architecture principles in an accessible way.

[22]

This source focuses on interpreting temperature and salinity data in ocean models. It explains how these variables influence density, circulation, and heat transfer in marine systems. The authors also provide methods for calculating ocean heat fluxes and content accurately. This work is important for understanding environmental conditions that impact marine vessel performance.

[23]

This paper investigates boat design inspired by water striders, which can move efficiently across water surfaces. It highlights how geometry and motion contribute to stability and resistance against waves. The study connects biological inspiration with engineering applications in boat design. It is particularly relevant for improving storm resistance and hydrodynamic efficiency.

[24]

This article reviews ship ventilation systems and their role in onboard air quality. It discusses how ventilation design can prevent the spread of airborne diseases in confined marine environments. The paper also evaluates different system configurations and safety measures. It is especially relevant for modern ship design with increased health and safety concerns.

[25]

This study examines how surface tension enables heavy objects to float under certain conditions. It explains why elongated shapes distribute weight more effectively and improve floating capability. The paper connects surface physics with practical floating behavior. It is useful for understanding small-scale flotation and bio-inspired designs.

[26]

This classic text provides a comprehensive foundation in fluid mechanics as applied to marine vessels. It covers wave resistance, ship motion, and hydrodynamic forces in detail. The book develops mathematical models to predict vessel behavior in water. It is widely used in naval architecture and ocean engineering education.

[27]

This source presents a unified treatment of hydrodynamics applied to marine problems. It balances theoretical development with practical engineering applications. The book connects diverse marine phenomena under common fluid mechanics principles. It is often used as an introduction to advanced research in ocean engineering.

[28]

This book analyzes the hydrodynamics of vessels operating at high speeds. It discusses resistance, propulsion, and wave interaction effects in detail. The author includes simplified and rational methods for engineering analysis. It is essential for understanding the performance and stability of fast marine crafts.

[29]

This work focuses on different categories of high-speed vessels, including hull-supported and air-cushion crafts. It examines wave effects, maneuvering, and structural interactions. The text links hydrodynamics with control systems and structural mechanics. It is widely referenced in advanced marine engineering studies.

[30]

This updated edition revisits the foundational principles of marine hydrodynamics. It reflects the continued relevance of classical theories in modern engineering. The text emphasizes real-world applications alongside theoretical analysis. It remains a key reference for students and professionals in naval architecture.

3.2.4 Alexander Davis Sources

[31]

The document is about creating and executing missions using waypoint navigation in ArduPilot. It talks about how ArduPilot handles position targets and mission sequencing and event triggers. This is important for the USV as the USV uses waypoint navigation to follow a path in a canal.

[32]

This source is about adjusting settings that impact how well the vehicle navigates. These settings include fixing cross-track errors, and how quickly the vehicle steers and controlling its speed. The source explains how certain settings like PID gains make the vehicle respond strongly or weakly when it deviates from its path.

[33]

This paper is about ways to reduce tracking errors in vehicles that do not have full control. For example, some vehicles use differential thrust of being able to move in any direction. The paper looks at how to minimize errors when the vehicle is not on the right path. It also looks at how to stay on course.

[34]

This document introduces the Line-of-Sight guidance method. The Line-of-Sight guidance method is a way to help marine vehicles navigate. It does this by figuring out the direction to go based on a point ahead on the path. This makes the vehicle move smoothly and stay on track. The Line-of-Sight guidance method is useful for the Unmanned Surface Vehicle because it helps turn the path into instructions for the thrusters.

[35]

This paper is about making the guidance system for boats better. It does this by adding some methods to deal with things like currents and forces from outside. The new system can handle two ways to make corrections, which helps the boat follow its path even when things are changing. This is important for boats that are operating in canals where we want to stay centered for accurate data.

[36]

This book gives us a look at how to design an Unmanned Surface Vehicle. The USV design includes things like propulsion systems and hydrodynamics. It also talks about control architecture. The book explains how all the different parts of the USV work together to make the vehicle perform well. This is

really helpful when we are designing a project and we need to make sure that everything works together properly.

[37]

This book is important for understanding how boats and other marine vehicles move and are controlled. It has all the equations for how water affects these vehicles, including the forces and motions involved. The book also talks about how to control vehicles that can operate on their own. The information in this book is useful for the calculations we did in this project, especially when it came to figuring out how powerful the vehicles were and how they interacted with the water.

[38]

The International Towing Tank Conference gives us ways to figure out how much a ship will resist the water and how drag it will have. The International Towing Tank Conference methods are based on a submarine that closely resembles our pontoon shape.

[39]

This guide has a lot of information about the T200 thruster. It tells us about the thruster's performance, like how thrust it can produce how efficient the thruster is and how much power the thruster uses at different voltages. The numbers for the maximum thrust of the T200 thruster are used to calculate how it will perform in different situations.

[40]

This book is about propellers and how they physically make things move. It talks about the power that propellers make and how well they work. The book also explains what happens to propellers when they are working hard and how they do when they are moving fast. This is important to know when we compare how much thrust propellers make and how much drag they have.

3.2.5 Christian Mpoyo Sources

[41]

This source provides a comprehensive foundation for understanding how images and video data are processed and analyzed. It explains key techniques used in image enhancement, compression, and interpretation, which are important for robotic vision systems. In the context of autonomous systems, it helps explain how cameras and visual sensors convert raw data into usable information. Overall, this source supports the understanding of perception systems used in robotics and sensor-based technologies.

[42]

This source focuses on how autonomous underwater vehicles (AUVs) collect and manage data in real-world environments. It explains the design of systems that allow AUVs to operate independently while gathering environmental and mission-critical data. The paper highlights challenges such as communication limitations and harsh underwater conditions. It is important because it shows how data collection systems are built to support autonomy in underwater robotics.

[43]

This source explains how multiple sensors are combined in real time to improve navigation accuracy. It focuses on sensor fusion techniques that allow robots to interpret their surroundings more reliably. By combining data from different sensors, the system reduces errors that would occur if only one sensor were used. This work is important because it demonstrates how real-time processing enables autonomous navigation in complex environments.

[44]

This paper evaluates different data logging methods used in robots that rely on multiple sensors. It focuses on how network limitations can affect performance when recording large amounts of sensor data. The study compares strategies to determine which methods are most efficient and reliable under constraints. This source is valuable because it helps improve system performance and data reliability in multi-sensor robotic systems.

[45]

This paper discusses how AUVs determine their position underwater using multiple sensors and algorithms. It explains that sensor fusion improves state estimation by combining data from different sources.

The source highlights common sensors like sonar and inertial systems used for navigation. It is important because it shows how accurate localization is achieved in environments where GPS is unavailable.

[46]

This source provides a broad review of modern AUV technologies, including navigation, control, and perception systems. It summarizes recent advancements and identifies challenges in improving efficiency and reliability.

The paper also discusses future trends in underwater robotics development. It is useful because it gives a complete overview of the field and its direction.

[47]

This study presents a sensor fusion method that combines mathematical models with filtering techniques to improve navigation. It uses advanced approaches like Kalman filtering to estimate position more accurately.

The paper shows how combining sensor data reduces uncertainty in underwater environments. It is important because it demonstrates practical improvements in navigation performance.

[48]

This paper explains how AUVs use sensor data and algorithms to plan paths and avoid obstacles. It highlights the importance of integrating multiple sensors to improve decision-making.

The study also discusses techniques like SLAM for mapping unknown environments. This source is valuable because it connects sensor fusion with real-world navigation tasks.

[49]

This source provides a general overview of different sensor fusion techniques used in underwater robotics. It classifies methods and explains how they combine data from multiple sensors.

The paper emphasizes the importance of fusion in improving accuracy and reliability. It is useful because it gives a structured understanding of available approaches.

[50]

This source explains how AUVs operate, including navigation, sensors, and communication systems. It highlights how multiple sensors like IMUs, pressure sensors, and Doppler velocity logs are combined to estimate position.

The source also explains challenges such as lack of GPS underwater. It is important because it provides real-world context for how these systems function in practice.

3.3 Mathematical Modeling -

3.3.1 William Calculations:

The first calculations William did was on what material should be used for the framing of the entire boat. He got his numbers off industry websites that were selling the rods at 20 mm by 20 mm by 20 inches, which is the size we are looking to use. His conclusion was that aluminum rods would be the best ones to use. The calculations are as follows:

$$\text{Aluminum Density: } 2700 \frac{\text{kg}}{\text{m}^3}$$

$$\text{Steel Density: } 7850 \frac{\text{kg}}{\text{m}^3}$$

$$\text{HPDE Density: } 950 \frac{\text{kg}}{\text{m}^3}$$

$$V = A * L: 20 \text{ mm} * 20 \text{ mm} * 0.508 = 0.0002032 \text{ m}^3$$

$$\text{Aluminum mass} = 2700 \frac{\text{kg}}{\text{m}^3} * 0.0002032 \text{ m}^3 = 0.55 \text{ kg}$$

$$\text{Steel mass: } 7850 \frac{\text{kg}}{\text{m}^3} * 0.0002032 \text{ m}^3 = 1.6 \text{ kg}$$

$$\text{HPDE mass: } 950 \frac{\text{kg}}{\text{m}^3} * 0.0002032 \text{ m}^3 = 0.19 \text{ kg}$$

From these calculations we decided that aluminum would be the best choice for the as it had the best balance between cost and support.

The next calculation that William completed was to see if there was a chance of overheating from the radiation coming from the sun and the heat generation coming from the box.

$$Q = 70 \text{ W (Max } Q \text{ in the box)}$$

$$\text{Box} = 0.5 \text{ m} * 0.4 \text{ m} * 0.2 \text{ m}$$

$$A = 0.84m^2$$

$$U = 5 \frac{W}{m^2} * k$$

$$\Delta T = \frac{70}{5 * 0.84} = 16.7 C$$

What was figured out from this calculation is that at max power the inside of the box will be heated by an extra 16.7 degrees C in already 100-degree weather. With a max temp of 70 degrees C for most of the electronics that means that without any other methods of heat resistance the electronics inside will overheat. We are currently figuring out if thermal resistant paint is enough to lower the temperature but if not we have plans to attach aluminum rods to the box that are cooled by the water to take a portion of the heat away.

3.3.2 Norah Calculations:

Subsystem-Deployment and Recovery

One of the calculations I did was to see if the wheels we are planning on using would be buoyant enough for our boat and not weigh it down by using the Archimedes' principle. The total displaced volume of approximately 20.755 in³ results in a buoyant force of about 0.749 lbf per wheel. This force is relatively small compared to the overall weight of the system, indicating that the wheels do not significantly impact flotation or stability, while still providing a small buoyant effect.

$$V_o = \frac{\pi h (D^2 - d^2)}{4} = 9.032in^3$$

$$V_i = \frac{\pi h_i (D_i^2 - d_i^2)}{4} = 11.723in^3$$

$$V_o + V_i = 20.755in^3$$

$$B = \rho V = 0.749lbf$$

Another analysis was conducted on the thruster power to see if the ones we have selected are able to meet the design requirements. The relationship between velocity, thrust, and power was evaluated using $V = V_c + V_g$, accounting for both current and ground speed, and thrust was estimated from manufacturer data and converted into usable force. The total available thrust was then compared to the calculated drag forces at different speeds. Results show that while upstream travel is not possible at lower thrust levels, the system achieves a maximum water-relative speed of approximately 3.02 m/s, resulting in an upstream ground speed of about 1.02 m/s against a 2 m/s current. At this condition, the required thrust and power are within the capability of two T200 thrusters, with a small but sufficient margin. This confirms that the selected thrusters are adequate for meeting the project's requirements of traveling upstream while maintaining reasonable times.

```

--- At U = 1.01 m/s ---
Re           = 6.509e+05
Fn           = 0.399
Total drag   = 11.15 N
Effective power = 11.22 W
Thrust per motor = 5.58 N
Upstream speed = -0.99 m/s
Boat would not make upstream progress at this speed.
2 x T200 appears sufficient, margin = 91.85 N
--- At U = 1.52 m/s ---
Re           = 9.823e+05
Fn           = 0.603
Total drag   = 25.19 N
Effective power = 38.24 W
Thrust per motor = 12.59 N
Upstream speed = -0.48 m/s
Boat would not make upstream progress at this speed.
2 x T200 appears sufficient, margin = 77.81 N
--- At U = 1.99 m/s ---
Re           = 1.288e+06
Fn           = 0.790
Total drag   = 43.11 N
Effective power = 85.82 W
Thrust per motor = 21.55 N
Upstream speed = -0.01 m/s
Boat would not make upstream progress at this speed.
2 x T200 appears sufficient, margin = 59.89 N

--- At U = 2.50 m/s ---
Re           = 1.619e+06
Fn           = 0.994
Total drag   = 67.87 N
Effective power = 169.89 W
Thrust per motor = 33.94 N
Upstream speed = 0.50 m/s
1 km upstream time = 33.1 min
2 km upstream time = 66.3 min
2 x T200 appears sufficient, margin = 35.13 N
--- At U = 3.02 m/s ---
Re           = 1.951e+06
Fn           = 1.197
Total drag   = 98.20 N
Effective power = 296.08 W
Thrust per motor = 49.10 N
Upstream speed = 1.02 m/s
1 km upstream time = 16.4 min
2 km upstream time = 32.8 min
2 x T200 appears sufficient, margin = 4.80 N

```

Figure 2: Thruster Calculations

3.3.3 Thrust Calculations – Alexander Davis:

To see if the chosen propulsion system can give the USV sufficient turning power, we did some differential thrust calculations using the two T200 thrusters at the back. The yaw moment that the thrusters create was calculated using $M_z = (T_R - T_L) \cdot \frac{b}{2}$, where T_R and T_L are the forces of the right and left thrusters and b is the distance between them. With the thrusters 12.5 inches, the maximum moment arm was 0.15875 meters.

| Voltage | Combo | Thrust | | M _z (N*m) | | Forward | Backward | $M_z = (T_R - T_L) \frac{b}{2}$ |
|---------|--------------|--------|--------|----------------------|-------------|---------|----------|---------------------------------|
| | | Right | Left | | | | | |
| 32 V | Nominal | 51.45 | -39.2 | 7.19534375 | Nominal kgf | 5.25 | 4 | |
| 40 V | Max | 65.66 | -49.49 | 9.14003125 | Max kgf | 6.7 | 5.05 | distance (b) |
| 16 V | Half Nominal | 51.45 | 0 | 4.08384375 | Nominal N | 51.45 | 39.2 | in |
| 20 V | Half Max | 65.66 | 0 | 5.2117625 | Max N | 65.66 | 49.49 | m |

Figure 3: Thrust Calculations

We got the data from the manufacturer and converted it to SI units. The forward and reverse thrust values are 51.45 N and 39.2 N. The forward and reverse thrust values are 65.66 N and 49.49 N. From these, we calculated the yaw moments. For Nominal differential thrust it was about 7.20 N·m. For Max differential thrust it was 9.14 N·m. For half-nominal thrust it was 4.08 N·m. For half-maximum thrust it was 5.21 N·m.

To estimate how the vehicle turns, we found the acceleration using $\alpha = M_z / I_z$. We estimated the moment of inertia with $I_z = k \cdot (b/2)^2 \cdot m$, where k is a factor for how the mass is distributed, m is the total mass, and b is the width of the hull. Assuming the vehicle weighs 50 pounds or 22.68 kilograms we looked at three mass distributions:

Center loaded, where $k=0.6$ and $I_z=0.343 \text{ kg}\cdot\text{m}^2$

Evenly distributed, where $k=0.8$. $I_z=0.457 \text{ kg}\cdot\text{m}^2$

Outside loaded, where $k=1.0$ and $I_z=0.572 \text{ kg}\cdot\text{m}^2$

| angular acceleration (rad/s ²) | | | | | |
|--|------------|-------|------------|-------|------------|
| M_z | $I_z=.343$ | M_z | $I_z=.457$ | M_z | $I_z=.572$ |
| 7.195 | 2.468 | 7.195 | 3.290 | 7.195 | 4.113 |
| 9.140 | 3.134 | 9.140 | 4.179 | 9.140 | 5.224 |
| 4.084 | 1.401 | 4.084 | 1.867 | 4.084 | 2.334 |
| 5.212 | 1.787 | 5.212 | 2.383 | 5.212 | 2.979 |

$$\alpha = \frac{M_z}{I_z}$$

Figure 4: Acceleration Calculations

The angular accelerations ranged from about 1.40 rad/s² to 5.22 rad/s² depending on the level and mass distribution. Since all cases are over 1 rad/s², which's what the project requires for turning acceleration, these results show that the chosen differential thrust configuration can provide enough turning performance, for the canal inspection USV.

3.3.4 Hydrodynamics Calculations – Alexander Davis:

Hydrodynamic calculations were done to estimate the drag force on the USV. This was to see if the chosen propulsion system can overcome that resistance. The analysis used a drag equation: $F_D=1/2*\rho C_{DAV}^2$. It also included skin friction, viscous resistance and appendage drag. The pontoon dimensions used in the MATLAB model were:

Length: 0.647 m

Width: 0.152 m

Height: 0.159 m

Center spacing: 0.319 m

From these dimensions estimates were made:

Draft: 0.1209 m

Area per pontoon: 0.01549 m²

Wetted area per pontoon: 0.17565 m²

Total wetted area: 0.35130 m²

frontal area: 0.05098 m²

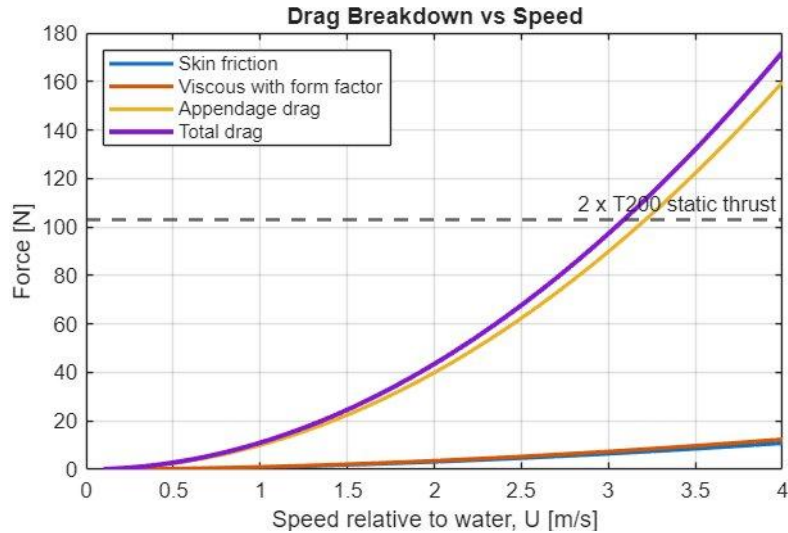


Figure 5: Drag Vs. Speed Graph

These values helped estimate resistance at different operating speeds. The drag breakdown plot shows that total drag increases rapidly with speed. Appendage drag dominates, while skin friction and viscous drag are smaller. At 4 m/s in water the total drag is 170 N. A comparison was made to the thrust from two T200 thrusters, which is about 103 N combined static thrust.

The Grad students' design cannot sustain the modeled speed. However, it has enough thrust to operate at lower speeds where drag is below the available thrust. Our current design has sufficient The calculations also show that the streamlined pontoon shape reduces resistance. The streamlined shape reduces resistance by an estimated 72% compared to a streamlined body. This hydrodynamic analysis supports using the catamaran hull and streamlined pontoon shape. It also helps define an operating speed range, for the USV. The USV and its propulsion system can work well together within speed limits. The design and analysis help ensure the USV operates efficiently and effectively.

3.3.5 Rikki Battery and Pontoon Generator Calculations:

Subsystem - Battery

One of the engineering calculations I used determines the total energy available in the battery system and estimates the operational runtime of the USV under expected power consumption and longevity. The total power consumption was estimated by accounting for all major electronic components, including the sonar transducer, flight controller, and thrusters operating at partial load conditions. Battery voltage was then determined based on the number of cells in series.

$$V = 3.7 \cdot N_s$$

$$N_s = \text{Number of cells in series } [4S, 6S, 8S]$$

$$V = 3.7 \cdot 4S = 14.8V$$

$$E_{\text{battery}} = V \cdot C$$

$$E = \text{Battery Energy [Wh]}$$

$$V = \text{Voltage [V]}$$

$$C = \text{Battery Capacity [Ah]}$$

$$E = 14.8V \cdot 20Ah = 296Wh$$

$$t = \frac{E_{\text{usable}}}{P}$$

$$t = \text{runtime[h]}$$

$$P = \text{Power Consumption [W]}$$

$$t = \frac{296Wh}{514.5W} = 0.575hr. = 34.5min.$$

Figure 6: Battery Calculations

The 4S lithium-ion battery configuration results in a nominal voltage of 14.8 V. With a capacity of 20Ah, the total available energy is 296 Wh. Based on an estimated system power consumption of 514.5 W, the expected runtime is approximately 0.575 hours (34.5 minutes). This result shows that the selected battery meets our mission duration requirements but may limit longer scanning operations in the future. This directly impacts system range and may require either increased battery capacity or reduced power consumption, although it gives us the ability to begin testing and data collecting.

Subsystem Support – Pontoon calculations

The next calculation was used to support the buoyancy subsystem and help the team decide if it would be more cost efficient to build our own pontoons, and to give us an idea of what sized dimensions would hold the weight necessary and its impact on speed.

$$L = 1m, W = 0.25m, H = 0.25m$$

$$a = 0.5, b = 0.125, c = 0.125$$

$$V = \frac{4}{3} \pi abc = \frac{4}{3} \pi (0.5)(0.125)(0.125) = 0.0327m^3$$

$$m = \rho V = (1000)(0.0327) = 32.7kg = 72.1 lb$$

Command Window

Length = 1.0000 m

Width = 0.2500 m

Height = 0.2500 m

===== CALCULATED PROPERTIES =====

Volume = 0.032725 m^3

Max buoyant force = 321.03 N

Max supported mass = 32.72 kg

Figure 7: Pontoon Matlab Results

With the use of MATLAB, the team could insert dimensions, such as 1m. by 0.25m. by 0.25m., and calculate a volume of $0.0327 m^3$. Assuming a water density of $1000 kg / m^3$, the maximum supported mass is approximately 32.7 kg. (72.1 lbs.). The calculated buoyant capacity exceeds the required floatability of 60 lbs. Confirming that the pontoon design meets the engineering requirement. This ensures the system will remain afloat while supporting all required components.

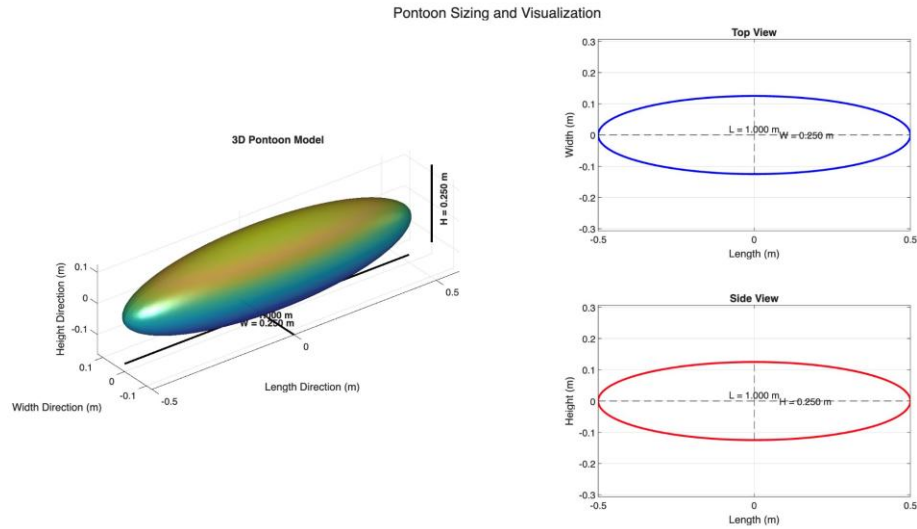


Figure 8: Matlab Pontoon Visualization

3.3.5.1.1 MATLAB Code

```

clc; clear; close all;

% Pontoon size generator
% Inputs: Length, Width, Height
% Output: Dimensions, volume, buoyancy, and visual

% Desired Dimensions
L = input('Enter pontoon length (m): ');
W = input('Enter pontoon width (m): ');
H = input('Enter pontoon height (m): ');

if L <= 0 || W <= 0 || H <= 0
    error('All dimensions must be greater than zero. ');
end

a = L/2; % semi-length
b = W/2; % semi-width
c = H/2; % semi-height

% Calculations
volume = (4/3) * pi * a * b * c; % m^3
rho_water = 1000; % kg/m^3
g = 9.81; % m/s^2
max_buoyant_force = rho_water * g * volume; % N
max_supported_mass = rho_water * volume; % kg

% Results
fprintf('\n==== PONTON DIMENSIONS =====\n');
fprintf('Length = %.4f m\n', L);
fprintf('Width = %.4f m\n', W);
fprintf('Height = %.4f m\n', H);

fprintf('\n==== CALCULATED PROPERTIES =====\n');
fprintf('Volume = %.6f m^3\n', volume);
fprintf('Max buoyant force = %.2f N\n', max_buoyant_force);
fprintf('Max supported mass = %.2f kg\n', max_supported_mass);

```

Figure 9: Matlab Code

3.3.6 Christian's Calculations:

In this analysis, buoyancy was calculated using Archimedes' principle to determine whether the pontoons can support the system's weight. The pontoon volume was first converted from cubic inches to cubic meters to maintain consistent SI units. The buoyant force for a single pontoon was calculated to be approximately 63.5 N. Since the system uses two pontoons, the total buoyant force is about 127 N. Dividing this force by gravitational acceleration gives a maximum supported mass of approximately 12.95 kg (28.5 lb). This result indicates that the current design is near its load limit and may require additional buoyancy for safe operation. In addition, the maximum power requirement of the system was estimated by summing the power consumption of all major components. The thrusters account for the majority of the load, followed by the onboard electronics, sensors, and system losses. The total estimated maximum power consumption is approximately 950 W. This value represents a worst-case scenario and is used to guide battery selection and overall power system design.

$$V_p = 395 \text{ in}^3 \left(\frac{0.0254 \text{ m}}{1 \text{ in}} \right)^3 = 6.47 \times 10^{-3} \text{ m}^3$$

$$F_{(b,p)} = \rho g V_p = (1000)(9.81)(6.47 \cdot 10^{-3}) = 63.5 \text{ N}$$

$$F_{(b, total)} = 2F_{(b,p)} = 127 \text{ N}$$

$$m_{(\text{max})} = \frac{F_{(b, total)}}{g} = \frac{127}{9.81} = 12.95 \text{ kg} \approx 28.5 \text{ lb}$$

4 Design Concepts - Alex

4.1 Functional Decomposition

The chart shown below is a decomposition chart which shows all the important functions the project must accomplish and how. The chart highlights some major ones like the function of the controller, the power supplied by the batteries, and how it will interpret everything. The chart is important due to it being an easy and fast way to look at what specific tasks are required by other tasks and what still needs to be done before we get to that task. For example, we are unable to start on how we will store the data until we figure out the power situation as shown in the chart. For the physical aspect, the only input and output is the departure and recovery of the boat. Electricity inputs from the battery to the thrusters, sonar, and the Orange Cube flight controller. The thruster uses that electricity to rotate, which moves the boat to the desired position. Sonar uses electricity to function and then stores data. Signal input comes from the controller where we input the destination and waypoints. The Orange Cube uses these and signals the thrusters which direction to rotate. All of this ultimately gets the boat to its desired point while scanning and storing the sonar data.

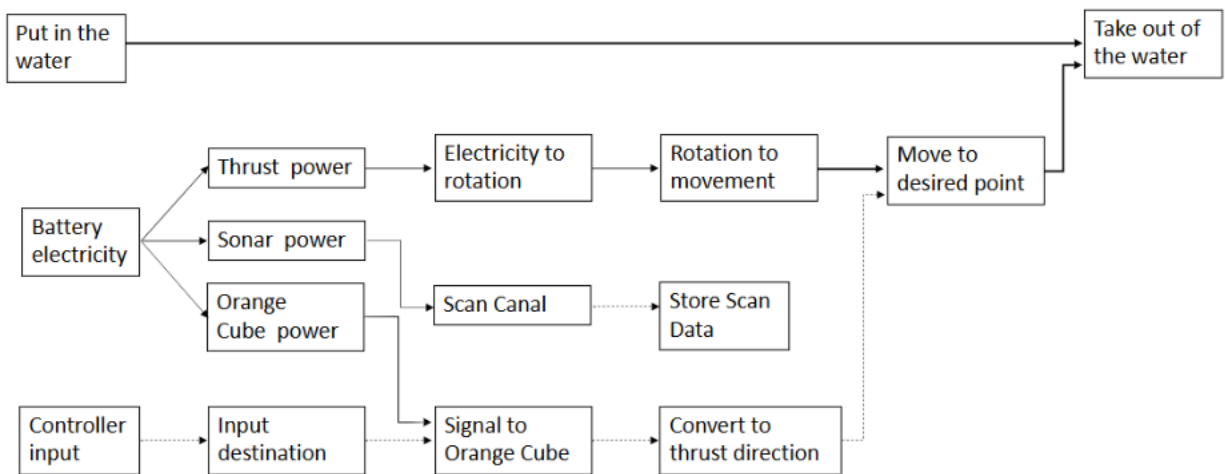


Figure 10: Functional Decomposition

4.2 Concept Generation

The team came up with design ideas to fix the big problems they found in the first version. These problems included the boat not being able to navigate well, being hard to put in and take out of the water and interfering with the sonar system. To come up with these ideas, we broke the system down into parts like the hull, the propulsion, where the sensors are, and how to recover it then thought of solutions for each part.

Hull Concepts

The first idea was to make the boat with one hull, either 3D printed or built. This idea would not cost a lot of money, and it would also be easy to make. There were some issues with the design; it was not very reasonable because the 3D print materials needed to withstand the salt water and Phoenix heat.

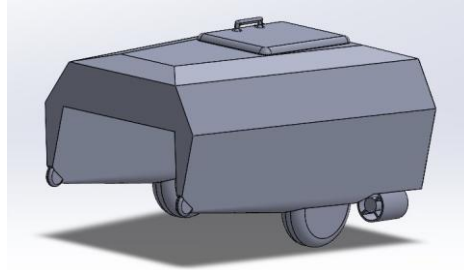


Figure 11: First Old Design

The second idea was to make a catamaran hull with two pontoons connected by a frame. This made the boat more stable. Gave enough space to put the sonar between the pontoons without anything getting in the way. It also made it easy to add parts like electronics and the thrusters

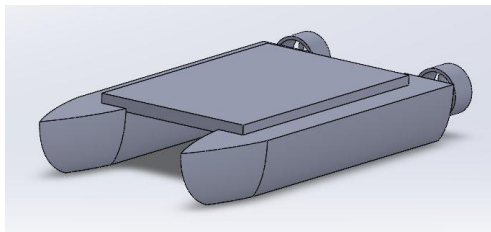


Figure 12: Second Old Design

The third idea was to make the hull flat like a surfboard. This would give it a lot of surface area and make it easy to put in the water. It was not very good at handling the water moving around it while staying stable and did not protect the sensors that were under the water very well.



Figure 13: Third Old Design

Propulsion Concepts

The team thought about ways to make the boat move. The simplest way was to use two thrusters at the back of the boat. This made the boat go forward. Could turn it a little bit by using the thrusters differentially. The only downside was that if it wanted to stay centered, it would have to be on an angle constantly.

A better idea was to add a thruster in the middle of the boat that could move from side to side. This helped the boat stay on course without having to turn the boat. This will make the navigation more accurate. We also thought about ways to make the boat move like using thrusters at an angle or ones that could move in any direction, but these ideas were too complicated, and we do not require extensive turning.

Sensor Mounting Concepts

Where to put the sensors was a deal because the sonar was not working well in the first version. One idea was to put the sonar inside the hull. This protected it, but this made the signal not very clear.

Another idea was to put the sonar under the hull. This made the signal clearer. The sonar could get damaged when putting the boat in or taking it out of the water.

The final idea was to put the sonar between the catamaran pontoons, a bit under the hull. This made the signal clear. Protected the sonar at the same time. This way the sonar could work well without getting damaged.

Deployment and Recovery Concepts

The team thought about ways to put the boat in and take it out of the water because it was hard to do in canals, with steep walls. The following ideas are the best options we could think of. Lifting the boat up and down by hand, which is simple but hard to do. Using wheels to make the boat roll along the canal walls. Using a cart to put the boat in and take it out of the water.

4.3 Selection Criteria

To check the proposed ideas, we made a list of factors based on what the project needed. These factors helped us judge each idea in a way and make sure it matched the main goals of the system.

The main factors included:

- **Stability:** Can it stay steady and not tip over in canal water moving up to 2 meters per second?
- **Navigation Accuracy:** Can it stay in the middle of the canal with a 0.5 meter error?
- **Sensor Performance:** Can it reduce noise from sonar. Give good data?
- **Deployment and Recovery:** How easy and fast is it to use, aiming for, under 5 minutes?
- **Robustness:** Can it handle bumps, water and operating outside?
- **Complexity:** Is it easy to make, put and control?

- Cost: Can it be made within our budget?

We checked each idea against these factors and found the best and most practical solution.

4.4 Concept Selection

A decision matrix was used to compare the generated concepts against the defined selection criteria. Each concept was scored relative to a baseline. This allowed for a comparison of strengths and weaknesses.



| Criteria | Weight |  | |  | |  | | |
|--------------|--------|---|-----------|---|-----------|---|-----------|-------|
| | | Unweighted: | Weighted: | Unweighted: | Weighted: | Unweighted: | Weighted: | |
| Deployment | 0.25 | 90 | 22.5 | 50 | 12.5 | 80 | 20 | |
| Recovery | 0.25 | 90 | 22.5 | 50 | 12.5 | 80 | 20 | |
| Navigation | 0.15 | 85 | 12.75 | 85 | 12.75 | 85 | 12.75 | |
| Waterproof | 0.1 | 100 | 10 | 85 | 8.5 | 90 | 9 | |
| Battery Life | 0.1 | 75 | 7.5 | 90 | 9 | 75 | 7.5 | |
| Data Logging | 0.1 | 80 | 8 | 80 | 8 | 80 | 8 | |
| Size | 0.05 | 90 | 4.5 | 90 | 4.5 | 90 | 4.5 | |
| Total | 1 | | Sum: | | Sum: | | Sum: | 81.75 |

Figure 14: Decision Matrix

The catamaran hull with a lateral thruster consistently ranked highest across most criteria. This configuration provided stability due to its wide stance. The buoyancy was also distributed well. It enabled sonar placement between the pontoons. This reduced interference compared to previous designs.

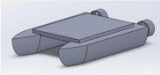
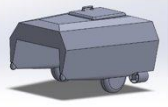


| Criteria |  |  |  |  | | |
|--------------|---|--|--|--|---|---|
| Deployment | - | S | Datum | - | | + |
| Recovery | - | S | Datum | - | | + |
| Navigation | - | - | Datum | + | | S |
| Waterproof | + | + | Datum | - | | + |
| Battery Life | S | - | Datum | + | | - |
| Data Logging | S | S | Datum | + | | S |
| Size | + | - | Datum | + | | S |
| Total + | | 2 | 1 Datum | | 3 | 3 |
| Total - | | 3 | 3 Datum | | 3 | 1 |
| Total Same | | 2 | 3 Datum | | 0 | 3 |

Figure 15: Pugh Chart

The lateral thruster allowed for cross-track corrections. This improved navigation accuracy. It did not require heading changes. This is particularly important for maintaining the canal midline. This is crucial under varying flow conditions.

Some alternative concepts, like the monohull and surfboard-style designs, offered advantages in simplicity. However they did not meet the performance requirements for stability and sensor integration. Complex propulsion and recovery systems were not selected. They were too costly and difficult to implement.

The final selected concept has the following features:

- Catamaran hull for stability and modularity
- Stern-mounted ducted thrusters for forward propulsion
- Central lateral thruster, for navigation correction
- Sonar mounted between pontoons for reduced interference
- deployment and recovery approach

This design directly addresses the shortcomings of the initial prototype. It meets all project requirements. The catamaran hull and central lateral thruster make it a good choice. The design is stable and modular.

5 Schedule and Budget - Norah

5.1 Schedule

The Gantt charts shown below are a breakdown of the project schedule for the first semester and a draft timeline for the second semester. It identifies all major tasks, their durations, and deadlines, providing a clear structure for tracking progress.

We split it up by foundation, planning and design, assignments, and individual research of the subsystems. The foundation phase established the project requirements through initial meetings and early deliverables. The planning and design phase focused on concept generation, evaluation, and selection of the final design. Assignments include ongoing reports, prototype demonstrations, CAD development, and analysis, while individual research covers key subsystems such as thrusters, electronics, and sensors.

We tracked our progress using completion percentages within the Gantt chart. At this point in the semester, most tasks are complete, with only a few remaining such as homework 4 analysis, the second prototype demonstration, final CAD, the final bill of materials, and website check 2.

The second semester draft shifts focus to building the boat, testing, and validation, ensuring the project progresses from the final design to a fully functional system.

ARWBCI Project

SRP Project lead

Project start: **Mon, 1/26/2026**
 Display week: **4**

SIMPLE GANTT CHART by Vertex42.com

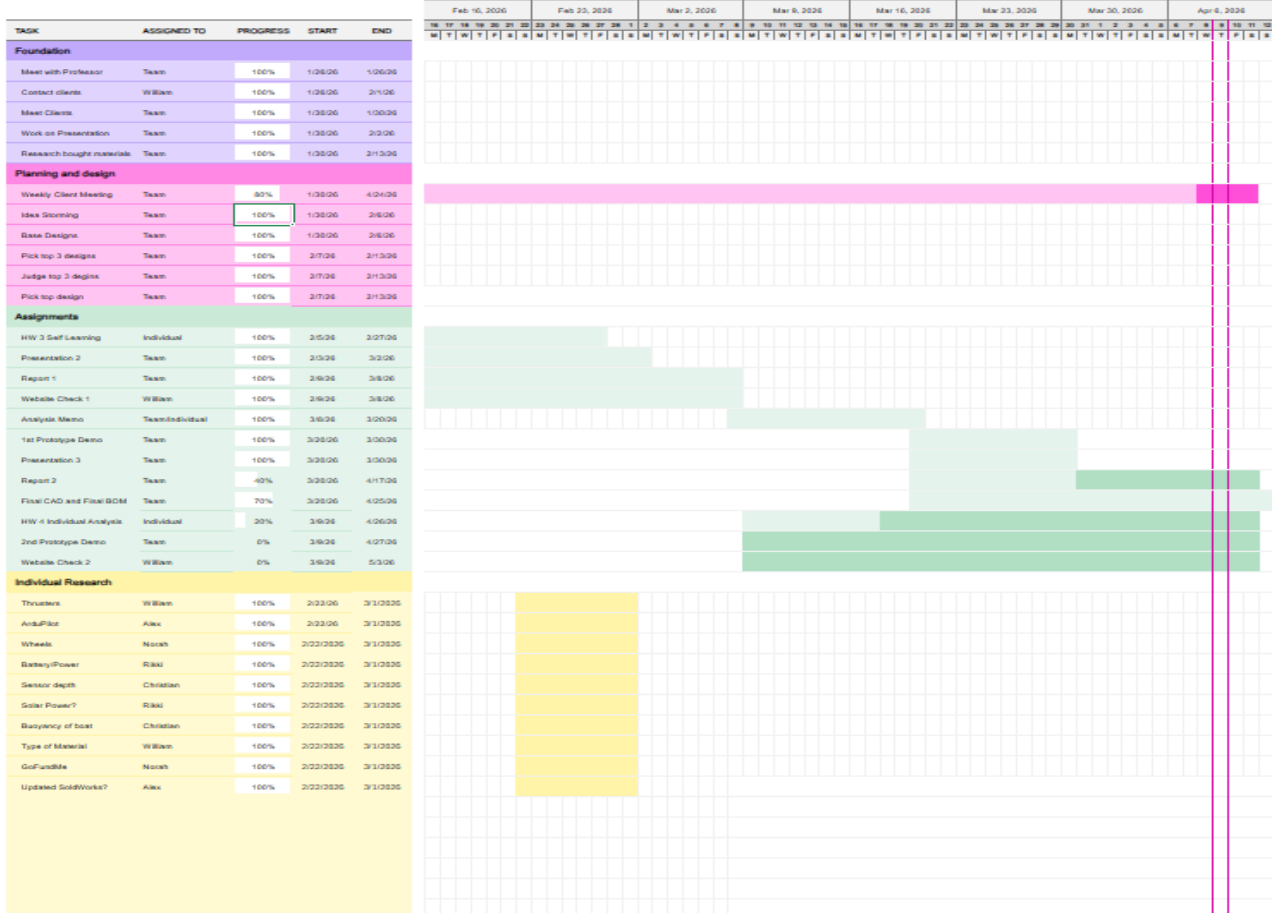


Figure 16: Gantt Chart Spring Semester

ARWBCI Project

SRP Project lead

Project start: **Tue, 8/25/2026**

Display week: **2**

SIMPLE GANTT CHART by Vertex42.com

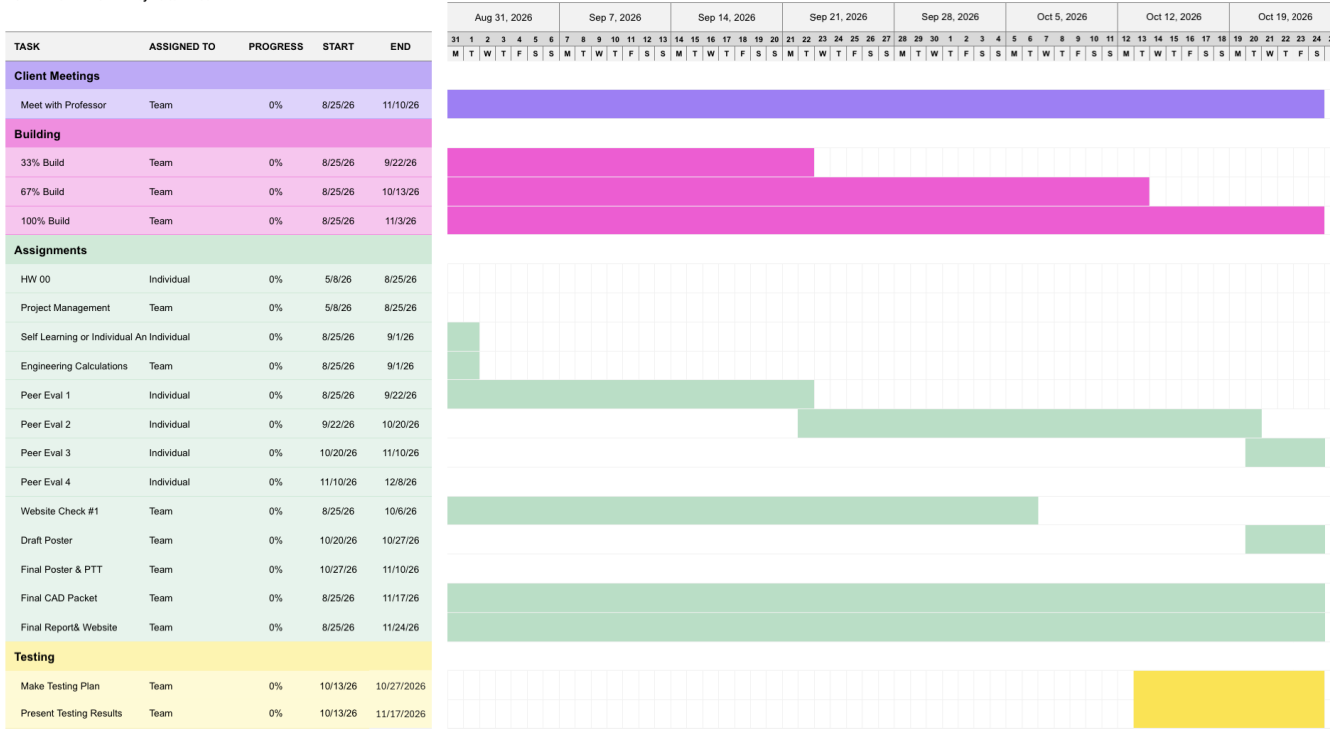


Figure 17: Gantt Chart Fall Semester

5.2 Budget

The project budget for the autonomous canal inspection USV is estimated at approximately \$2000. A significant portion of the total cost is mitigated through contributions from the Raz Lab, including critical components such as the sonar system, controller and charging equipment. The remaining budget is allocated toward structural materials such as aluminum framing and pontoons, thrusters, ESCs, telemetry systems, and fabrication supplies. Current expenses remain within the projected budget, with most costs driven by propulsion and electronics subsystems. To supplement available funding, the team plans to pursue fundraising efforts and external support to raise \$500. The only supplies that have already been purchased are a 2x4 plank, a 10-pack of small wood planks, and a pack of screws to do our physical prototype which came out to be \$40.36.

5.3 Bill of Materials (BoM)

Below is a complete bill of materials for one unit of our current final design. The total estimated value of the full system is \$3,631.21, which includes several major components that have already been acquired through prior funding. These include the Herelink controller, Lowrance transducer, and Lowrance HDS-7

sonar system. If we do not include these items, the remaining cost of the final design is \$2005.22 which sits close to our budget.

This bill of materials includes commercially available items making it reliable while keeping the cost down due to not having to pay for manufacturing and there should not be long lead times. The major expenses are the equipment needed for the control system and the sonar system but most of the expensive equipment has already been provided, making the cost more manageable.

| Item | Price | Units | Total |
|---|------------|-------|-----------|
| <u>Kayak Stablizers</u> | \$215.99 | 1 | \$215.99 |
| <u>T200 Thruster</u> | \$270.00 | 2 | \$540.00 |
| <u>Apisqueen</u> | \$42.00 | 1 | \$42.00 |
| <u>Aluminum Extrusions (4 pack)</u> | \$40.64 | 2 | \$81.28 |
| <u>Cube Orange + Standard Set</u> | \$400.00 | 1 | \$400.00 |
| <u>Here3</u> | \$225.00 | 1 | \$225.00 |
| <u>SiK Telemetry Radio</u> | \$58.99 | 1 | \$58.99 |
| <u>Basic ESC</u> | \$40.00 | 3 | \$120.00 |
| <u>Waterproof Electrical Junction Box</u> | \$114.99 | 1 | \$114.99 |
| Wheels | \$27 | 2 | \$53.98 |
| Screws | \$20 | 1 | \$20.00 |
| <u>Batteries</u> | \$116.99 | 1 | \$116.99 |
| <u>Wires</u> | \$16.00 | 1 | \$16.00 |
| <u>Herelink Controller</u> | \$1,529.62 | 1 | \$1529.62 |
| <u>Lowrance Transducer</u> | \$343.00 | 1 | \$343.00 |
| <u>Lowrance HDS-7</u> | \$1282.99 | 1 | \$1282.99 |

6 Design Validation and Initial Prototyping - William

6.1 Failure Modes and Effects Analysis (FMEA)

[Discuss your team's FMEA, including critical potential failures and how your design mitigated these potential failures. Discuss the risk trade-off analysis that your team has performed.]

For our FMEA we looked at some of the most critical aspects of our design and how they could fail and what would happen if they did fail. What we see as the biggest possible failure of our design is the chance of our electrical box not being waterproof and causing our electronics to get destroyed. With how catastrophic this failure could be we of course rated the severity of it at a full 10, but we don't believe it will be too much of an issue, so it has an occurrence of 3. With the box we have chosen and testing it without electronics, we should be able to determine if it is waterproof or not for what we are trying to do, which is how we are trying to mitigate the potential failure. When it is in the water, there is a chance one of the exposed underwater electrical wires can get damaged or pulled out which will cause the box to not be watertight, which we will mitigate by being careful when controlling the boat in the water. Two of the other critical potential failures are similar to each other being loss of power to the thrusters and a full power depletion of the battery. The failure associated with power failure to the thrusters would be unable to control the direction or motion of the boat, and it would be floating adrift. To mitigate this possible failure before deploying into water, we will do a check of how the thrusters are working. The other critical failure is a full depletion of battery power which would a complete lack of response from the sensor to the thrusters. To mitigate this critical failure, we will check the battery life of the battery and how much life it has left before deploying it into the water. Shown below labeled figure _____ is a full look at the FMEA we calculated showing the failures already mentioned and some lesser failures that could happen.

| Product Name: Canal Boat | | Development Team: ARBWCI | | | | Page No 1 of 1 | | |
|--------------------------|----------------------------|---|--------------|--|---------------|---|---------------|-----|
| System Name | | | | | | FMEA Number: 1 | | |
| Subsystem Name | | | | | | Date: 3/30/26 | | |
| Component Name | | | | | | | | |
| Part # and Functions | Potential Failure Mode | Potential Effect(s) of Failure | Severity (S) | Potential Causes and Mechanisms of Failure | Occurance (O) | Current Design Controls Test | Detection (D) | RPN |
| Electrical Box | Water leakage | Damage all electronics and lose control | 10 | Bad seal, leaking cable connector, damage | 3 | Seal inspection | 3 | 90 |
| Rear Thrusters | Lose power/breaks/fails | Unable to move/control boat | 8 | Motor burnout, loose wiring, collision | 3 | Pre-run thrust check | 3 | 72 |
| Lateral Thrusters | Lose power/fails | Boat won't be able to adjust for drift | 5 | Motor burnout, loose wiring | 3 | Pre-run thrust check | 3 | 45 |
| GPS | GPS has the wrong location | Autopilot could send the boat into a wall | 4 | GPS having a bad read on the data from the | 4 | Double Check GPS before testing | 3 | 48 |
| Battery | Power depletion | Loss control of thrusters, sensor, data logging | 9 | Not fully charged, stronger current | 5 | Check charge level, charge before | 3 | 135 |
| Controller | Loss of Signal | The boat would not be able to be controlled | 6 | The chartplotter would stop sending signal | 3 | When testing see if/when the controller | 3 | 54 |
| Sonar | Data Tracking Fails | Whatever we are testing would not have data | 10 | Bad connection between sensor and chart | 4 | Make sure there's no loss in data | 3 | 120 |

Figure 18: FMEA Table

6.2 Initial Prototyping Physical

For this first prototype that we did, we wanted to answer the question of how much could be around the sensor without causing feedback. To do this, we built a wood rig to put on a prototype boat where we were able to move it up and down linearly and look at the sensor to see if there was feedback. What we saw when we did the tests was obvious feedback being shown when there was wood covering or partially covering the sensor. When the wood wasn't covering the sensor but was still barely in the water above it, we were still able to see some amount of feedback. What this told us about our design is that we needed to make sure that there was nothing near the sensor at all as to keep the date clean. In between the initial prototyping and the publications of this report we did a second test and understood the sensor more clearly to where we won't need to make changes to our design.

6.3 Initial Prototyping Virtual

For the second prototype that we did, we wanted to see if a third thruster in the middle of the boat could work and give the boat lateral movement to stabilize it better. We wanted to test this because we weren't sure if a third thruster would actually do anything. To test this, we used ArduPilot to make a virtual version of our boat so that we could see how it would move. What we saw from this virtual boat was that when veered off course parallel to the line it was supposed to be following it was able to correct itself laterally and go back to the line it was supposed to be following. The information that we received from this test informed us that the third thruster would work and we will continue to have it in future iterations of our design

6.4 Other Engineering Calculations

Once we decided on what design we wanted to do we did calculations on how a thruster in the middle of the boat would affect drag and if it would be effective. Additionally, we also calculated how much heat the electronics will be producing and how hot that will make the system as a whole. We did these calculations because once we had the design figured out, we needed to make sure these subsystems that we wanted to include would actually work in the finished design. The math for the calculations can be found above in the mathematical modeling section of the report.

6.5 Future Testing Potential

In the future, we are looking to test some of the other sub systems in our design to validate what they will do. One of those tests as mentioned previously was a redo of our first physical test with a better understanding of the sensor. Now that we knew what we were truly looking at with the data, we did many of the same tests we did previously but with a larger boundary size of around 30 feet to see how far it could scan stuff. For a future virtual test, we are going to set up a heat transfer test in solid works to see how hot the electronics get in the heat. To do this, we are going to set up a radiation test in SolidWorks with our current cad model to see what it will give us. Additionally, one of our members will bring a box and thermometer down to the testing area to see what temperature the thermometer reads.

7 CONCLUSIONS

In this report the updated progress of our project had been discussed and every different aspect that come from it. The ARWBCI project believes that it will be able to create something to analyze these dirty canals to the best of its ability and what is being asked of it. With us now having a better understanding of the sensor and technology of the thruster, we should now be able to read the data better and know what to look for when testing. With the updated calculations we believe the CAD model shown will be the final version of the boat and will be what we start to build next semester. We believe that the final design will be able to solve some of the problems the previous grad student design had while also being able to meet the demands of what our client is looking for when we were assigned this project.

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