Team 14: The P.A.L

The Personal Autonomous Lifeboat

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EXECUTIVE SUMMARY

Swimming alone on open waters is dangerous, especially when traveling long distances. The current measures that long-distance swimmers take are to either (1) attach a flotation device to themselves, increasing drag through the water, or (2) to ask a friend to paddle next to them. These solutions are inefficient and not always feasible.

Team 14 designed the P.A.L. to make long distance swimming safer. The P.A.L. autonomously follows a swimmer and provides a flotation device that allows the athlete to ride back to shore if necessary. Much of the electrical and mechanical design of the P.A.L. lies inside of the hull which takes the form of a Hydro Kaddy, an injected molded plastic hull originally intended to be pulled behind a kayak.

The electrical design focused on utilizing both radio and ultrasonic communication in congruence to control the response of the boat and allow for the autonomous tracking of the swimmer. A radio signal is sent from the boat to the swimmer, triggering ultrasonic waves to be transmitted from the swimmer. The P.A.L. then receives those ultrasonic waves with receiving sensors. As a result, the boat calculates the swimmer's position.

The swimmer's position is used to control two motors. One motor controls the thrust which revolves around the uniquely designed jet propulsion unit. The second motor controls the yaw of the boat. Control lines and a custom nozzle were designed to connect the electrical response to the mechanical action in directing the boat to follow the swimmer.

Finally, to help with smooth control and protection of the internal components, the team conducted proper weight distribution testing and waterproofing. For the swimmer's personal benefit, an LCD displays the distance swam and the temperatures of the water and the air. The finished product resulted in a working proof-of-concept, demonstrating the possibility of safer long-distance swimming.

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1. INTRODUCTION

1.1 Context

Athletes are drawn to the water despite the dangers. In the United States, drowning is the fifth leading cause of unintentional injury death per year, accounting for an average of 3,536 deaths per year between 2005-2014. According to The Sports & Fitness Industry Association, participation in water sports continues to increase; triathlon participation has increased 59% from 2008 to 2011. With this rise in individuals on open water, a more efficient product is needed to create a safer experience. The P.A.L. (Personal Autonomous Lifeboat) is a device to enhance the mobility and accessibility for water athletes while staying safe on open water. To keep the focused on the safety of the swimmer, the team looks to Psalm 46:1 which states, "God is our refuge, and ever-present help in trouble." This reminds team 14 to seek refuge in the Lord while working to do the Lord's work in creating a refuge for open-water swimmers.

1.2 Problem Definition

Swimming on open waters alone is dangerous, especially when swimming long distances. Currently, there are a few different measures that athletes have taken to ensure safety. However, these solutions have proven to be inefficient; they either require a second person following on a boat to act as lifeguard, or the water athlete to pull a flotation device behind them, increasing drag for the swimmer. As can be seen, both solutions are inefficient and not always feasible. For this reason, it would be beneficial to have an autonomous device that can ensure the water athlete's safety.

1.3 Design Norms

Design norms play a large role in the construction and prototyping of the P.A.L. Though the team considers all design norms as important and pertinent to the project, the team focuses on stewardship, caring and trust as the main design norms. Stewardship reminds the team to use parts that provide optimal performance while minimizing cost, weight, power consumption, and environmental impact. Stewardship promotes the use of components that keep the swimmer in mind by reducing the overall cost, creating a lightweight and sustainable P.A.L. In addition to stewardship, there was also focused on caring. The team desired to build a system that protects the user while increasing their ability to be free and independent. No longer will the swimmer be "tied" down with a floatation device or finding someone with free time. Because the team focuses on the user's independence and safety, the athlete can give their full attention to swimming. Moreover, the team puts trust as their third and final design norm. The P.A.L. is designed with quality parts for optimal performance. This allows the swimmer to know they can rely on the P.A.L. during their swims. In conclusion, the team designed the P.A.L. to be good stewards of the environment while ensuring the safety of the user while on the open water.

1.4 Team Members

1.4.1 Megan Anders

Megan Anders grew up in a small town outside of Champaign-Urbana, IL. She is currently majoring in Mechanical Engineering with an international and sustainability designation. During the summer of 2017, Megan interned at Integrated Packaging Machinery (IPM) designing packaging equipment. In her Calvin College career, she studied abroad in Cambodia and Germany. While in Germany she studied at the Technical University of Berlin where she gained valuable international experience. She wants to integrate her passion for innovation, curiosity, and knowledge of engineering to help others and create a more sustainable world. Megan was an RA her junior year and served as the Treasurer for Engineering Unlimited, an organization to implement sustainable engineering projects worldwide. In her free time, she enjoys participating in intramural soccer, teaching herself to play the guitar, and being outdoors.

1.4.2 Ryan Bradley

Ryan Bradley is an electrical and computer engineering student from Clarkston, Michigan. Ryan spent the last two summers interning at an American Semiconductor Company called Allegro Microsystems. He plans to work at Allegro full time upon having graduated. During his time at Calvin, Ryan studied abroad in Germany at the Technical University of Berlin. He played on the Calvin Varsity Hockey team all four of his years where he was a captain during his Senior Year. Ryan also served as an officer for Calvin College's IEEE student chapter. IEEE is the world's largest technical professional organization dedicated to advancing technology.

1.4.3 Austin Roden

Austin Roden was a senior electrical and computer engineering student with a minor in business and an international designation. During the summers of 2016 and 2017, he worked with NiSource, a gas and electric distribution utility, as an instrumentation and controls intern. This experience helped the team troubleshoot problems in the control loop of the P.A.L.'s electrical system and the overall management of the project. In addition, Austin's unique interest in business and his experience with Knight Investment Management helped lead the team's finances and manage their budget. Outside of work and academics, Austin has been involved in helping lead the youth group at Berkeley Church and playing varsity lacrosse for Calvin. The combination of experiences helped him lead the team and effectively design and troubleshoot the control system within P.A.L.

1.4.4 Laura Van Winkle

Laura is a mechanical engineering major at Calvin College from St. Joseph MI. During the summer of 2016 she interned at SeaLandAire Technologies in Jackson, MI and in the summer of 2017 at Gentex Corporation in Zeeland, MI. During her internship at SeaLandAire she worked as a mechanical engineering intern, helping to build prototypes for their Riverine contract, a small remote-controlled jet boat, gaining some exposure to SOLIDWORKS and boat design. At Gentex she worked as a quality engineering intern, primary focusing on customer quality. At Calvin Laura is the student manager at the climbing wall on campus, managing risk assessment training, quality checking all the gear associated with the climbing wall and all the scheduling. She also led week long backpacking, kayaking and climbing trips in the wilderness, for incoming students. Laura will pull from her experience with small jet boats to assist in the design of P.A.L and will use her experience in scheduling and leadership to plan with the team to insure the project's completion.

2. PROJECT MANAGEMENT

The team was divided into two distinct groups with the same concentrations partnered together. These two groups were electrical and mechanical. Upon design completion, both groups collaborated closely to create one unified system. The team's advisor was Professor Nelson, who served as the team's timeline enforcer. SeaLandAire Technologies located in Jackson, MI, was a resource for any questions that the team had during their prototyping process. Austin Roden served as the team's website developer, keeping the site up to date as well as aesthetically pleasing.

2.1 Mechanical Breakdown

The team broke down P.A.L.'s mechanical design into four main categories: jet propulsion, steering, waterproofing, weight distribution, and lifeboat structure. The mechanical team members divided tasks and allocated a lead to each with the intentions of working closely.

2.1.1 *Jet Propulsion System*

The jet propulsion system is a multifaceted problem; the size of the intake, pressure head, type of impeller, and thrust of the system being some of the bigger design decisions. These decisions will shape how fast the P.A.L will move through the water and the amount of power required from the motor. This task was led by Laura Van Winkle with design assistance from Stephen Ziegenfuss at SeaLandAire Technologies. While Megan Anders oversees modeling the system in SOLIDWORKS.

2.1.2 Steering System

The primary goal of the steering system is to allow the P.A.L to track long distance swimmers in any forward direction. Critical to the design is the ability to switch from autonomous to manual steering at the press of a button. The steering will be affected by water and wind conditions and that was factored into the final design after tests were done. One of the problems that the team dealt with was the collaboration between the electrical and mechanical divisions of the team. The mechanical task leader is Megan Anders.

2.1.3 Waterproofing and Weight Distribution

Because the P.A.L. contains many electrical components the team was very mindful of the holes that were cut for the jet unit, buttons, access hatch, antennas and bolt holes; making sure that there were no leaks. In addition to water proofing, the team designed the system to be at the desired water line, the entirety of the jet unit needed to be under water so that water would naturally be in the system. This involved adding weight, ensuring that the P.A.L. stayed level in the water and that no weight would shift while in use. This involved making a bottom compartment with partitions to secure bags of sand. Laura Van Winkle oversaw the water proofing and weight distribution.

2.1.4 Lifeboat Structure

The hull of the P.A.L is a re-purposed HydroKaddy with holes cut through the plastic to accommodate the jet propulsion unit, steering mechanisms, additional access hatch, and antennas. The goal is to have all electronics inside the boat with an external LCD screen tracking the user's swim distance. Megan Anders is heading the lifeboat structure.

2.2 Electrical Breakdown

The team broke down the P.A.L.'s electrical design into five main categories: wireless communication, motor control, central processing unit, GPS, and power. The two electrical team members divided the lead for each of these. Although the categories were separated, the two electrical team member worked together to complete each task. The task's leader job ensured the progress and completion of each task while the team shared the responsibility of each task's development.

2.2.1 Wireless Communication

The primary goal of wireless communication was to transmit a signal from the swimmer to the boat to indicate the swimmer's distance from two external receivers on the P.A.L. Using the information, calculations were made to indicate the trajectory that the boat followed in order to trail behind the swimmer. This innovation freed the swimmer from needing any tether or buoy strapped to them. Determining the best form of wireless communication and where to place the receivers was the foundation to the control loop of the autonomous mode. Austin Roden lead the wireless communication design.

2.2.2 Motor Control

Determining motor control was important for the P.A.L.'s manual mode and autonomous mode as it was the main driver of the boat. The thrust, the forward motion, and the yaw, the side-to-side motion, were the two directions that were controlled. Accurately controlling these motors was critical, especially with the small size of the boat. The primary goal was to have the P.A.L. follow water athlete by implementing the two motors. Ryan Bradley oversaw the motor control design.

2.2.3 Central Processing Unit

The central processing unit (CPU) was the "brains" of the system, bringing the whole control system together. The team aimed to use a microcontroller that precisely brought each component together with precision while connecting the motors and the wireless communication with minimum time delay. This was particularly important for the responsiveness of the boat as it autonomously followed the swimmer. Austin lead the CPU design.

2.2.4 Global Processing – GPS

The global positioning system (GPS) was used for tracking the distance of each swim. This allowed the swimmer to know how far he or she swam. The added feature provided great feedback for athletes in training. Ryan oversaw the GPS design.

2.2.5 Power

The power supply for the system was a key component in providing energy for the components. The batteries chosen for the power supply had to hold a charge for the length of the swim. With that in mind, the chosen components must consume minimal power while providing optimal performance. Austin lead the power design.

2.3 Method of Approach

Having the correct method of approach when managing their team was very important for the group throughout this project. In terms of the team's communication methods, they found it necessary to implement a weekly meeting in order to ensure that both the Mechanical and Electrical team members were on the same page. They set up a shared drive on Microsoft OneDrive for easy transfer of documents as well as texted each other frequently to arrange worktimes. Looking more into the design methodology and research methods, the team used many resources available to them. These include technical reports, videos, forums, patents, and research publications. The research for this project was very extensive due to the complicated nature of the project. Utilizing all of these assets played a large role in their design's success.

2.4 Schedule

To stay on schedule and meet big due dates the team made a work break down structure (WBS) in the fall and updated at the beginning of the second semester. The WBS can be seen in Appendix A. In addition to the WBS the team kept a monthly calendar at their work station and had weekly meetings each Monday and Friday to update one another on what needed to happen and what had happened. During the first semester, the team spent about 7 hours a week on the project equaling about 91 hours. During the second semester, the team spent on average 17 hours on the project, which equals 900 hours. Putting the first and second semester together the team spent almost 1000 hours into creating the P.A.L.

2.5 Budget

Calvin granted the team a budget to use for the design of the P.A.L. To ensure the team kept under the allotted sum, Austin updated the team on the remaining balance during the weekly meeting each Monday. This weekly update also acted as accountability to ensure the team was keeping on schedule. In addition, Austin kept track of the budget and made sure all the information was correct and current. If a dispute arose, the problem was addressed that day and typically resolved with a simple conversation.

3. SAFETY REQUIREMENTS AND SPECIFICATIONS

3.1 Safety Considerations and Operations

3.1.1 Environmental Conditions

The team acknowledges that weather presents a huge design variable. Adjusting to temperature, wind, and wave conditions could cause a critical failure situation for the P.A.L. putting the swimmer at risk. Therefore, the P.A.L. was designed for calmer conditions with a proof of concept that could then be altered for more serious conditions.

3.1.2 Jet Propulsion System

The jet propulsion unit is an impeller system that protects the user whether loading or unloading the P.A.L. from their vehicle or swimming near the P.A.L.'s vicinity in opens waters. The jet propulsion system is designed with the user's safety in mind.

3.1.3 Waterproofing

For the proper operation of the P.A.L., waterproofing was imperative. Waterproofing not only protects the components from shorting inside the autonomous lifeboat but also protects the user from electric shock.

3.1.4 Battery Life

Battery life was an important safety factor to consider in gaining the swimmer's trust. It is essential to have a battery that will be powerful enough to supply P.A.L. with enough energy to not only follow the swimmer out and back but also take the swimmer back to shore if needed. The swimmer's attachment battery life was also a concern for the system to operate correctly. The team aimed to provide a battery life around two hours.

3.1.5 Size and Weight

It was important to keep the P.A.L. as light weight and small as possible. The goal is for a single person to safely carry and launch the P.A.L., continuing to give them independence. The size is user friendly and protects the components while not being too bulky for the swimmer to carry.

3.1.6 Wireless Communication – Safe Failure

Parameters within wireless communication are important for keeping the swimmer safe, and therefore the team carefully designed a fail-safe mode. It is a priority to keep the swimmer within a seven-foot radius, which means that when the swimmer is less than seven feet, the P.A.L. will idle until it picks up a signal that the user is seven feet away again. This reconnection dead band prevents the P.A.L. from moving away from the swimmer. If any signal is ever lost between the user and the P.A.L., the system will idle while trying to reconnect to the swimmer. This fail-safe wireless communication protects the swimmer not only while boarding the P.A.L., but also prevents the lifeboat from being too close to the swimmer.

3.1.7 Final Requirements

To complete this project there were documentation and implementation requirements.

- Project Proposal and Feasibility Study
- Final Report
- Functional Prototype

- Design Documentation
- Team Website

3.2 Aesthetics

3.2.1 Lifeboat

The aesthetics of the lifeboat are designed to ensure safety of water athletes. It can be difficult to see a swimmer in the water, therefore, the P.A.L. is an indicator for other water crafts to be aware and conscious of their surroundings. Caring for the water athlete is the main priority of Team 14. The design of this product is also to create a device that looks professional with many features to create intriguing product.

3.2.2 Swimmers Device

The Xbee device that wirelessly connects a water athlete to the P.A.L is clipped on to the back of a swimmer's goggles. This device needs to be small, lightweight, and simplistic. The purpose of this device is to keep the P.A.L. tracking the swimmer, so it needed to be a small lightweight device to produce little to no drag.

4. DESIGN ALTERNATIVES AND SELECTION

4.1 Drive System

4.1.1 Design Research

Team 14 conducted research to determine how the *P.A.L.* would move through the water. Research was done on the drive system for an impeller and propeller drive system. The amount of thrust needed for the drive system was determined to be a minimum of 2 lbs. of thrust for every 100 lbs. of vessel weight. The *P.A.L.'s* maximum specified weight limit is 300 lbs. Thus, the system needs a minimum of 6 lbs. of thrust.

Four types of DC motors were researched to drive the system: Permanent Magnet Motors, Series Motors, Shunt Motor, and Compound Motors. Permanent Magnet Motors have excellent starting torque capabilities and good speed regulation. They have a little amount of load they can drive and a limited rated torque to prevent demagnetizations. Through industrial experience a permanent magnet motor is used more frequently than other types. Series motors require a large amount of starting torque and speed control with little to no load, causing damage to the motor. Shunt motors have good speed regulation, but produce high torque startup. Lastly, Compound Motors have efficient starting torque and speed regulation, but can have series field control problems.

4.1.2 Design Alternatives

The propeller drive system uses external rotational motion to convert power into thrust creating a propulsive force that causes the watercraft to move forward. In the conversion from power to thrust, the propeller converts rotational motion into linear motion. A propeller system is an external system that has an open design that would require a cage or housing unit for the safety of the water athlete. Implementing a housing unit can cause more drag, therefore requiring more thrust.

An impeller drive system is a jet propulsion system that is comparable to a centrifugal pump, in which internal rotational motion converts power into thrust. This conversion occurs by using the rotational motion to suck in water, increasing its pressure and pushing it out the back to propel the watercraft forward, utilizing Newton's Third Law.

Team 14 considered the resources at Calvin College Engineering Department for motor selection. From previous years, a Minn Kota Endura C2 40 trolling motor and a Papst-Motoren 902 7557 011 motor were used for a drive system. Each motor provides a thrust of 55 lbs.

Team 14 has decided to use a jet propulsion system with aa Minn Kota Endura C2 40 55lb Thrust Motor trolling motor.

Figure 1: Minn Kota Endura C2 40

A jet propulsion system is safer for a water athlete, eliminating potential risk of injury from a spinning propeller. The Minn Kota Endura C2 40 provides Team 14 with the opportunity to design and implement a housing unit for the drive system while using Calvin's resources. This will be a benefit financially.

4.2 Steering System

4.2.1 Design Research.

Team 14 wanted a mechanical steering system that can be controlled either autonomously or manually. Enabling the system to switch from autonomous to manual will allow the water athlete to steer themselves back to land if needed. To create oneness through the steering system, the mechanical structure will the same as between autonomous mode and manual mode. The nozzle or rudder will be manipulated by a joy stick, handle bars or physically by a tension cable system. Research was conducted for these possibilities.

4.2.2 *Design Alternatives*

A rudder is typical form of navigating through water when using a propulsion system. The rudder, a small slender board, acts as a guide under the boat to direct the watercraft in an intended direction. Additionally, a rudder would help the lifeboat to track in a straight line.

The nozzle is a narrow tube at the end of the jet propulsion system that allows the steering system to push the water in a specific direction to steer the watercraft. The nozzle, is only used on impeller drive systems. The nozzle does not help track the boat in a straight line.

In either steering system, rudder and nozzle, need to be controlled by a motor in autonomous mode. The options considered were a stepper motor or a servo motor. The stepper motor is a brushless DC electric motor that divides a full rotation into equal steps, this allows for the motor to hold a position with no feedback or a position sensor. A stepper motor must be selected for the appropriate torque and speed. The servo motor option is a rotary actuator that allows for precise control of location with a sensor for feedback. This option would allow for a motor with more torque. Both options would have cables attached to the rotating part of the motor.

The manual steering system can be controlled by a mechanical system or an electrical system. The mechanically controlled steering system could be implemented using a handlebar with a throttle and a gear train to navigate the watercraft. This system requires a gear train because of the inversely related relationship between the flow direction and the steering direction. Alternatively, the manual steering could be controlled by the nozzle or rudder pointing straight and physically directing the boat, much like a scuba diving scooter, this would not require a gear train.

Electronic controlled system, while in manual mode, would be implemented using a joystick that would send a signal to the stepper motor or the servo motor to move the nozzle or rudder. All of these options require a sort of throttle.

The steering system will use a nozzle to steer the boat, and in manual mode the nozzle will point straight and physically guided by the user holding the handles and a push button. In autonomous mode, the system will be controlled by a servo motor. This design does not give any stability or directional alignment assistance; therefore, a fin will be added to provide directional alignment and prevent side slipping.

4.3 Waterproofing

4.3.1 Design Research

Waterproofing the *P.A.L.* is vital to the development of a successful product. Research indicates that a material needs a high resistance to corrosion due to the contact with salt and freshwater. The inflow tube, lifeboat, and swimmer's contact device needs to be carefully analyzed to ensure a product that does not have leakage. Because of the multiple areas and facets in which waterproofing is necessary, no one option will create a solution for all of the purposes necessary.

4.3.2 Design Alternatives

Due to the different materials and functions used in the P.A.L. waterproofing does not have one set answer. The team researched different solutions for different areas of the vessel. The three major water proofing solutions were an epoxy resin, silicon sealant, gorilla glue, and hatches and locking mechanisms.

Epoxy resin is a thermoset polymer material proven to yield a very high tensile strength. This material is waterproof, durable, and non-corrosive. Epoxy resin has high strength and a waterproofing adhesive.

Silicon Sealant is easy, inexpensive, and works well to fill in small gaps. Applied as a liquid, therefore, the material will morph and mold into small crevasses and cracks. The effectiveness of the sealant decreases dramatically with larger voids.

Latches and locking mechanisms are an alternative to options to using a permanent sealant such as carbon fiber and silicon sealant. Latches provide accessibility into the compartments that need regular maintenance and battery power supply. Latches and locking mechanisms need regular maintenance to insure sealing is watertight.

Waterproofing of the *P.A.L.* is multi-faceted and therefore, each of these alternatives was used for a different purpose. Epoxy resin was used to patch holes and the jet propulsion system because of its corrosion resistant properties which can withstand being immersed in water. hatches and locking mechanisms was used to seal off the lifeboat compartment with the circuity system for easy access to the power supply for charging and maintenance.

4.4 Lifeboat Structure

4.4.1 Design Research

The lifeboat structure is the foundation of the *P.A.L.,* the research dealt with the weight of the boat, capacity of the boat, and stability. For stabilization of the boat, the team used one-foot waves as one of their parameters.

4.4.2 Design Alternatives

A creek boat kayak was the fundamental structural design of the P.A.L. The creek boat chosen will need to be able to be launched by a single person and be stable on the water before any of the team's technology is added. The original design function of the creek boat is to easily spin on water, allowing for the kayaker to maneuver swift white water. In order for the P.A.L. to perform in the teams intended purpose, a center board like fin will be implemented on the bottom of the hull. In addition to creating a larger turning radius the fin will help with stability and tracking straight through the water. Sun Dolphin Arbua, Figure 2 and Figure 3.

Figure 2: Sun Dolphin Aruba 8ft Kayak

Figure 3: Pyranha Jed Kayak

Much like a creek boat a Hydro Kaddy is made from a similar material as the Pyranha Jed Kayak but is made to be pulled along-side any non-motored water craft. In the specifications for the Hydro Kaddy it lists its max weight to be 50 lbs, an original weight of 11 lbs, and has roughly 35 liters of space inside. As purchased the Hydro Kaddy has one access hatch 11 inches in diameter, a deck bungee, and a drain plug located on the top back portion of the boat, this can be seen in Figure 4: Hydro Kaddy.

Figure 4: Hydro Kaddy

All of the previously specified options would require help the water craft to track straight through the water. There are many options that the team can pursue; they can model like a sail boat with a large rectangular center located on the bottom of the boat. Another option is modeling the system after a sea kayak with a skeg. Or the system could be modeled like a surf board with the fins being varying triangluar shapes, sizes and amount.

The alternative option to the proposed creek boats and kaddy is to design and build the base floatation device. This would give Team 14 the opportunity to be innovative and custom with the floatation design and size. The obstacles that occurs with creating the watercraft is waterproofing and floatation.

Team 14 decided to use the Hydro Kaddy as the lifeboat structure, due to its small size and water tightness. To keep the system tracking through the water straight the team will add three fins to the bottom in the thruster position.

4.5 Wireless Communication

4.5.1 Design Research

Wireless communication is the standard technology in the industry for autonomous control. The purpose of the wireless communication was for the P.A.L. to be able to follow the swimmer. The autonomous system had to be a two-part system, the master being on the P.A.L. and the slave on the swimmer. Preliminary research led the team to investigate Bluetooth, GPS, Zigbee, and Ultrasonic.

4.5.2 Design Alternatives

Each possible method of wireless communication had to be investigated. A table was created to compare Bluetooth, GPS, Zigbee, and Ultrasonic for connectivity over water, accuracy within plus or minus a foot, a minimum range of 25 feet, conveniently sized, and consumed little battery. The comparison table for these devices can be seen in

Table 1.

Table 1: Wireless Communication Comparisons

Criteria	Bluetooth	GPS	Zigbee	Ultrasonic
Connection Over Water	Yes	Yes	Yes	Yes
Accuracy ± 1’	No- RSSI	No	No-RSSI	Yes
Range	10’-300’	Positioning	300’	15’
Size	Embedded Chip	Embedded Chip	Module Needed	Hardware Needed
Pairing	Required	Satellites Needed	Required	Not Needed
Current Draw	15 mA	40 mA	50 mA	15 mA

Bluetooth, a commonly used wireless system, operates on the 2.4 GHz spectrum which allows for a rapid transfer of data but will not cause any interference with water at shallow depths. The approximate distance for Bluetooth varies based on class. Class 3 transmits less than 10 meters with a transmit power of 1mW, Class 2 transmits at about 10 meters with a transmit power of 2.5 mW and Class 1 transmits up to 100 meters with a transmit power of 100 mW. Antennas for the transmitter and receiver must be placed in the same horizontal or vertical plane. Otherwise, polarization mismatch occurs, causing a loss of about 3 dB. In addition, Bluetooth is based on signal strength rather than a positional reading.

On the other hand, GPS, is based on position where it uses satellites to locate the GPS device. The range and the size of the chips are small and convenient, however the GPS chips available at the time were only accurate to within 2.5 meters. In the near future, chips are to be accurate within a few millimeters. GPS appeared to be the best option if the accuracy was within a foot.

Zigbee is a radio communication protocal that uses the module XBee to send and receive data packages. This communication network is great up to a range of 300 feet, however, it uses signal strength for the basis of positioning. Also, the current draw compared to the other devices is relatively high, which could call for large battery packs.

Ultrasonic implements sonar to calculate the distance of an object. By sending sound waves from the transmitter, the sound waves bounce off an object and return to the ultrasonic receiver. To calculate the distance of an object, the processor uses the time it took for the sound waves to be transmitted and then received. These ultrasonic devices are great for position reading and consuming low amount of power. The issue with ultrasonic is that its range is limited to fifteen feet.

In the fall the team decided to pursue Bluetooth which allowed for fast data transfer while maximizing the control and responsiveness of the P.A.L. However, after further investigating and trying to implement a way for Bluetooth to work, the team was unsuccessful. The team decided to use an alternative design that utilizes the range and communication of XBee while taking advantage of ultrasonic’s accuracy. This method required the XBee master to be on the P.A.L. and the XBee slave to be on the swimmer. The ultrasonic sensors were rigged to only have receivers on the boat and a single transmitter on the swimmer. This implementation increased the range of the ultrasonic while maintaining its accuracy. The only concern with this method was the amount of current being drawn and the effect it would have on the battery selection. Together, the XBee and the ultrasonic consumed 65 mA.

4.6 Motor Controlling unit

4.6.1 Design Research

The research related to the motor controlling unit involved the Electrical team members working closely with the Mechanicals. The team began by researching the most efficient types of DC motors needed for this project. After selecting the desired motors, the Electrical team was then able to research and select the appropriate motor drivers needed for the system. A decision was made early on that Team 14 would use motor drivers supplied by Allegro Microsystems, an American semiconductor company. However, this decision was later changed due to the fact that Calvin doesn't supply surface mount components. This forced the team to research other viable options for their system.

4.6.2 Design Alternatives

When exploring alternatives for the motor controlling unit, the team only needed to worry about purchasing an appropriate driver for the system's trolling motor. They would be able to use their microprocessor to control the servo motor directly and therefore wouldn't need to purchase any external hardware for this component. For the trolling motor, the team decided to explore the various types of motor drivers that they could use. Because a trolling motor is a brushed motor, the team had the option of using either a half bridge or a full bridge. They also needed to select a driver that could withstand above 30 Amps of current due to their motor's maximum current draw. The main alternative that the team looked at for this driver was the IBT-2 H-bridge module based on two BTS7960 chips. This board had a very large heat sink and had current capabilities of up to 43 Amps. It also had bidirectional current, acting like a full bridge of sorts. The team was not able to find anything on the market comparable and therefore this stands as the only alternative that they considered. The team decided to use this component in their final design.

4.7 Central Processing Unit

4.7.1 Design Research

The research led the team to pursue a micro-controller for their central processing unit (CPU). Micro-controllers are mini computers that have the capability to execute read and write commands at basic levels. This allows code to be written to the micro-controller, and command the connected hardware components to execute the controller. Early on the team decided to use the Raspberry Pi3, however this decision was later changed.

4.7.2 Design Alternatives

When choosing between the micro-controllers, the team had to consider the following criteria: multiple general-purpose input/output (GPIO) pins, many pulse-width modulation (PWM) pins, and a minimum of two communication pins. In addition, the CPU had to be a processor that executed quickly and efficiently so that the P.A.L. could respond quickly.

Research of teams in the past and the team's knowledge of microcontrollers lead to use the Raspberry Pi brand. Within the Raspberry Pi brand itself, the microcontrollers varied based on the desired needs and specifications. The two considerations were the Raspberry Pi2 and the Raspberry Pi3. Each of these microcontrollers use the same Broadcom BCM2837 SoC with a 1.2 GHz 64-bit quad-core ARM Cortex-A53 processor. They also shared the same on-board RAM with 1 GB and the same number of GPIOs with 40. Side-by-side the two were almost identical until it came to the wireless connectivity and the power ratings. Unlike the Pi3, the Raspberry Pi2 does not have onboard Wi-Fi or Bluetooth. In addition, the Pi3 allows for a power rating of 1.34A at 5V while the Pi2 allows for a power rating of 800mA. These comparisons and specifications can be seen in

Table 2. The final difference was $35 for the Pi3 versus $30 for the Pi2.

Table 2: Raspberry Pi Comparison

Details	Raspberry Pi 3	Raspberry Pi 2
SOC Type	Broadcom BCM2837	Broadcom BCM2837
Core Type	Cortex-A53 64-Bit	Cortex-A53 64-Bit
No. of Cores	4	4
CPU Clock	1.2 GHz	900 MHz
Bluetooth and Wifi	Yes- Onboard	No
RAM	1 GB	1 GB
GPIO	40	40
PWM	Two Channels	Two Channels
Operating Voltage	5V	5V
Price	$35.00	$30.00

http://socialcompare.com/en/comparison/raspberrypi-models-comparison

The team chose the Raspberry Pi 3 and used it in the testing during the fall. However, the team needed more PWM ports to connect the two motors and the four ultrasonics. This lead the team to pursue a search for a new micro-controller.

The alternative micro-controller needed to have at least 6 PWM pins (4 for the ultrasonics, 1 for the servo motor, and 1 for the trolling motor. While researching further, the team discovered the Arduino Mega 2560 whose specs can be seen in Table 3.

Table 3: Arduino Mega 2560 Specifications

Details	Arduino Mega 2560
Microcontroller	ATmega2560
CPU Clock	16 MHz
Bluetooth and Wifi	Modules
RAM	256 KB
GPIO	40
PWM	14
Operating Voltage	5V
Price	$38.00

The Arduino Mega 2560 provided exactly what the team needed. The microcontroller contained enough PWM pins for all the devices while also fulfilling all the other requirements. In addition, the Arduino Mega 2560 was donated from the engineering department, thus not costing the team. The team's final decision was to implement the Arduino Mega 2560 as the microcontroller.

4.8 Global Positioning – GPS

4.8.1 Design Research

The research for the global positioning system (GPS) involved considering different potential GPS receivers. First, the team researched different GPS chips that could provide them with sufficient accuracy while consuming minimal amounts of power. Second, the team researched different receiver antenna options. The team needed this antenna to be sufficient in picking up the desired signal strength of the GPS satellites. Additionally, the team had to do research regarding the software required for proper signal processing of the GPS receiver's raw data.

4.8.2 Design Alternatives

After thorough research, the Team decided to select an Adafruit breakout board built around a MTK3330 chipset as their primary GPS unit. This chip is a high-quality GPS module that can track up to 22 different satellites on 66 channels. It is an excellent high sensitivity receiver (-165 dB trafficking) containing a built-in antenna as well as a port for attaching an external antenna. After selecting this breakout board, the team had a few design alternatives regarding its implementation into the overall system. The first alternative was to purchase an external antenna that could be hooked up to the GPS chip. This would allow the receiver to be stronger and pick up a clearer satellite signal. On the down side however, this alternative would require additional hardware adding to the total cost of the project. The second alternative for the team was to use the chip's internal antenna to pick up GPS signals. This is not as strong as adding an external antenna, but it has the potential to be sufficient for the project. After weighing the alternatives, it was clear that the team wanted to choose the alternative involving an external GPS antenna. The team had been donated a powerful antenna from the company NiSource, and therefore they chose to use this in their design. This wouldn't cost the team any extra money to include this feature and it would also minimize risk of the internal GPS antenna not being strong enough for the Team's application.

4.9 Power

4.9.1 Design Research (Battery and Regulators)

The research involving the P.A.L.'s power source entailed multiple different things. First, the team needed to research different types of batteries for the P.A.L. They needed to consider the battery life of each of these as well as their weight and stability. Along with this, they also needed to research different voltage regulators to step down the primary power sources of the system.

4.9.2 Design Alternatives

Regarding the batteries, the team was set on using a rechargeable 12V battery as one of their power sources for the system. Because Calvin offered to provide a free rechargeable 12V battery for the team, they chose to take full advantage of this due to their limited budget. Regarding other power sources to the system, they had a number of different alternatives. They needed to power their servo motor at a voltage of 6.7V along with many of the electrical components at 5V and microcontroller at 6V. They looked into multiple different ways of implementing this.

The first alternative they had was to use batteries for all of the different voltage rails they needed (12V, 6.7V, and 5V). Upon research however, they found this option to be incredibly inefficient due to the number of batteries that would have to be replaced extremely often. Another option was to use a 12V battery along with two external buck boost voltage regulators for their system. However, this had problems as well since microcontrollers generally require a high stability and current draw. A voltage regulator therefore might not be the best option for providing its power. Therefore, their last design alternative was to use two power sources, a 12V automotive battery along with a 6V battery pack. This microcontroller has an onboard 5V regulator that the team would utilize. They would also purchase one additional extra voltage regulator to provide power to the Servo at a voltage of 6.7V.

5. PRODUCT DESIGN AND IMPLEMENTATION

5.1 System Overview

The P.A.L. is a small boat that consists of a Hydro Kaddy as its shell. It uses a jet propulsion unit to have the ability to move through the water along with a cable tensioning system to steer itself. The steering system is a two-part unit: autonomous and manual. For the autonomous mode, the steering nozzle is controlled by a wireless communication system. For the manual mode however, the swimmer is given the ability to control the direction of the boat by using external handles. The transition between autonomous and manual mode is done through a mechanical switch that sits within reach of the swimmer. In terms of the boat's weight distribution, all of the electrical components are placed towards the front of the boat in a waterproof housing. This allows for easy access to the electronics when testing. Along with this, an external LCD screen and two switches are mounted onto the frame of the boat. The Solidworks model for the P.A.L. can be displayed in Figure 5.

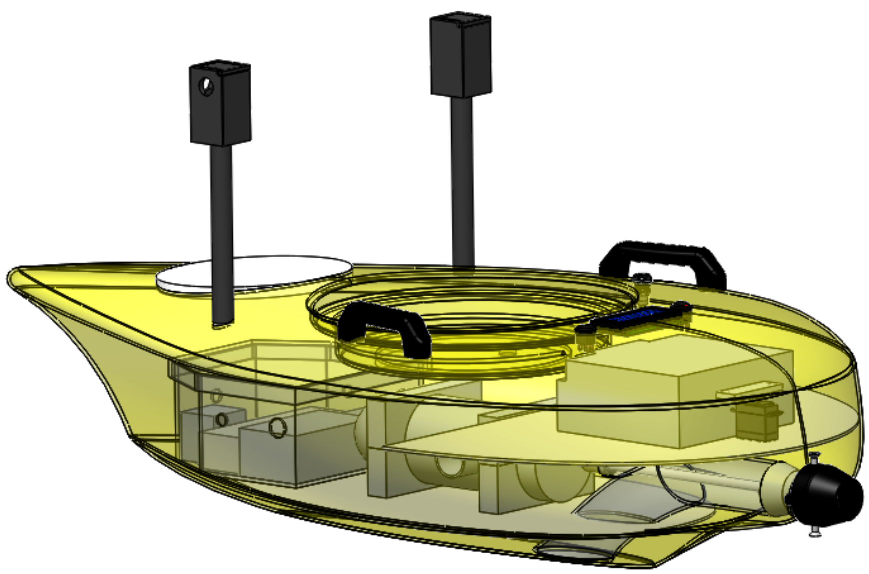


Figure 5: The P.A.L. Solidworks Model

5.2 Modeling-Mechanical

5.2.1 Jet Propulsion System

Modeled in Solidworks, the jet propulsion system fits into the shell of the Hydro Kaddy. Flow simulations were conducted by the team in order to determine the forces acting on the system, areas of concern for cavitation, and the non-uniformity of water, shape of the intake, shaft intrusion, and impeller shape. In creating the P.A.L., the housing of the jet propulsion unit was formed out of fiber glass. The fiber glass was molded around a foam form, which was developed using the CNC machine.

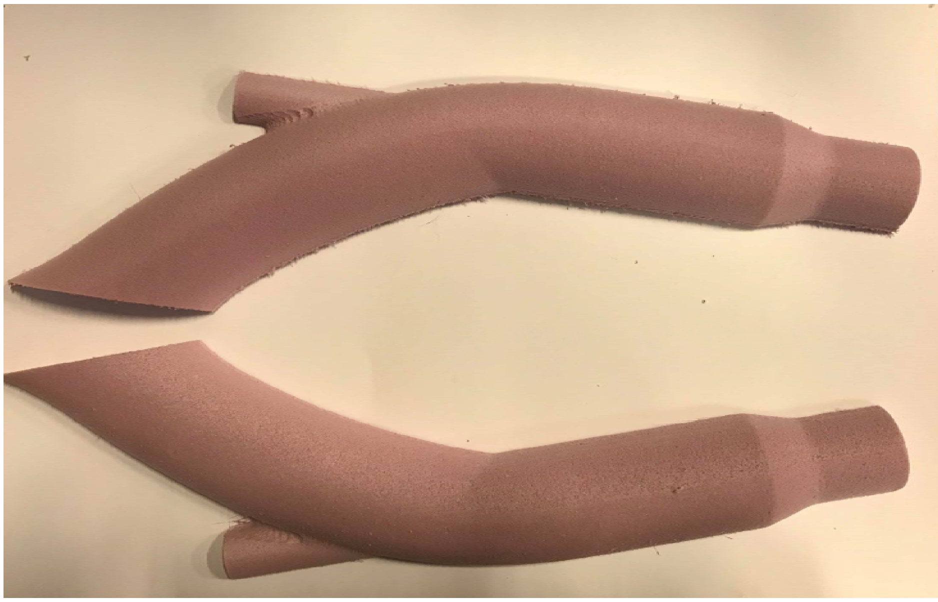


Figure 6: CNC'd Intake Housing

To determine the size that the intake needed to be along with the forces acting on the intake, a mathematical model of the boat was created. The mathematical model of the system was determined using four velocities: V_{ship}, V_{in}, V_{pump}, and V_{out}. V_{ship} stands for the velocity of the vessel. V_{in} stands for the velocity at the intake, which was found as mass-averaged over the cross-sectional shape of the stream tube as defined by the intake. V_{pump} stands for the velocity of the fluid going through the pump, also known as the impeller, calculated by the flow rate. Lastly, V_{out} stands for the velocity coming out of the nozzle. These critical velocities are related as seen in Equation 1, Equation 2, and Equation 3.

Wake Fraction $$\boldsymbol{w = 1 - \frac{V_{in}}{V_{ship}}}$$

Equation 1

Inlet Velocity Ratio $$\boldsymbol{IVR = \frac{V_{ship}}{V_{pump}}}$$

Equation 2

Jet Velocity Ratio $$\boldsymbol{\mu = \frac{V_{in}}{V_{out}}}$$

Equation 3

The wake fraction, w, represents the ratio between the free stream velocity and the actual velocity into the unit, also referred to as the velocity deficit. The jet velocity ratio is calculated through the analysis of the thrust of the motor, V_{in} and the cross-sectional area of the nozzle. The wake faction is normally found to be between 0.10 and 0.14.

The wave fraction is a complex calculation based around the cross-sectional shape of the stream tube, which is not known until the entirety of the calculation is done. After talking to Stephen Ziegenfuss who has design similarly sized jet boats for the past five years, the wake fraction was determined to be 0.12.

Inlet Velocity Ratio, IVR, is a representative number of the flow conditions into the water jet. When a vessel is traveling at low speeds the IVR will be below one. At these low speeds, there is a potential issue of cavitation due to the acceleration of the water at the inlet of the intake. This flow phenomena can be seen in Figure 7; and because the P.A.L. will be traveling at low speeds this was an issue that was carefully monitored.

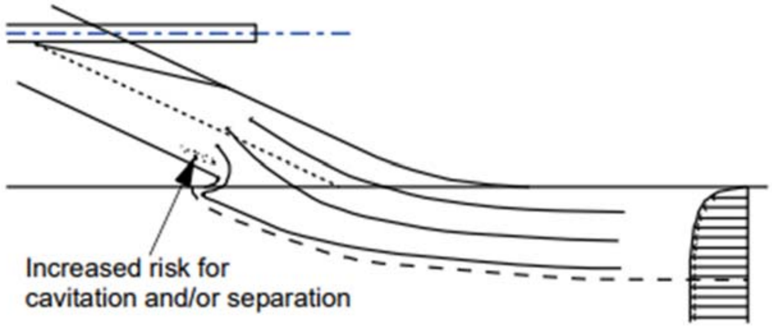


Figure 7. Inflow Cavitation Phenomena

When designing the inlet, it needed to accommodate an IVR from 0 to the desired velocity because the vessel starts at a zero velocity and builds up to the desired speed. For that reason, the team decided on an IVR of 0.8 for design purposes.

The jet velocity ratio, μ, is reliant on thrust, water density, inlet velocity, and the area of the nozzle. The thrust of the boat is dependent on the ship resistance, number of water jets, and the trust deduction factor. To determine the ship resistance the Taylor equation for finding a ship's friction factor is used as seen in Equation 4.

$$R_f = C_f \left(\frac{\rho}{2}\right) SA_{wetted} v_{Ship}^2$$

Equation 4

Where ρ is density of the water, SA_{wetted} is the wetted surface area and C_f is defined as follows in Equation 5.

$$C_f = 0.02058 \left(L \frac{v_{ship}}{\nu}\right)^{-1/8}$$

Equation 5

Where L is the length of the boat touching water and ν is the kinematic viscosity of the water and ambient temperature and pressure. In addition to the ship resistance, to calculate the thrust required of the system is the thrust deduction factor, *t*. Normally *t* is found to be 0.2 but Stephen suggest that the team use the value 0.15.

After calculating the thrust required of the vessel, predicted water density, inlet velocity and assigning a reasonable nozzle area the jet velocity was found allowing for the team to back solve for the $v_{out.}$ To find the flow rate through the unit, allowing the team to determine the size of the inlet, Equation 6 is used.

$$\mathbf{v_{out}} = \frac{\mathbf{Q}}{\frac{\pi}{4}\mathbf{D_{nozzle}^2}}$$

Equation 6

Q represents the flow rate through the system. Through this mathematical model, the propulsion unit was sized and functional. More testing needed to be done in Solidworks however, to truly account for the non-uniformity of the water flowing through the system and the potential cavitation at the inlet. To see the math calculations, see Appendix D.

There are four factors in the unit that add to the non-uniformity of water flow: the boundary layer velocities, the deceleration or acceleration into the unit, obstruction of flow from the shaft and the bend in the system. This will be looked at more fully in Solidworks simulations.

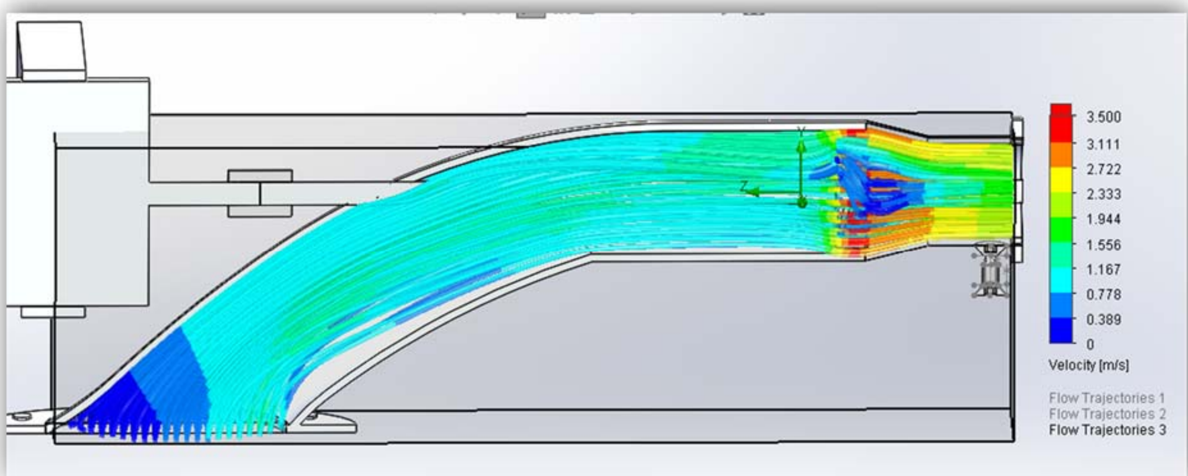


Figure 8: Solidworks Flow Simulation

After discussing the mechanics of the jet propulsion system, there is also an electrical unit for controlling the propulsion and thrust. The P.A.L. requires this controller so that it can follow a swimmer at a specified distance while in autonomous mode and be controlled by the swimmer in manual mode. For this system, the primary component was a DC brushed trolling motor. This was mounted into the frame of the boat and was the primary source of power consumption for the P.A.L. This motor draws its power from a 12V battery onto which it is attached. The way that the team designed to control the current to this trolling motor was by using a half-bridge MOSFET gate driver. This controller runs on a 5V power rail that is supplied from the Arduino and is directly controlled by software written on the team's microcontroller. This software was very extensive to account for both the autonomous and manual mode.

Considering the software, its architecture has two primary modes – manual and autonomous. The software keeps track of which state the P.A.L is in and uses this to drive the unit's propulsion. If the system is in autonomous mode, the primary inputs to the microcontroller are four ultrasonic receivers. The distances that these relay are plugged into an algorithm created in software to adjust the propulsion based on the swimmer distance. The software does this by adjusting the trolling motors speed after varying the signal to the Half-bridge gate driver. If the system is in manual mode, the primary input to the microcontroller is a push button that sits next to the handle straps that the swimmer grabs onto. When the button is pushed, the system runs at a constant speed pulling the swimmer behind. If at any point during autonomous mode the swimmer is within 7 feet of the boat, the microcontroller then cuts all current to the trolling motor, placing it in an off condition. If the swimmer breaks this 7-foot barrier, then the trolling motor receives a large amount of current to propel the boat forward.

5.2.2 Steering System

The steering system of the P.A.L. operates in two modes, manual and autonomous. To cut back on costs and add oneness to the system, the two modes of control use the same infrastructure. In manual mode, the steering is controlled by handle straps. The swimmer can turn the boat by shifting their weight while hanging on. In autonomous mode however, the P.A.L. is controlled by a microprocessor that provides logic to determine how the lifeboat will follow a swimmer. This microcontroller that the team selected was the Arduino Mega 2560 and one of its functions is to adjust the servo motor in proportion to the swimmers perceived position. Whether in manual mode or autonomous mode, the P.A.L.'s components work in tandem.

Each mode of operation controls the direction that the nozzle is pointed. The nozzle is pointed straight on when in manual mode and has a variable position when in autonomous mode. The nozzle has an inverse relationship to the direction that the boat moves Figure 9. This means that the water nozzle also moves in the opposite direction than that of the servo motor. The servo rotates a mechanical arm that uses two cables to direct the nozzle. This allows the system's microcontroller to accurately control the boat's direction.

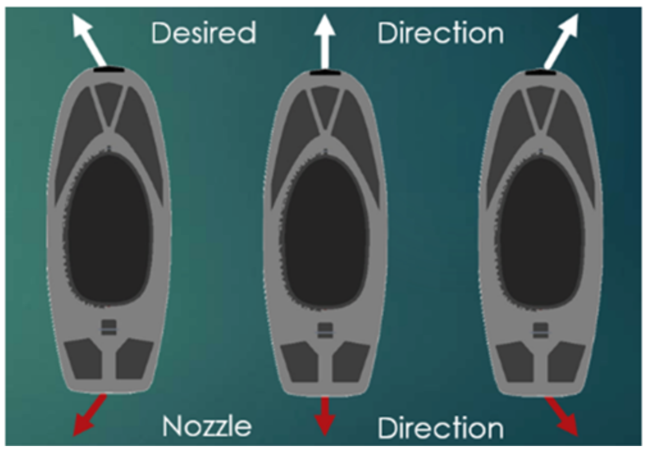


Figure 9: Inverse Relationship between Water Nozzle and Boat Direction

For the microprocessor to control the direction of the boat, the wireless communication plays an important function in successfully having the boat follow the swimmer. The P.A.L. contains four Ultrasonic receivers that sit above the boat and a XBEE module encased inside. Two of the ultrasonic receivers are mounted facing forward, while the other two are placed on the sides. The main XBEE module inside of the boat constantly sends out radio signals to a device clipped onto the back of a swimmer's goggles. When the radio signal is received, an ultrasonic transmitter on the swimmer's device transmits multiple ultrasonic waves back towards the boat that in turn are picked up by the sensors on the boat. The boat's microcontroller then calculates the position of the swimmer by recording the distances of the swimmer to each sensor. An extensive timing analysis done in the software allows for this functionality.

After having calculated the position of the swimmer, the angle of the servo motor is then calculated to control the position of the servo motor. The servo motor is connected to a voltage regulator that steps the 12V battery down to 6.7V. It is also connected to the system's microcontroller that varies the duty cycle of the signal sent to the servo allowing the boat to turn. After receiving this signal, the servo motor then has the functionality of mechanically turning the jet stream to the inverse direction that the boat must go.

5.2.3 Lifeboat Structure

The structure of the P.A.L. consists of a Hydro Kaddy as its shell.

Inside the Hydro Kaddy, the weight is distributed as follows: the lighter elements such as the electrical components are placed towards the front, the trolling motor is placed towards the middle, and the battery and jet propulsion unit are placed towards the back. To ensure that enough weight is in the boat, a weight test was conducted to find the amount of weight needed to ensure that the jet propulsion system sat completely submerged in the water. It can be seen in Appendix E, that the final result was 61.5 lbs. Therefore 16.5 lbs of sand were placed under the bottom shelf in the Hydro Kaddy. To guarantee that the weight would not shift around while moving, partitions were glued creating secured spaces in the hull. In addition to providing compartments, these partitions also provide additional water proofing.

The exterior of the boat was similar to the initial Hydro Kaddy form. The only alterations that the team made consisted of cutting holes into the hull. The team cut a hole for the intake, jet stream, steering wires, LCD screen, 2 switches and a throttle button. To avoid any water leakage from the intake and jet stream holes, an epoxy resin was used to seal any gaps between the intake and boat. To minimize the gaps, the holes were cut after strict measurements were taken. The steering cables used a very tight rubber seal, ensuring that no water was able to enter but still providing the necessary movement for the steering nozzle. To waterproof the cockpit of the boat, a silicon sealant was used. This ensured that any wave or splash hitting the P.A.L. would stay outside the unit.

Regarding the electrical hardware of the system, all the basic components were placed into a waterproof compartment within the boat. The CPU, the Arduino 6V battery pack, the buck boost voltage regulator, the motor controllers, the XBEE module, the circuit breaker, the relay, and the GPS unit were all placed within this compartment. Externally, the team wired out to two external antennas, sensors, motors, buttons, switches, and displays located around the boat. The four ultrasonic sensors were placed on the front and sides of the boat with a fixed distance apart. The GPS antenna on the other hand was placed on the front of the boat. Information from the boat's sensors are relayed through wires to the XBEE module and Arduino. After this information is received, distance information is tracked on an external LCD. This LCD was mounted onto the back of boat and the user is given the ability to view the distance of their swim. It also displays other items such as the temperature of the water and air. It is relatively a small size and is connected to the CPU directly.

5.3 Modeling – Electrical

The electrical model consists of the various components shown below. The breakdown for the hardware of the swimmer's headpiece can be seen below in Figure 10 and the breakdown for the boat in Figure 11. Along with this, the UML software flow diagram can be found in Figure 12.

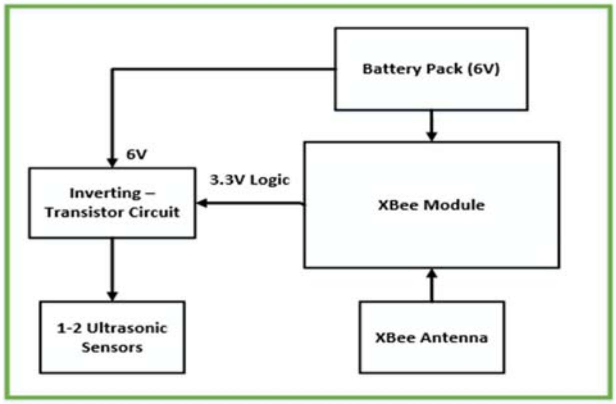


Figure 10: Electrical Breakdown - Block Diagram for Swimmer Gear

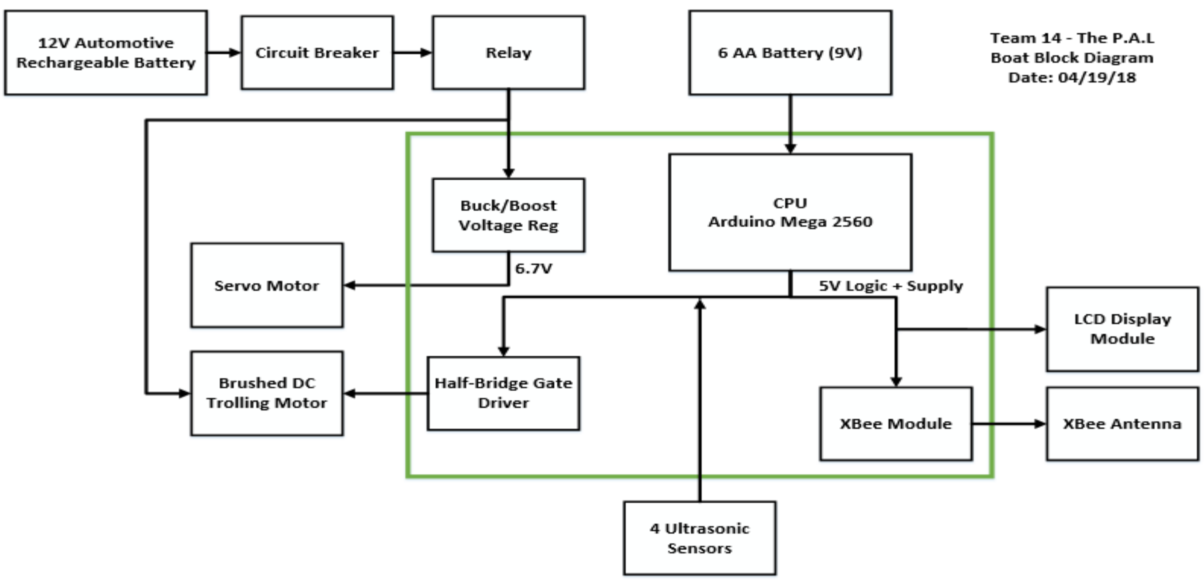


Figure 11: Electrical Breakdown - Block Diagram for Boat

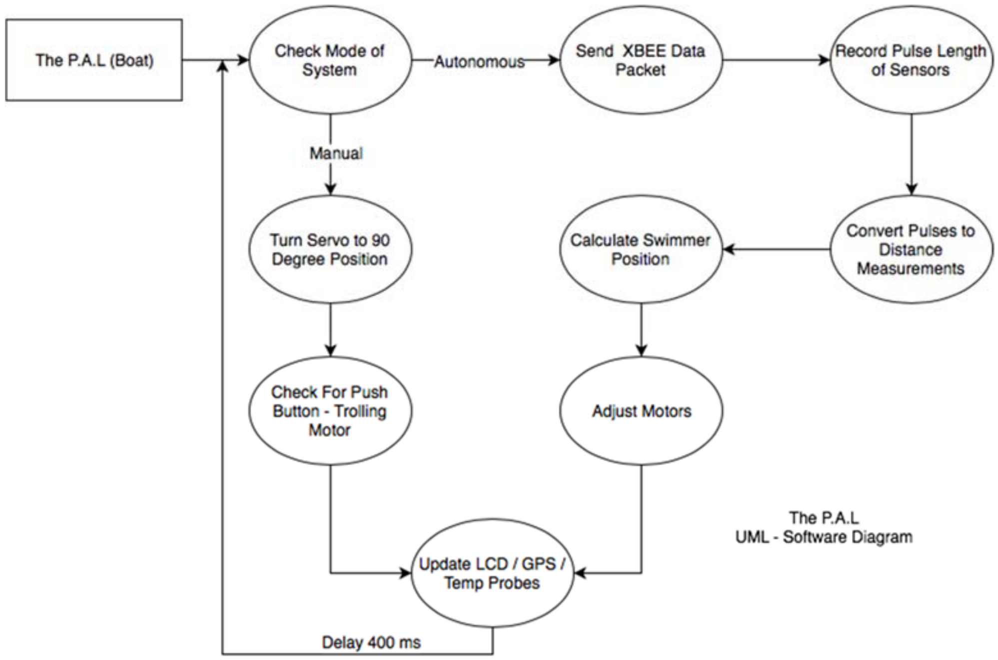


Figure 12: UML Software Diagram

5.4 Design Solution

The P.A.L. is an autonomous and manual small jet boat that takes the form of a modified Hydro Kaddy with the wireless capability of following an open water swimmer. The propulsion unit is made out of fiber glass to ensure that the pressure head can follow the swimmer traveling at 1.28 m/s while still fitting into the Hydro Kaddy. For the steering system, the steering nozzle is connected to a servo motor by a cable tensioning system. In autonomous mode, the boat has the ability to follow a swimmer autonomously using XBEE radio communication along with Ultrasonic waves. To do this, the boat periodically sends out a XBEE radio signal to a device worn by the swimmer. When the radio signal is received, an ultrasonic transmitter on the swimmer's device transmits multiple ultrasonic waves back towards the boat that in turn are picked up by the sensors on the boat. The boat's microcontroller then calculates the position of the swimmer and pushes the motors to respond properly. When in manual mode, the tired swimmer has the ability to steer the craft back to shore by shifting their weight while holding on to handle straps.

The exterior aesthetics of the boat are similar to that of the initial Hydro Kaddy. The only differences are that holes are cut for the jet unit and steering cables as well as the antennas and screen. The interior of the craft on the other hand, is quite different. A motor, battery and electrical components are enclosed inside the hull. Partitions are constructed to ensure that weight does not shift will the craft is moving and provide additional waterproofing. As an extra precaution, all the electronics are encased in a plastic waterproof box.

6. SYSTEM TESTING

6.1 Dry Testing

6.1.1 Communications

In terms of the electrical system, communication was definitely one of the most difficult and time-consuming components to test. To verify the P.A.L.'s system's stability and functionality in autonomous mode, several tests were conducted by the team. Before having implemented their wireless system, the team wrote many software programs to simulate a swimmers' trajectory in various shapes – see Figure 13. This testing was geared to test the responsiveness of the motors with communication from the CPU. As the simulated swimmer moves along the software trajectory, the servo motor correctly adjusts its angle to correlate with the swimmer's position. An example of this software can be found in Figure 12**.**

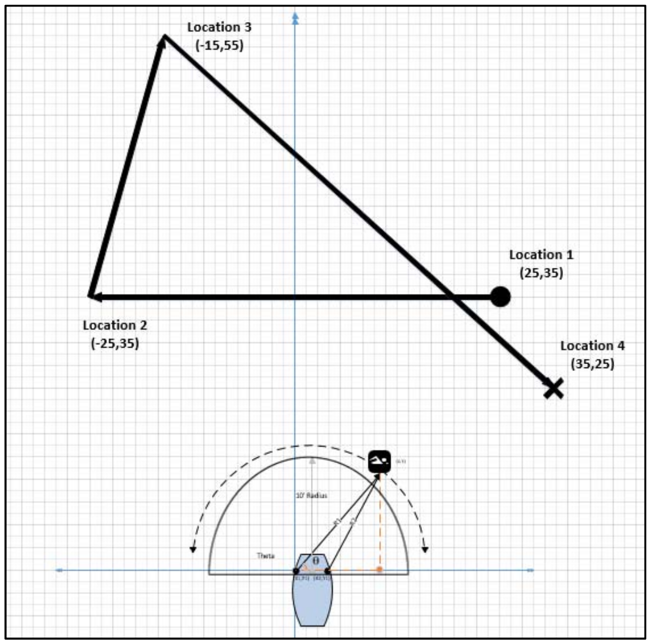


Figure 13: Swimmer's Simulated Trajectory

After having successfully completed this testing, the team's next focus was on the wireless portion of the communication system. They started this testing by establishing a secure connection between two XBEES, one set as the coordinator and the other as an end point. After this was proven to reliably send radio messages that the team needed, they then used the XBEE modules to trigger ultrasonic sensors and calculate a swimmer's position. This was the bulk of the Electrical work that the team underwent and was their most difficult task. Gathering reliable data from an ultrasonic sensor requires very precise timing algorithms especially when introducing a variable radio delay. They did large amounts of testing in this regard at various locations. Their first major test involving the ultrasonic sensors dealt with observing the range that their selected sensors had. This took place inside of the engineering building and can be seen in Figure 14. It consisted of separating the ultrasonic transmitter and receiver to a maximum distance where they were still able to hold a connection. Through testing, the team found this range to be approximately 30 feet. Another critical test that the team underwent can be seen in Figure 15. Here, a few members walked around the gymnasium to gather data on XBEE and sensor performance. Their goal was to observe the functionality of the system and troubleshoot errors they were having. After acquiring data, they plotted this information in Excel and constructed software algorithms to counteract any misreading's.

Figure 14:Team Testing the Range of the HCSR04 Ultrasonic Sensors

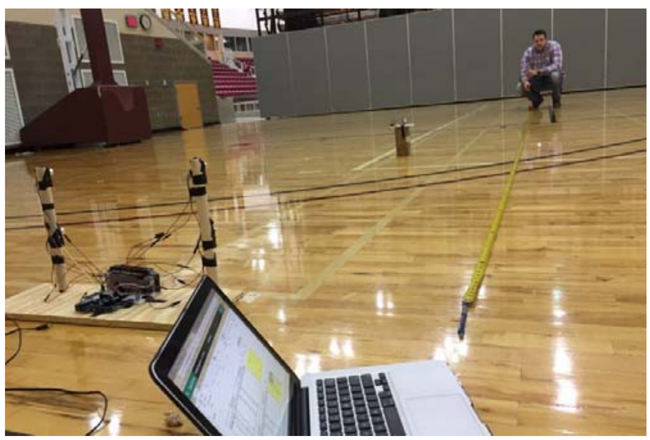


Figure 15: Team Gathering Data for Their Software Timing Algorithms

While doing all of this testing, the team was very attentive to the design of their hardware. They wanted to allow for a system with a maximum possible range and quickest response. Therefore, the team decided to mount all of their communication hardware on a prototype while testing. This would allow them to vary the positioning of their sensors in hope of optimizing their system. The prototype used in a majority of their testing can be seen below in Figure 16. It consists of ultrasonic sensors, XBEE modules, an Arduino, and an LCD.

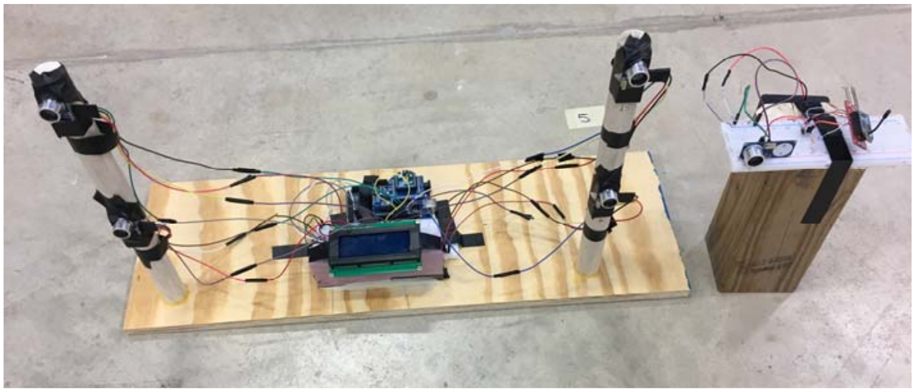


Figure 16: Hardware Used for Wireless Position Testing

6.1.2 Motor Control

Once the communications were tested and completed, the team made sure that each of the motors were accurately responding to the position of the swimmer. Before connecting the motors to the communications, each motor was tested independently. The drive-shaft of the trolling motor was first analyzed using a vibration analysis and the finite element analysis (FEA). This allowed the team to confirm that the designed shaft would not be damaged or cause damage from unwanted vibration caused by resonance frequency. The shaft and motor were tested together in a tub, which can be seen in Figure 17**.** The test proved once again that no unwanted vibration was occurring and that the system functioned as designed.

Figure 17: Shaft and Motor Testing

After the successful shaft and motor testing, the team integrated the communications. The dry-testing involved connecting the servo motor and the trolling motor with the intake system to the microcontroller. As the swimmer's piece was removed from the 7-foot safety zone, the trolling motor's response was tested for speeding up and slowing down based of the swimmer's piece relative to the system. The test proved that the motor responded appropriately, speeding up the further away the swimmer's piece was and slowing down the closer the swimmer's piece was.

Once the trolling motor testing was complete, the servo motor testing was done. The tested was conducted by starting on one side of the system, and slowing making a semicircle around to the other side. The test was to verify that the servo turned appropriately and that the nozzle would be appropriately controlled. While integrating the nozzle into the system, the team observed that the P.A.L. would not make the turn if the angle was proportional to the swimmer. Thus, the team adjusted turning radius to be 30 degrees towards the swimmer until the system sees that the swimmer is straight ahead. This 30-degree turn in each direction was implanted into the physical nozzle and to the servo motor.

Finally, the team constructed the whole system and dry tested the two motors in congruence. As the swimmer's piece was removed from the safety zone, the trolling motor turned on and the servo motor turned the nozzle to where it had to be. Together, the system worked as desired and was ready for water testing.

6.1.3 Weight Distribution

The team accounted for the added weight in the design process but there was extensive testing for the actual process of adding the weight. Originally the team conducted a weight test in the engineering building tub, recording how much weight was added, the location of the added weight, and how far the Hydro Kaddy was submerged. Figure 18 shows the original water line in red and the desired water line in blue.

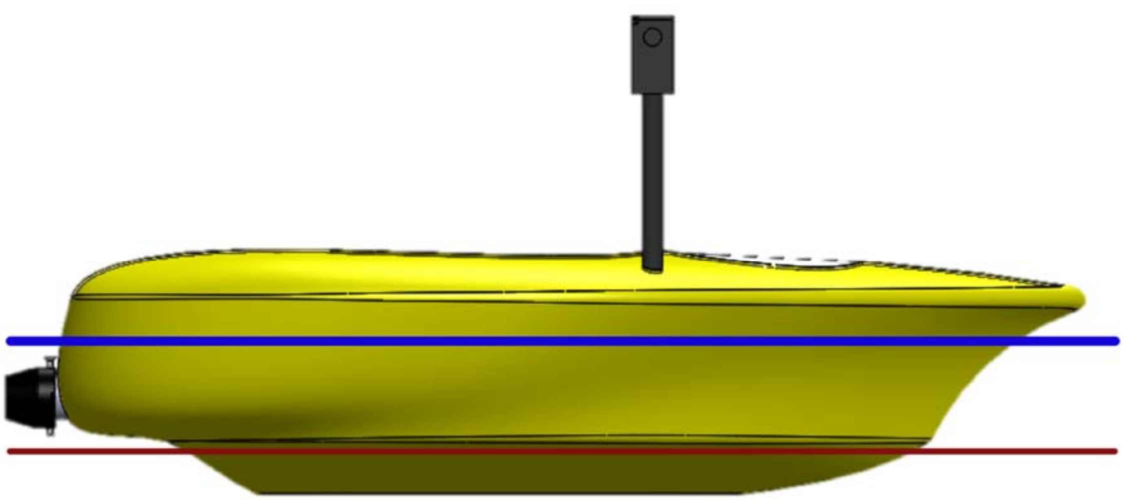


Figure 18: The P.A.L. Waterline Comparison

They went from 0lbs to 80lbs. From this they determined that the targeted weight for the P.A.L. would need to be 61lbs. To achieve the 61lbs the team used the required components and bags of sand. The total amount of sand under the lower shelf weighed in at 15.6lbs, a more in-depth analysis can be seen in Table 11.

6.1.4 Waterproofing

To make the P.A.L. water ready the team sealed 28 holes; five of those holes were located under the water and were sealed by an epoxy resin. To water proof the top of the P.A.L. the team used a combination of silicon adhesive and epoxy. All of these seals were tested before any of the electronic components were wired into the boat by spraying the exterior and then checking for water. The hardest area to seal was inside the boat, where the shaft went through a bearing into the intake. Because the shaft is constantly spinning while in use the seal needed to be very strong but also small as to allow for the inner part of the bearing to still spin. In the end the team used small dabs of gorilla glue.

6.2 Water Testing

6.2.1 Final Integration

Once the team had completed their dry testing with a fully integrated system, the team brought the P.A.L. to the pool for its final testing. In total, they tested for five days. The first day the team had anticipated seeing issues and were fully prepared to fix any bugs. What they found to be the trouble spots were the water flow through the steering nozzle and the speed of the trolling motor. To fix these issues the team created a duct tape water guard to prevent back flow. This allowed for maximum thrust and patched the software to have the trolling motor run at full speed.

On the second day, the team observed an improvement to the P.A.L.'s speed but the steering in autonomous mode malfunctioned. In the original software, the P.A.L. had six defined states that dictated the position of the servo motor depending on which ultrasonic receivers were picking up a signal. To fix this bug, two of the malfunctioning states were deleted. This left the P.A.L. with a slight dead spot, but an over-all improved system.

On the third day the team noticed that steering was still an issue for the P.A.L.. It had trouble tracking straight through the water and coming out of a turn. Having known from the beginning that the P.A.L. would need fins or a centerboard, they were prepared with ideas to the solution for this issue. They made a combination of fins, centerboards and skegs to test on the P.A.L. and decided to go with three fins that were three inches tall, in a thruster position. The thruster position is most common on surfboards, and consists of one center fin perfectly straight and two side fins at a seven-degree angle away from center.

On the fourth day, Team 14 found a lot of success and decided to test a fifth day to have their videographer come in and get footage for Senior Design Night.

7. BUSINESS PLAN

7.1 Market Research

The target market for this design is long distance swimmers and triathletes. The sport of Triathlon has seen a steady increase of participants from 1974, when the first triathlon occurred. The sport saw a dramatic increase in participants in 2012 and now each year is sees that same dramatic increase. With this leap in participation comes more people who need to swim train in open water, pushing their limits and maybe endangering their lives. The goal of P.A.L. is to be a security blanket for those athletes traveling through water.

7.2 Cost Estimate

7.2.1 Development

The team's goal going into the project was a proof of concept through the construction of a prototype. The team broke their activity down into five categories: Research, Design, Construction, Testing, and Other. During the fall semester, the research was conducted to ensure the feasibility of the P.A.L. Beginning in December and January, the team became to come up with a design and the details of the P.A.L. This was the most time-demanding activity and took until mid-March. Testing occurred throughout the project on individual parts and then at the end of the project as an integrated system. The other activities are things such as documentation, presentations, and reports. In total, the team spent 947 hours to research, design, construct, and to test the P.A.L. The breakdown can be seen in Table 4.

At the end of the project, the team found the prototype of the P.A.L. to be successful. However, with the proof-of-concept, the team determined that the current prototype would need much improvement to be a production-type of product.

Table 4: Activity and Time Allocation

Activity	Time Spent
Research	91
Design	550
Construction	108
Testing	130
Other	68
Total Time	947

During the prototyping of the P.A.L., Calvin provided the team with a starting balance of $900.00. Barb and Ben Reitema also donated $200.00, which we did not have to use. Together, the team was provided with enough money to build a prototype of the P.A.L. A shortened budget statement can be seen in Table 5 while the complete budget, broken down by part, can be seen in Appendix B.

Table 5: Budget Statement

	Debit	Credit	Balance
Starting Balance			$ 900.00
December	$97.81		
January	$286.42	$ 34.67	
February	$268.19		
March	131.39		
April	$73.31	$ 0.52	
May	$0.00		
Total Credit	$857.12		
Total Debit		$ 35.19	
Remaining Balance			$ 78.07

7.3 SWOT Analysis

7.3.1 Strengths

There is currently nothing like the P.A.L. on the market and once there is proof of concept it is a very updateable device. It would make it possible or the swimmer to go on the open water swims whenever it was convenient from them without needing to coordinate with a second person to provide safety. It also does not increase the drag on the swimmer.

7.3.2 Weaknesses

It will be costlier than the alternative of dragging in an inflated protection which is currently on the market for $35-50. Another weakness is that depending on duration of excursion the boat might be the limiting factor to length of swim due to battery charge. The P.A.L. is also heavier than alternative options.

7.3.3 Opportunities

Tri-athletes are willing to spend the extra money on the next cool new gear that could give them a leading edge on the competition. It is also a great way to keep track of how far and in what conditions the athlete swam. Allowing the consumer to set and meet goals. The P.A.L. will also provide peace of mind for the swimmer and their loved ones while allowing the athlete to push their body further in training.

7.3.4 Threats

A threat might be needing to register the watercraft as a boat. People need access to an open body of water to swim and it needs to be deep enough that they cannot stand up. The battery needs to be sustainable and secure from water damage to meet the team’s design norm of being a good steward. Along with that, the electronic components of the system can be compromised in water.

8. Conclusion

8.1 Potential Risks and Issues

Throughout the planning, designing, and developing of the P.A.L, there are multiple issues and risks that are bound to arise. For example, one of the biggest issues that Team 14 faced was waterproofing and making sure that all the electronics and battery stay dry. Another issue that arose involved making sure that the P.A.L was fail safe. The team needed to make sure that if there are any distortions or loss of signal from the swimmer, that the motor shut off and the P.A.L shuts down. A mechanical issue that the team will have to deal with, is making sure that the boat doesn't tip when the P.A.L is in manual mode and the swimmer is being taken back to shore. They also need to make sure that the boat has a proper distribution of weight so that it doesn't ever run the track of continuous circles. An electrical issue that the team will have to deal with is ensuring that the software is written correctly for real use. For example, weight distribution and turning tendencies will play a role in the way the software was implemented. This issue was resolved during the testing phase. Another issue, is that the water may distort signals travelling between the boat and the swimmer. This was a very difficult problem that the team will have to figure out, but through testing it was resolved.

8.2 Summary

In conclusion, the team feels confident that they created a successful project. Team 14 learned about learning to communicate between concentrations and the importance in understanding the difference in knowledge base and how to create a successful project through that. On the technical side, Team 14 learned how to implement a jet propulsion system and connect a wireless system. If implemented again, Team 14 would use a cup steering system rather than a nozzle, because it performs better at slower speeds. Another change, would be getting manufactured waterproof sensors, rather than waterproofing them.

9. ACKNOWLEDGEMENT

Stephen Ziegenfuss, from SeaLandAire Technologies, a mentor for the mechanical design of this system. The design of the jet unit would not have been possible without his extensive knowledge and experience of designing similar systems.

Ben and Barb Rietema, financial aid, their contribution allowed the team bought the P.A.L..

Bob DeKraker, purchased all of the materials for the team and providing the team with an extra computer for the semester and the tech during senior design night.

Phil Jaspers, provided the shop expertise and extra material and fasteners. Without Phil's base knowledge, the team would not have found success.

Ryan from Hydro Kaddy, provided all the CAD files of the Hydro Kaddy.

Ned Neilsen, the team's advisor.

Eric Medema, created the logo.

Devon Leorop, videographer.

10. CITATION

Bulten, Norbert Willem Herman. *Numerical Analysis of a Waterjet Propulsion System*. The Netherlands, Library Eindhoven University of Technology, 2006.

"Home and Recreational Safety." *Centers for Disease Control and Prevention*, 28 Apr. 2016, www.cdc.gov/homeandrecreationalsafety/water-safety/waterinjuries-factsheet.html.

11. APPENDIX

Appendix A: Work Breakdown Structure

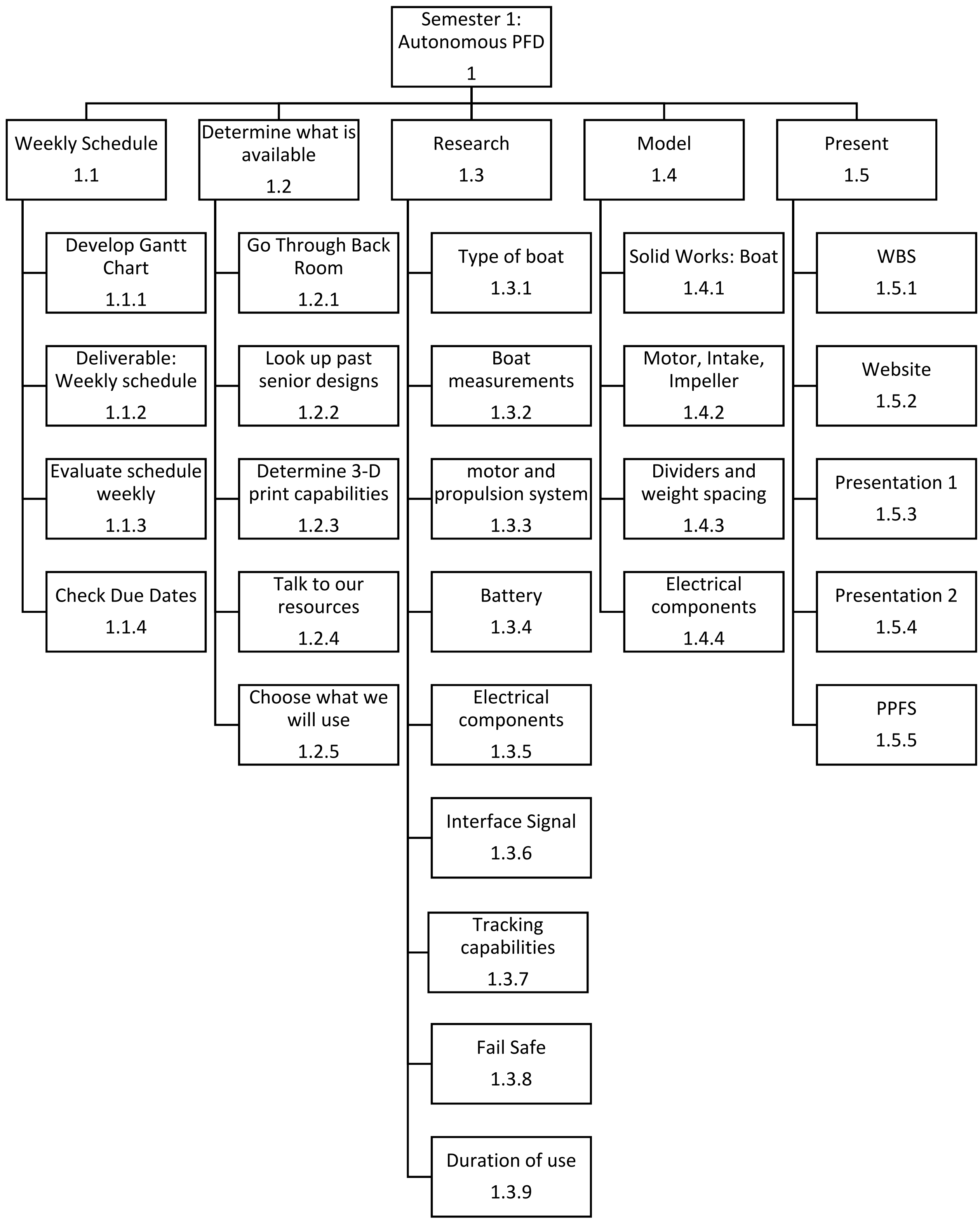
Appendix B: Budget

Appendix C: Python Servo Motor Code

Appendix D: Final P.A.L. Design Software

Appendix E: Mechanical Analysis of the Jet Unit

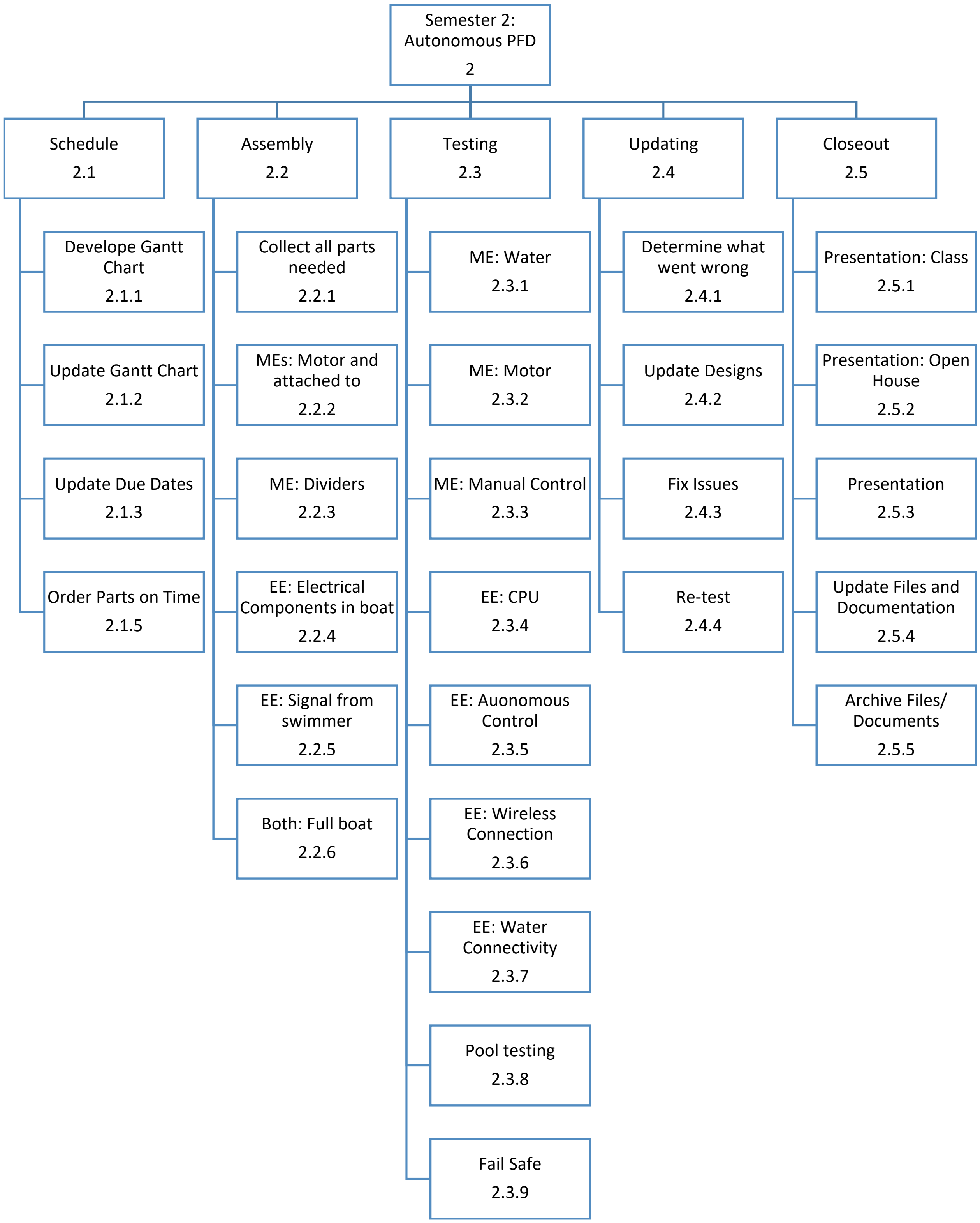
APPENDIX A: WORK BREAKDOWN STRUCTURE



1. Semester 1: Autonomous PFD
   1.1 Weekly Schedule
      1.1.1 Develop Gantt Chart
      1.1.2 Deliverable: Weekly Schedule
      1.1.3 Evaluate weekly schedule
      1.1.4 Check Due Dates
   1.2 Determine What is Available
      1.2.1 Go through Back Room
      1.2.2 Look up past senior designs
      1.2.3 Determine 3-D printer capabilities
      1.2.4 Talk to our Resources
      1.2.5 Choose What we will use
   1.3 Research
      1.3.1 Type of boat
      1.3.2 Boat measurements
      1.3.3 Motor and Propulsion System
      1.3.4 Battery
      1.3.5 Electrical Components
      1.3.6 Interface Signal
      1.3.7 Tracking Capabilities
      1.3.8 Fail Safe
      1.3.9 Duration of Use
   1.4 Model
      1.4.1 SOLIDWORKS: Boat
      1.4.2 SOLIDWORKS: Motor, Intake, Impeller
      1.4.3 Dividers and weight spacing
      1.4.4 Electrical components
   1.5 Present
      1.5.1 WBS
      1.5.2 Website
      1.5.3 Presentation 1
      1.5.4 Presentation 2
      1.5.5 PPFS

Level	WBS	Element Name	Definition	Time
1	1	Semester 1: Autonomous PFD	Work to have a complete plan of action for the autonomous PFD.	9/5-12/11
2	1.1	Weekly Schedule	Our weekly guide.	9/29 – 12/11
3	1.1.1	Develop a Gantt Chart	Overview of the semester with estimated times and due dates includes is a WBS.	9/29 – 10/9 2 hours
3	1.1.2	Deliverable: Weekly Schedule	Give Advisor a copy of Gantt Chart and WBS.	10/13
3	1.1.3	Evaluate Weekly Schedule	Check each week to see if we are on schedule.	All semester 1hour/week
3	1.1.4	Check Due Dates	Check the online course schedule.	15min/week
2	1.2	Determine What is Available	Using resources appropriately.	10/1 – 10/16
3	1.2.1	Go through the back room	Determine if there are any parts in the engineering building back room that could be used on the autonomous PFD.	10/2 1 hour
3	1.2.2	Look at past senior designs	Determine if and where previous groups got their materials.	10/1 – 10/16 Total: 3 hrs
3	1.2.3	Determine 3-D Printing Capabilities	Determine if we could 3D print any of the parts we need.	10/14–10/16 2hrs
3	1.2.4	Talk to our Resources	Figure out best way to approach the problem.	10/15-11/3 4hrs
3	1.2.5	Choose what we will use	Decide on the materials that we will use from the engineering building, what we will purchase and what we can make.	10/1 – 10/16 8hours
2	1.3	Research	The planning process.	10/3-11/3 80hours
3	1.3.1	Type of Boat	Determine what type of boat to use.	Throughout the month
3	1.3.2	Boat Measurements	Determine the specs of the boat.	Throughout the month
3	1.3.3	Motor and Propulsion System	Consider different systems and designs of impellers.	Throughout the month
3	1.3.4	Battery	Determine how big and how many.	Throughout the month
3	1.3.5	Electrical components	Determine what will be needed.	Throughout the month

3	1.3.6	Interface Signal	Determine what signal to use.	Throughout the month
3	1.3.7	Tracking Capabilities	Determine how will it move through the water following the swimmer.	Throughout the month
3	1.3.8	Fail Safe	Determine the process for the boat to fail and ensure that it will be safe.	Throughout the month
3	1.3.9	Duration of Use	Determine how long it will need to run.	Throughout the month
2	1.4	Model	Create a model for comprehension and future implementation.	10/10–12/11 65 hours
3	1.4.1	Solidworks: Boat	In Solidworks create a model of the boat.	10/10–10/19 3 hours
3	1.4.2	Solidworks: Motor, Intake, Impeller	In Solidworks create models of the motor, intake, and impeller. Then fit into the boat.	10/10-10/24 10 hours
3	1.4.3	Dividers and weight spacing	In Solidworks create dividers in the boat for different parts and ensure that the boat is balanced.	10/20-11/4 15 hours
3	1.4.4	Electrical components	Model the electrical signals and circuits in a program like LabVIEW.	10/10-11/15 20 hours
2	1.5	Present	The deliverables.	10/13-12/11
3	1.5.1	WBS	Present the WBS to our advisor	10/13 4hours
3	1.5.2	Website	Create a website (have a webmaster)	10/23-10/30 3hours
3	1.5.3	Presentation 1	Present to the Senior Design class	10/15-10/20 2hours
3	1.5.4	Presentation 2	Present to the Senior Design class	11/25-12/1 2hrs
3	1.5.5	PPFS	Deliver this to advisor.	11/1-12/11 8hrs


Semester 2: Autonomous PFD 2
Schedule 2.1
Develope Gantt Chart 2.1.1
Update Gantt Chart 2.1.2
Update Due Dates 2.1.3
Order Parts on Time 2.1.5
Assembly 2.2
Collect all parts needed 2.2.1
MEs: Motor and attached to 2.2.2
ME: Dividers 2.2.3
EE: Electrical Components in boat 2.2.4
EE: Signal from swimmer 2.2.5
Both: Full boat 2.2.6
Testing 2.3
ME: Water 2.3.1
ME: Motor 2.3.2
ME: Manual Control 2.3.3
EE: CPU 2.3.4
EE: Auonomous Control 2.3.5
EE: Wireless Connection 2.3.6
EE: Water Connectivity 2.3.7
Pool testing 2.3.8
Fail Safe 2.3.9
Updating 2.4
Determine what went wrong 2.4.1
Update Designs 2.4.2
Fix Issues 2.4.3
Re-test 2.4.4
Closeout 2.5
Presentation: Class 2.5.1
Presentation: Open House 2.5.2
Presentation 2.5.3
Update Files and Documentation 2.5.4
Archive Files/ Documents 2.5.5

2. Semester 2: Autonomous PFD
   2.1 Weekly Schedule
      2.1.1 Develop Gantt Chart
      2.1.2 Update Gantt Chart
      2.1.3 Update Due Dates
      2.1.4 Order Parts on time
   2.2 Assembly
      2.2.1 Collect all parts needed
      2.2.2 MEs: Motor and attached to motor
      2.2.3 ME: Dividers
      2.2.4 EE: Electrical Components in boat
      2.2.5 EE: Signal from swimmer
      2.2.6 Both: Full Boat
   2.3 Testing
      2.3.1 ME: Water
      2.3.2 ME: Motor
      2.3.3 ME: Manual Control
      2.3.4 EE:CPU
      2.3.5 EE: Autonomous control
      2.3.6 EE: Wireless Connection
      2.3.7 EE: Water Connectivity
      2.3.8 Pool Testing
      2.3.9 Fail Safe
   2.4 Updating
      2.4.1 Determine what went wrong
      2.4.2 Update Designs
      2.4.3 Fix Issues
      2.4.4 Re-test
   2.5 Closeout
      2.5.1 Presentation: Class
      2.5.2 Presentation: Open House
      2.5.3 Presentation
      2.5.4 Update Files and Documentation
      2.5.5 Archive Files/Documents

Level	WBS	Element Name	Definition	Time
1	2	Semester 2: Autonomous PFD	Work to have a complete autonomous PFD.	1/29-5/17
2	2.1	Weekly Schedule	Weekly guide.	1/29-5/17 6hours
3	2.1.1	Develop a Gantt Chart	Overview of the semester with estimated times and due dates	1/29-2/3 3hours
3	2.1.2	Update Gannt Chart	When things change need to update	1/29-5/17 15min/week
3	2.1.3	Update Due Dates	Check online due dates to stay on top of assignments	1/29-5/17 15min/week
3	2.1.4	Order Parts on time	Make sure that everything that we need to order is here on time	Hopeful in Interim. 8hours
2	2.2	Assembly	Putting everything together	1/29-3/1 40hours
3	2.2.1	Collect all parts needed	Gathering everything that is in the engineering building purchased	1/29-1/30 3hours
3	2.2.2	MEs: Motor and attached to motor	Securing the motor and placing the intake and shaft properly in line.	1/29-2/26 6hours
3	2.2.3	ME: Dividers	Placing dividers in the boat to separate sections and ensure the weight is evenly distributed.	1/29-2/26 4hours
3	2.2.4	EE: Electrical Components in boat	Circuit board, wires and receivers secured and functional in boat	1/29-2/26 6hours
3	2.2.5	EE: Signal from swimmer	Assemble and ensure that the signal from the person is working and being received by the boat.	1/29-2/26 4hours
3	2.2.6	Both: Full Boat	Making sure that the boat is properly assembled and safe for testing.	2/26-3/1 7hours
2	2.3	Testing	Putting the boat through tests to ensure that it will function when in real life.	3/1-4/30 110hours
3	2.3.1	ME: Water	Ensuring that the boat is indeed water proof.	April
3	2.3.2	ME: Motor	The motor, steering and weight is conducive for the boat to travel in the desired direction.	April
3	2.3.3	ME: Manual Control	If/When the swimmer needs to get to shore they can drive the boat with minimal effort.	April
3	2.3.4	EE:CPU	Software testing	March & April
3	2.3.5	EE: Autonomous control	Ensuring that the boat can follow a swimmer at the desired distance.	April

3	2.3.6	EE: Wireless Connection	The signal is broadcasted and not easily lost	March & April
3	2.3.7	EE: Water Connectivity	The boat has capabilities to track stats as the swimmer swims.	March
3	2.3.8	Pool Testing	Real life testing: have the boat follow a swimmer around the pool.	End of April
3	2.3.9	Fail Safe	If the swimmer stops and wants to use the boat as a PFD, or gets close to an object the boat will fail safely.	April
2	2.4	Updating	When the autonomous PFD does not function as expected documenting and fixing the problem.	3/15-4/30 20hours
3	2.4.1	Determine what went wrong	Why did it do what it did? Does this affect the result? How can it be fixed?	April
3	2.4.2	Update Designs	Go into Solidworks, PPFS and any other documentation and note the fix	March, April, & May
3	2.4.3	Fix Issues	Fix the Issue and ensure that everything else is still working.	April
3	2.4.4	Re-test	Go back to the test that it failed and see if the issue is fixed.	April
2	2.5	Closeout	Final Steps to the Senior Design Project	5/1 – 5/10
3	2.5.1	Presentation: Class	Present to the Senior Design Class (maybe multiple times)	End of April
3	2.5.2	Presentation: Open House	Present in the fieldhouse and hopefully be the cool project that everyone wants to know about.	5/5-5/5 2hours
3	2.5.3	Presentation	Present in a more formal way to people (probably just our parents)	5/5-5/5 1.5hours
3	2.5.4	Update Files and Documentation	Update any changes that we made and make sure that the report is professional and awesome.	5/7 – 5/10
3	2.5.5	Archive Files/Documents	Make sure that everything is turned in as it should be.	5/10

APPENDIX B: BUDGET

Table 6: Budget

Date	Team member	Description	Debit	Credit	Balance
11/2/2017	Austin Roden	Amazon Servo Motor- Austin Paid $17.99	$0.00		$900.00
12/11/2017	Austin Roden	Raspberry Pi 3 B with Heat sink & Power	$42.99		$857.01
12/11/2017	Austin Roden	Adafruit GPS Breakout - v3	$34.95		$822.06
12/11/2017	Austin Roden	Raspberry Pi Header and Cable	$7.88		$814.18
12/11/2017	Austin Roden	Circuit board and Jumpers	$11.99		$802.19
1/3/2018	Ryan Bradley	High Power - Half Bridge	$21.99		$780.20
1/3/2018	Ryan Bradley	Buck Voltage Regulator	$8.89		$771.31
1/5/2018	Ryan Bradley	Temperature Probes	$11.99		$759.32
1/5/2018	Ryan Bradley	20x4 LCD Display	$12.99		$746.33
1/18/2018	Laura Van Winkle	HyrdoKaddy	$209.98		$536.35
1/30/2018	Austin Roden	Raspberry Pi 3 B with Heat sink & Power Return		$34.67	$571.02
1/30/2018	Austin Roden	AA Batteries	$11.59		$559.43
1/31/2018	Austin Roden	AA Battery Holder	$8.99		$550.44
2/1/2018	Austin Roden	2 Zigbees	$53.90		$496.54
2/2/2018	Austin Roden	Zigbee Shield	$11.90		$484.64
2/3/2018	Austin Roden	Ultrasonic Sensors	$9.79		$474.85
2/6/2018	Laura Van Winkle	Impellers and posts	$34.11		$440.74
2/9/2018	Laura Van Winkle	shaft coupling & Ball bearing	$14.32		$426.42
2/9/2018	Ryan Bradley	Xbee to USB Breakout Board	$24.95		$401.47
2/15/2018	Laura Van Winkle	Insulation Foam	$30.48		$370.99
2/19/2018	Laura Van Winkle	Waterproofing, handles, cables, and hatch	$88.74		$282.25
3/1/2018	Laura Van Winkle	Epoxy Resin	$42.34		$239.91
3/13/2018	Austin Roden	3 V Coin Batteries (10 Pack)	$5.25		$234.66
3/13/2018	Austin Roden	Coin Batter (2 Pack)	$6.89		$227.77
3/13/2018	Austin Roden	Circuit Breaker	$12.99		$214.78
3/13/2018	Austin Roden	LED Switches (5 Pack)	$8.69		$206.09
3/13/2018	Austin Roden	LED Push Button	$9.99		$196.10
3/13/2018	Austin Roden	Ultrasonic Sensors (5 Pack)	$19.58		$176.52
3/16/2018	Laura Van Winkle	Bearings and Acetone	$25.66		$150.86
4/5/2018	Austin Roden	Gorilla Glue	$18.97		$131.89
4/5/2018	Austin Roden	Polyethylene Tubing	$8.44		$123.45
4/5/2018	Austin Roden	Hinges	$7.92		$116.05
4/6/2018	Ryan Bradley	12V 80Amp Relay	$12.99		$103.06
4/10/2018`	Megan Anders	3D print Material	$24.99		$78.07

			Debit	Credit	Balance
		Total Spent	$857.12		
		Amazon Discount		0.52	
		Raspberry Pi Return		$34.67	
		Total Spent			$821.93
		Budget		$900.00	
		Donation		$200.00	
		Spent	$821.93		
		Remaining Balance			$278.07

Table 7: Monthly Balance Breakdown

December			
	Debit	**Credit**	**Balance**
Starting			$ 900.00
Spent	$97.81		
Ending			$ 802.19

January			
	Debit	**Credit**	**Balance**
Starting			$ 802.19
Spent	$286.42		
Returns		$ 34.67	
Ending			$ 550.44

February			
	Debit	**Credit**	**Balance**
Starting			$ 550.44
Spent	$268.19		
Ending			$ 282.25

March			
	Debit	**Credit**	**Balance**
Starting			$ 282.25
Spent	$131.39		
Ending			$ 150.86

April			
	Debit	**Credit**	**Balance**
Starting			$ 150.86
Spent	$73.31		
Discounts		$ 0.52	
Ending			$ 78.07

May			
	Debit	**Credit**	**Balance**
Starting			$ 78.07
Spent	$0.00		
Ending			$ 78.07

APPENDIX C: PYTHON SERVO MOTOR CODE

This can be found at http://engr.calvinblogs.org/17-18/srdesign14.

Appendix D: FINAL P.A.L. DESIGN SOFTWARE

The software can be found at http://engr.calvinblogs.org/17-18/srdesign14

APPENDIX E: MECHANICAL ANALYSIS OF THE JET UNIT

Table 8: Input Assumptions

Description	Variable	Value	Units
Ship Speed	Vs	2.49	kts
		1.2818848	m/s
Ship Resistance	Rt	3.625	N
Number of Waterjets	Ne	1	
Taylor Wake Fraction	w	0.12	
Thrust Deduction Factor	t	0.15	
Nozzle Loss Coefficient	phi	0.01	
Inlet Loss Coefficient	epsilon	0.18	
Inlet Velocity Ratio (V1/V3)	IVR	0.80	
Pump Efficiency	eta-p	0.90	
Water Density (T=15C)	rho	1025.9	kg/m^3
Vapor Pressure (T=15C)	Pv	1646	Pa
Atmospheric Pressure	Patm	101353	Pa
Acceleration due to gravity	g	9.81	m/s^2

Table 9: Design Variables

	Variable	Values	Units	Notes
Nozzle Diameter	D6	0.050	m	
Nozzle Diameter/Impeller Diameter		0.7		
Impeller Diameter	D3	0.071	m	
Flow Coefficient	Qstar	0.85		
Thoma Cavitation Number	Sigma-1	0.5		(1% efficiency drop due to cavitation)

Table 10. Computed Values

	Variables	Values	Units
Inlet Velocity:	V1	1.128	m/s
Thrust:	T	4.26	N
Area Nozzle:	A6	0.00196	m^2
Quadratic Terms on JVR:			
a:		1	
b:		-1	
c:		-1.6638	
SOL-1:		1.883	
SOL-2:		-0.883	
JVR:	mu	0.531	
1/JVR		1.883	
Velocity at Nozzle	V6	2.12	m/s
Flow Rate:	Q	0.0042	m^3/s
mass flow rate	m_dot	4.279630128	kg/s
Velocity at Impeller Plane:	V3	1.41007328	m/s
Pump Head	H	0.179	m
Impeller Rotational Speed	n	13.5	rev/s
Impeller Rotational Speed	N	808	rpm
Shaft Power	Pshaft	8	watts
NPSH-required	NPSH-R	0.090	m
NPSH-available	NPSH-A	9.960	
Hull Efficiency:	Eta-h	0.966	
Jet Efficiency:	Eta-j	0.640	
Overall Efficiency:	OPC or (Eta-d)	0.556	
Area at the intake	A1	0.003698022	m^2

Table 11:Weight Testing

bag 1	**bag 2**	**bag 3**	**bag 4**	**bag 5**	**bag 6**	**bag 7**	**bag 8**	**bag 9**	**Bag 10**
1742.5 g	**1925.5 g**	**1666.4 g**	**1873.4 g**	**Not used**	**not used**	**999.1 g**	**1234.3 g**	**1430.2 g**	**521.2 g**
Bay 9	bay 3 and bay 4	Bay 10	Bay 10			Bay 5	bay 6	Bay 8	Under the intake