ASV TECH 797 REPORT

2018-2019

This is documentation of all work completed throughout the 2018-2019 academic year on the ASV project.

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Abstract

The Autonomous Surface Vehicle (ASV) team is completing the second year of a three-year project in partnership with a Naval base in Keyport, Washington. The ultimate goal of the project is autonomous ocean floor mapping, using ASV-UUV (Unmanned Underwater Vehicle) pairs. The team this year had the goals of improving ASV autonomy, improving the smaller platform for testing ASV autonomy, and deploying sensors for the UUV's autonomy.

The team designed and is assembling a motorized system for deploying acoustic sensors off of the ASV. The team has finalized the design and finished assembling the second iteration of the Testing Unmanned Performance Platform (TUPPS), the smaller ASV platform used in indoor testing. The team has investigated the buoyancy and stability of the ASV and has a method of analytically quantifying some of these properties of the ASV once the locations of all components have been finalized. Additionally, this buoyancy and stability analysis has been used to find better locations for components of the ASV, to avoid the ASV tipping over or sinking. A mathematical model of the system has been developed and is modifiable so as to suit the next team's needs. PID controls for speed and heading are currently being implemented into the model.

The team, in collaboration with Electrical and Computer Engineering and Computer Science students have worked on switching the TUPPS platform from using MOOS-IvP to implement autonomy to using ROS (Robot Operating System). This was after realizing that MOOS-IvP is more difficult to transition between each year's teams. After careful consideration, a

LIDAR has been purchased to be used in obstacle avoidance algorithms for the ASV, and some of the electronics necessary for autonomous ROV deployment are controlled through an Arduino.

The team is partnered with the Remotely Operated Vehicle (ROV) team, whose ROV is being changed to a UUV.

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INTRODUCTION

Introduction

OVERALL PROJECT SUMMARY

Over 90% of the ocean floor is currently unexplored; the Navy is interested in learning about this large portion of our planet that we know nothing about. However, given the large amount of the planet that is ocean (70%), it is not feasible to fund ocean mapping missions with large crews of people. Additionally, ocean mapping is largely data collection; the most difficult part is getting the sensors down to the ocean floor [1]. If ocean mapping can be turned into an autonomous ("self-driving") robotic operation, human crews can be reallocated to jobs which require human input or be sent only to areas of interest identified during the initial ocean mapping missions.

The Autonomous Surface Vehicle (ASV) team is completing the second year of a 3-year long project with the Remotely Operated Vehicle (ROV) team and the U.S. Navy. The goal of the project is to provide proof-of-concept for an Autonomous Surface Vehicle (ASV) and Unmanned Underwater Vehicle (UUV) pair to conduct autonomous ocean mapping missions (Please note: the UUV in this project is sometimes referred to as an ROV, because of the project team's name. Normally these are two separate things, but in this case, they are interchangeable terms that refer to autonomous underwater robots).

Ultimately, the plan is for the ASV to be autonomously deployed either from the shore or from a larger boat. The ASV will autonomously travel the ocean floor using waypoint navigation (waypoint=desired coordinate). It will use sensors to detect obstacles in its path and reroute itself accordingly, all while headed toward its desired waypoints. While it is travelling along the surface, it will use sonar to scan the ocean floor. If it identifies any anomalies (ex: extreme changes in depth), the ASV will pause its waypoint navigation and stop in the water. At this point, the ROV will be deployed from the ASV into the water and will explore the ocean floor in more detail. The ROV uses a system called an "Underwater GPS" (this "GPS" is actually underwater acoustic sensors connected to a GPS on the ASV) to know its coordinates in the water, and its location relative to the ASV. This sensor setup is deployed when the ROV is in the water and is retracted once the ROV has returned to the ASV. Once the ROV is back on the ASV, it resumes heading to its next waypoint. The details of how the ROV navigates the water will be explored in the ROV team's report.

GOAL OF 2018-2019 ASV TEAM

The goal of the 2018-2019 ASV team was to prepare the deployment system for the sensors necessary for ROV autonomy, assist in the ROV deployment system's implementation, improve the autonomy and control of the ASV, and improve the indoor testing platform for the ASV ("TUPPS").

RELATIONSHIP WITH REMOTELY OPERATED VEHICLE (ROV) TEAM

As mentioned in the introduction, the ASV team is partnered with the ROV team on this project, with the ROVs being repurposed to act as UUVs (Unmanned Underwater Vehicles). Due to the joint nature of our projects, there has been some overlap in the teams' tasks. For example, the ASV team was working on the Underwater GPS deployment system, while the ROV team was working on the actual Underwater GPS sensors.

RELATIONSHIP WITH NAVAL BASE IN KEYPORT, WA

The ASV and ROV teams are partnered together with the Navy Base in Keyport, WA through our joint advisor Dr. May-Win Thein. It is a three-year contract through the Naval Engineering Education Consortium (NEEC) and was agreed on by both representatives of the Naval center and Dr. Thein. They agreed that the project would be for a proof-of-concept mission for autonomous seafloor mapping using ASV-UUV pairs. The team is in the second year of the project.

Due to our relationship with the Navy, the ASV team has additional events that we participate in throughout the year. During the Fall 2018 semester, our advisor from the Keyport base, Dr. Martin Renken, visited us for a few days. For that visit we presented a presentation on our initial progress, along with our plans for the rest of the academic year. Dr. Renken visited again during the Spring 2019 semester, along with two additional Keyport representatives. We gave a more in-depth progress report during this time and discussed the project with these researchers.

PROGRESS MADE BY THE 2017-2018 ACADEMIC YEAR AND SUMMER 2018 TEAMS

Last year’s ASV team worked on the assembly of the SEAMOOS ASV (shown below), and the implementation of MOOS-IVP for autonomous waypoint-to-waypoint navigation.

However, MOOS-IVP is no longer being used, due to the difficulty in repeatable testing using the program.

Figure 1: ASV at the end of the 2017-2018 academic year.

As can be seen in the figure above, there was an initial idea for ROV deployment. This idea was modified by the 2018-2019 ASV and ROV teams, so some of those components were changed. Additionally, the ASV no longer uses MOOS-IVP, and instead is transitioning to using the Robot Operating System (ROS).

INTRODUCTION

OUTREACH

The ASV team has participated in the following events to promote TECH 797 and the ASV team:

- Ocean Discovery Day
- University of New Hampshire Sea Grant Site Visit
- Seacoast SeaPerch Challenge
- College of Engineering and Physical Sciences (CEPS) Admitted Students Day
- UNH 603 Challenge
- Rye Junior High School visit
- Undergraduate Research Conference (URC)

Financial Summary

Thank you to all the following groups who have provided financial support for the ASV team

SOURCES OF FINANCIAL SUPPORT

Sources of Financial Support for the 2018-2019 Academic Year

Table 1: Sources of Financial Support

NAME OF ORGANIZATION OR GRANT PROVIDING FUNDING	AMOUNT
UNH Mechanical Engineering Department	$600
UNH Electrical and Computer Engineering Department	$200
UNH Computer Science Department	$100
NEEC Research Grant	~$1,000*
CEPS Student Organization Grant	$1,500
SeaGrant	$1,500
Ocean Discovery Day and UNH Open House at Chase Engineering Lab	$400
Parents Association Grant	$2,000
TOTAL	**~$7,300**

**This is an estimate of money available to be allocated from the larger grant to directly support the ASV team as needed*

FINANCIAL SUMMARY

PROPOSED BUDGET

Proposed allocation of funds for the 2018-2019 Academic Year

TO BE PURCHASED	**ESTIMATED COST**
TUPPS (Testing Unmanned Performance Platform) 2, 3 & 4 Sensors and Electronics *Includes infrared sensors, TUPPS frame, and flotation materials.*	$900
ASV Improvements for Motors *Includes purchasing better electronic components and better mounts for motors.*	$400
GPS Deployment System *Includes motors to deploy 4 sensors, and the tracks/casings to deploy the four sensors.*	$800
Sonar Sensor *Sonar is to be purchased to help improve autonomy.*	$500
LIDAR Sensor *LIDAR is to be purchased to help improve autonomy.*	$2000
Lake and Estuary Testing Tools *Includes life jackets, walkie talkies, and rope to secure loose parts and electronics to ASV.*	$150
Additional ASV Buoyancy Support *Includes flotation equipment.*	$300
ROV Deployment System *Includes winch and electronics for deployment of ROV, as well as ROV casing and tether reel.*	$2000
Electronics Waterproofing and Protection *Includes waterproof fabric and plastic containers.*	$100
Total Cost = $7,150	

PURCHASING SUMMARY

Please see Appendix C for full purchasing information for the 2018-2019 academic year.

Testing

JERE A. CHASE ENGINEEIRNG TANK TESTING

Figure 2: ASV being tested in engineering tank.

The engineering tank is the main location of testing for the Autonomous Surface Vehicle (ASV) and the Testing Unmanned Performance Platforms (TUPPS). This tank is used to test the control of the TUPPS, along with its obstacle avoidance capabilities. The tank is also used to test the ASV buoyancy and stability. The deployment systems for both the sensors and the ROV are also tested in the tank. Some sensors themselves are tested in the engineering tank.

The tank is unable to be used to test ASV waypoint-to-waypoint navigation or obstacle avoidance. This is because the ASV is too large, and has too large a turning radius, to navigate the tank area in this manner. The Global Positioning System (GPS) also does not function indoors.

JERE A. CHASE WAVE TANK TESTING

The wave tank is not usually used for ASV or TUPPS testing, unless the engineering tank is unavailable. The wave tank has been used for testing the “Underwater GPS” sensors, because the platform setup was ideal for our initial sensor configuration.

There are plans for the ASV to be put into the wave tank to see how it behaves when it encounters waves. However, this cannot be done until all deployment systems and other components have been secured to the ASV and the system has been balanced out. Currently, the ASV might tip over if it encountered too extreme waves.

ASV LAKE TESTING

Figure 3: ASV autonomy and remote control being tested in lake.

There are many reasons that it is important for the Autonomous Surface Vehicle (ASV) to be tested outside of the Jere A. Chase Engineering Tank. Sensors are less accurate when tested in the tank, due to reverberations off of the walls distorting the sound. All of our sensors are validated in a lake, and the results we get from the lake tests are used to determine how much the results from testing in the tank differ. If the difference is acceptably small, the sensor can be worked on indoors, and is a priority for the team to work on during the academic year. Sensors that are unable to be properly applied indoors are prepared as much as possible to be tested by the team of undergraduate workers that work on the ASV during the summer.

Additionally, the GPS for the ASV only works outdoors. As a result, all waypoint-to-waypoint navigation, and controls testing, must be conducted outside. Additionally, the size of the ASV also prevents it from being able to be tested anywhere but outdoors in a larger body of water.

Underwater GPS Deployment System

Figure 4: Underwater GPS (Photo from Waterlinked [2])

The Waterlinked Underwater GPS system is used to locate the ROV with respect to the ASV. The name “Underwater GPS” is a misnomer, as GPS signals do not propagate through water due to their high frequency. The system employs five nodes, one emitter and four receivers; the receivers are to be kept stationary, at least one meter below the surface of the water, and at least one meter from each other as per the manufacturer. The emitter, which gives off an acoustic signal, is to be mounted on the object for which GPS coordinates are desired; in the case of this project, it will be mounted on the ROV. The receivers detect the signals produced by the emitter, and triangulate its position to within one percent of the distance. Additionally, the system’s onboard computer, housed in a waterproof case, has a built-in GPS, allowing it to assign coordinates to the emitter. Data from the Underwater GPS is gathered by connecting it to a PC via ethernet, and interfacing with it through a web browser, as the GPS computer has its own IP address. The Underwater GPS system, when interfaced with a PC, has its own graphical user interface where a user can input the exact location of the receivers relative to the onboard computer, whether the unit is operating in a pool or natural body of water, as the disparity in reflectivity between these environments contributes to substantially different readings, and other such parameters. An important limitation of the system, however, is that the receiver nodes are delicate and sensitive; they must be submerged in relatively still water to deliver accurate data and avoid damage. For the ASV – ROV project, this means that the ASV should not have the nodes in the water while it is moving. The ASV must be able to move, therefore the receiver nodes must be able to be placed in the water and removed autonomously. This fact necessitated the creation of a GPS deployment system [2].

The GPS deployment system went through three major iterations, but they all followed the same basic principles. First and key among them was the modular aspect; each receiver node was to have its own separate, functionally identical deployment module. These modules, generally referred to as ‘arms,’ for the apendage-esque way they reach forth from the ASV, were individual due to the need for the receiver nodes to be at least a meter away from each other node. Additionally, as the layout of the ASV was in constant flux, with proposed modules claiming precious space on the deck, the individual nature of the arms allowed for them to be moved and rearranged in accordance with any possible future change to the ASV’s floor plan.

The first iteration consisted of four arms which went along a respective track, passing over a rounded edge to lower into the water. Each sensor was secured by small poles bracketed between two sheets of thin metal to prevent any air getting trapped in the deployment mechanism and creating a buoyancy force. However, many of the components were significantly idealized; they required significant manufacturing effort, as they were not available off-the-shelf.

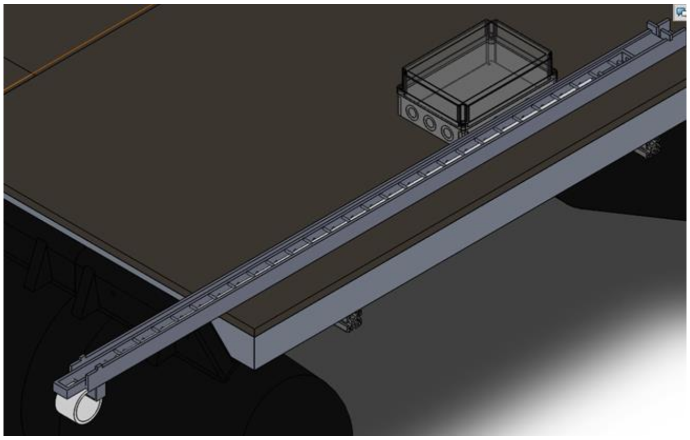

Figure 5: Initial Underwater GPS Deployment Design

The second iteration sought to reduce the degrees of freedom experienced by the receiver node, be easy to assemble by anyone with the SolidWorks model, and be a more complete design (including electronics). The power transmission, a belt-pulley system actuated by a DC motor, was the focus of the design. The pulley ran along a length of aluminum square tubing, and the driving wheels were mounted at each end, placed in the middle of the tube to preserve the structural loop. A notch was cut down the length on the top face so that a 3D-printed track runner could free slide along the tubing when not connected to the pulley belt. A length of PVC tubing was placed on top of the track runner, affixed with four bolts; the receiver node was to be mounted to the end of the PVC tube, and its connecting wire routed through. This system was to be mounted at a steep angle, supported by angled lengths of T-slotted framing, so that the linear nature of the deployment module would place its respective node steadily and firmly below the water, at or below the required depth. An added boon of this mounting method was that it consumed less space on the deck, which was still uncertain and prized at the time. Unfortunately, the mounting method would soon be challenged. The concurrent stability and buoyancy study would show that the ASV was not as immune to capsizing as originally thought, and four metal poles protruding vertically from the penthouse would raise the center of buoyancy to potentially dangerous heights. It was decided that the system must evoke the horizontal properties of the original design; utilizing more deck space but keeping the center of buoyancy of the whole vessel at a reasonable location.

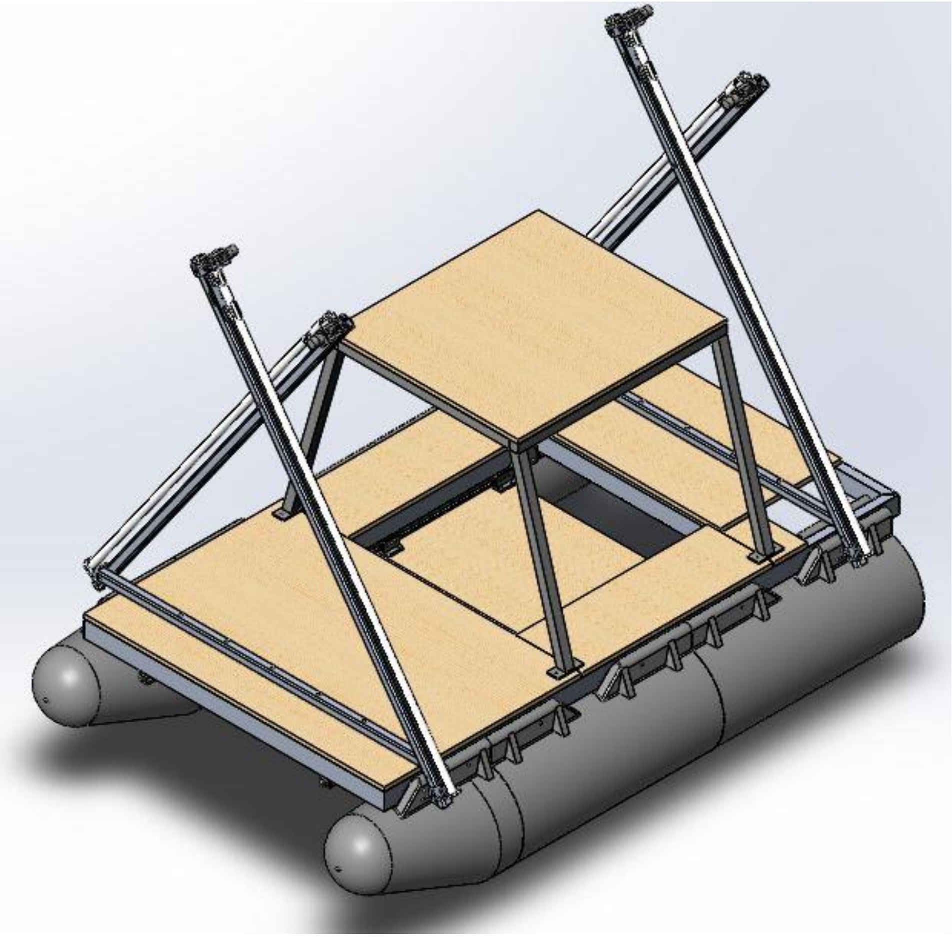

Figure 6: Second Generation Deployment System with Nodes Retracted

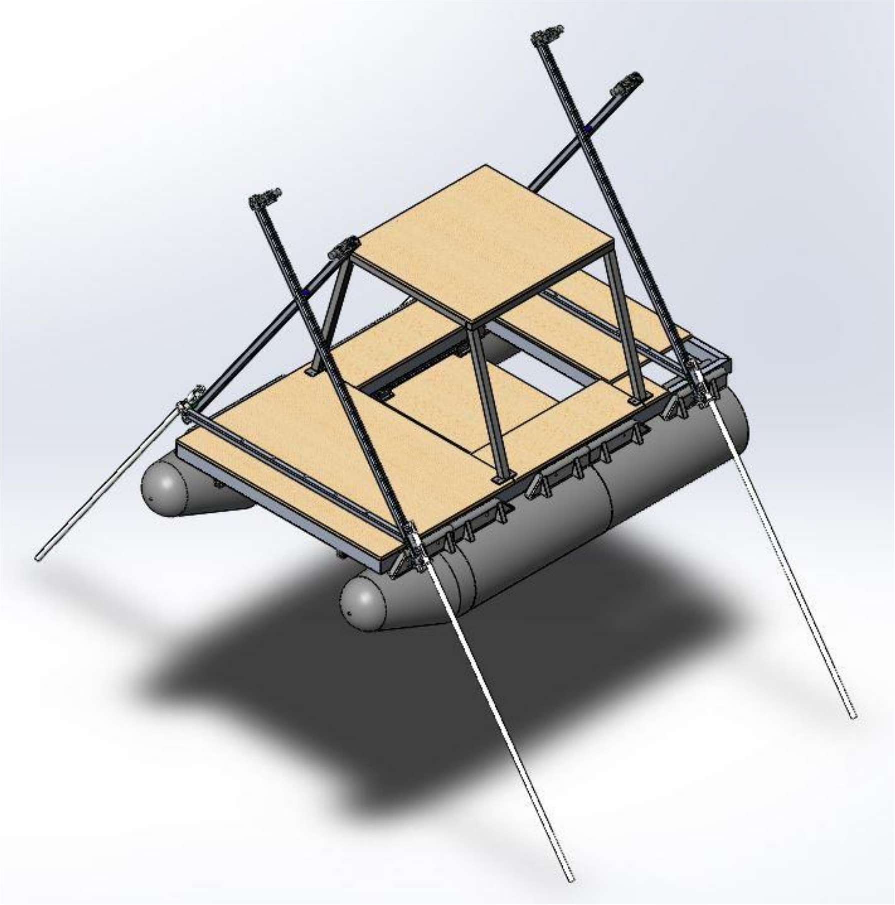

Figure 7: Second Generation Deployment System with Nodes Deployed

The third iteration used most of the hardware resources from the second, and borrowed heavily from the ideas of the first; a conveyor system was present in both and a working one had been developed, and the PVC tube used to deliver the receiver node was still long enough to reach the operating depth of one meter. The third iteration was a combination of the first two, it used the same number of degrees of freedom as the first but included the power transmission utilized in the second. By adding a 3D-printed hinge that allowed the PVC tube to pitch down into the water as the conveyor moved forward, no additional machining was required to transition between the second and third iterations. The third iteration, with its balance between robust deployment and low-profile construction, 3D-printed parts and easy assembly, is the currently serving Underwater GPS deployment system.

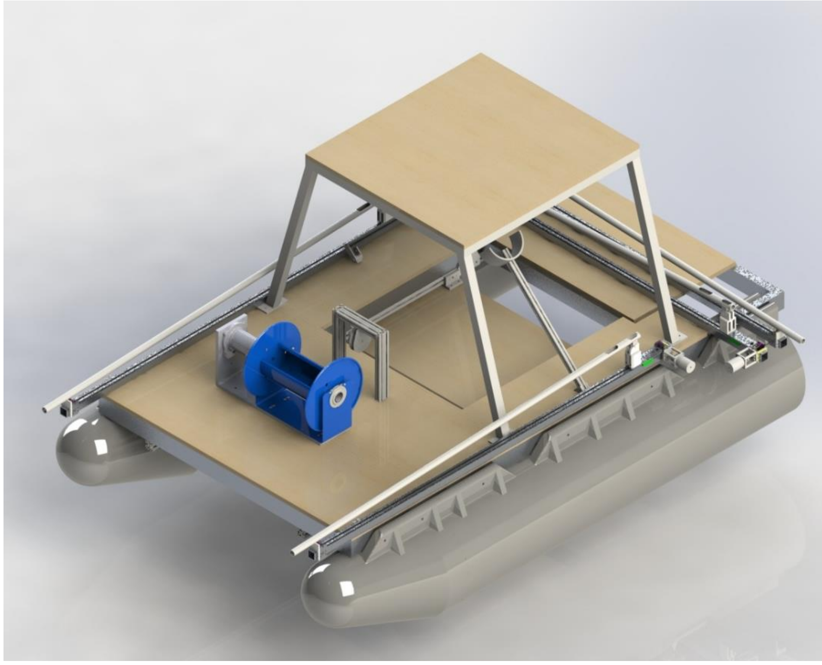

Figure 8: Third Generation Deployment System with Nodes Retracted

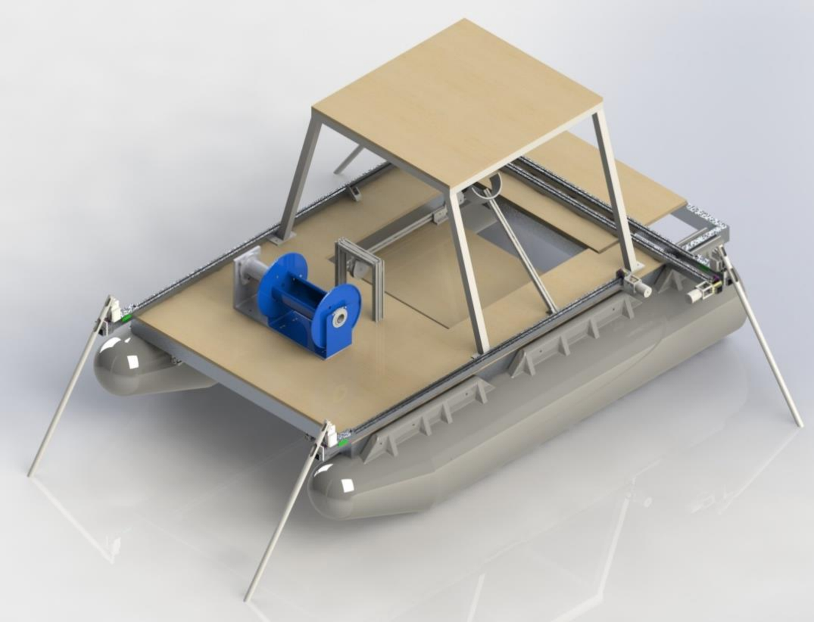

Figure 9: Third Generation Deployment System with Nodes Deployed

There are still potential issues with the new system. The PVC pipe deforms in the water, and its strength may deteriorate if it gets repeatedly bent by waves. Further testing will indicate whether the tubing will bend under weak currents in a way that will interfere with the data gathered by the Underwater GPS system. The other issue is the lack of feedback controls regarding the position of the track runner; the computer programs used to raise and lower the nodes will simply run the motors for a fixed amount of time in one direction to deploy, and the other to recover. However, should there be any belt slippage or a discrepancy in power between the motors, there will be no way to determine that the arm is not completely deployed or recovered. Additionally, the receiver nodes are free-floating at the end of their respective

PVC tubes; it is known that the angle at which the nodes are oriented may influence the range of directions in which the transmitter node can be located, but more experiments need to be conducted to identify the optimal angle(s). It is currently unknown if fixing the angle of each receiver node will have a significant impact on the system's ability to locate the ROV through its entire operating envelope.

The Underwater GPS deployment system has grown from a strong idea into a fully realized system, and future tweaks and adjustments will only further its impact on the mission of the ASV – ROV project.

TESTING UNMANNED PERFORMANCE PLATFORMS (TUPPS)

Testing Unmanned Performance Platforms (TUPPS)

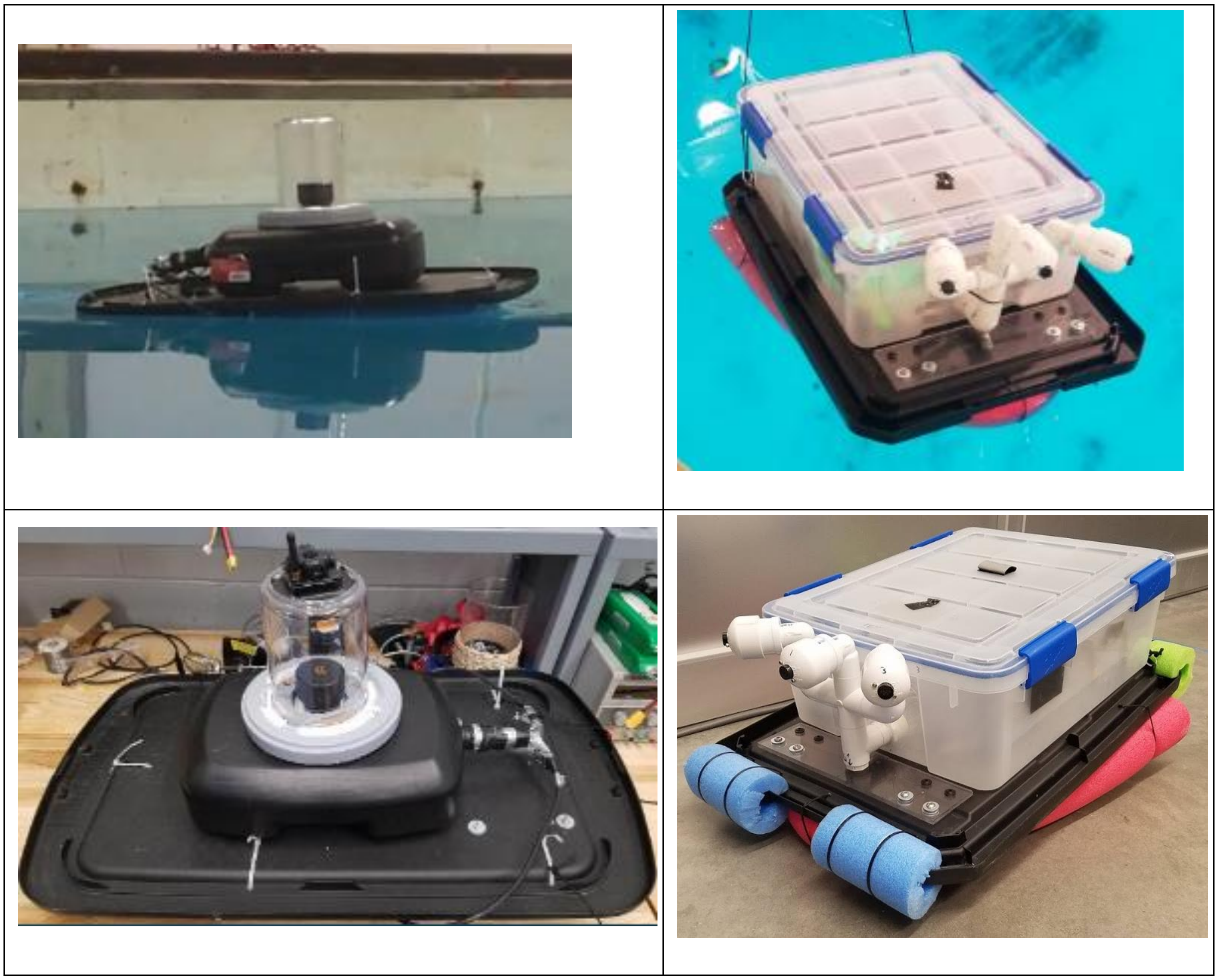

Figure 10: TUPPS 1 (left) and TUPPS 2 (right)

Due to the constraints that came with the size of the larger ASV, a smaller testing platform for the ASV controls, obstacle avoidance, path planning, and swarm capabilities was developed. This testing platform, referred to as the Testing Unmanned Performance Platform (TUPPS), was created over the summertime to act as a small-scale ASV. A second-generation model, TUPPS 2, was then created during the academic school year in order to improve upon the original platform and expand the capabilities. The required considerations for the construction of TUPPS 2 consisted of 3 range finding sensors, adjustable sensor housing, modularity to change sensors, water-resistant easy access electronics box, sturdy and compact hull design, two Blue Robotics motors, use of Arduino and other open source controllers, and a lightweight platform. The main goal of this platform is to use waypoint-to-waypoint navigation and utilize obstacle avoidance controls for navigation.

The search began for cost-effective range finder sensors. Infrared (IR) and ultrasonic sensors are very common, and both work well with Arduinos and other open-source electronics. IR sensors utilize light waves being reflected off an object to determine its distance. However, they are sensitive to environments with different lighting, as this can affect the sensor accuracy. Ultrasonic sensors emit sound waves to determine an object's distance. The waves are reflected off an object and detected by the sensor. The amount of time between the emission and return of the reflected waves is measured and used to estimate distance to the object. While ultrasonic sensors aren't ideal for determining the distinct shape of an object, there are many factors that don't interfere with the object detection, such as fog, dust, or light [3]. The benefits of using an ultrasonic sensor seemed to outweigh the IR sensor, so 3 ultrasonic sensors were purchased. TUPPS 1 utilized a LiDAR sensor for obstacle detection and avoidance. While that type of system is ideal for the ASV, the device that was used proved to be unreliable and needlessly expensive.

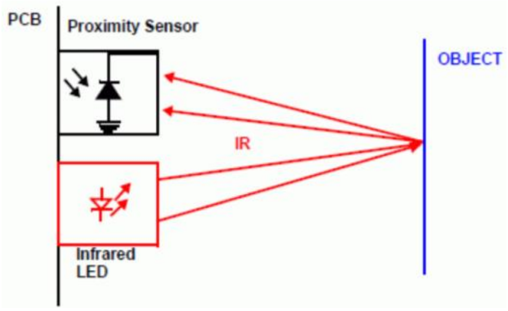

Figure 11: Infrared Sensor (Photo by MaxBotix [3])

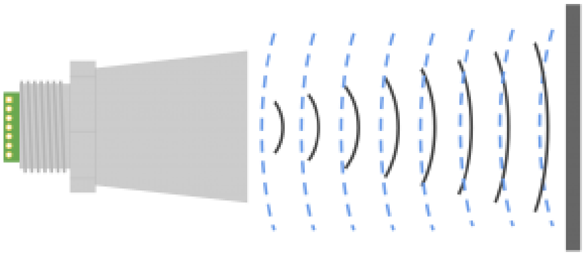

Figure 12: Ultrasonic Sensor (Photo by MaxBotix [3])

Once the ultrasonic sensors were delivered, their implementation into the TUPPS 2 platform began. The need for a modular sensor housing arose, being able to adjust the height, width between, and angle of each sensor. The final design used PVC pipes and elbows, due to the modularity, low cost, and ease of working with plastic. With the PVC, the height of each sensor could easily be adjusted, along with the rotation of each sensor to push the limits of the field of view. This design also allowed for a more water-resistant construction. In order to maximize modularity and have the ability to remove the ultrasonic sensors to instead attach another sensor, the wiring would need to be made in a way that allowed for a “plug and play” operation. Jumper wires were used to connect the pins to the breadboard. This allowed for the connections to be much more organized and user friendly for others. Pictures displaying the connections can be seen below.

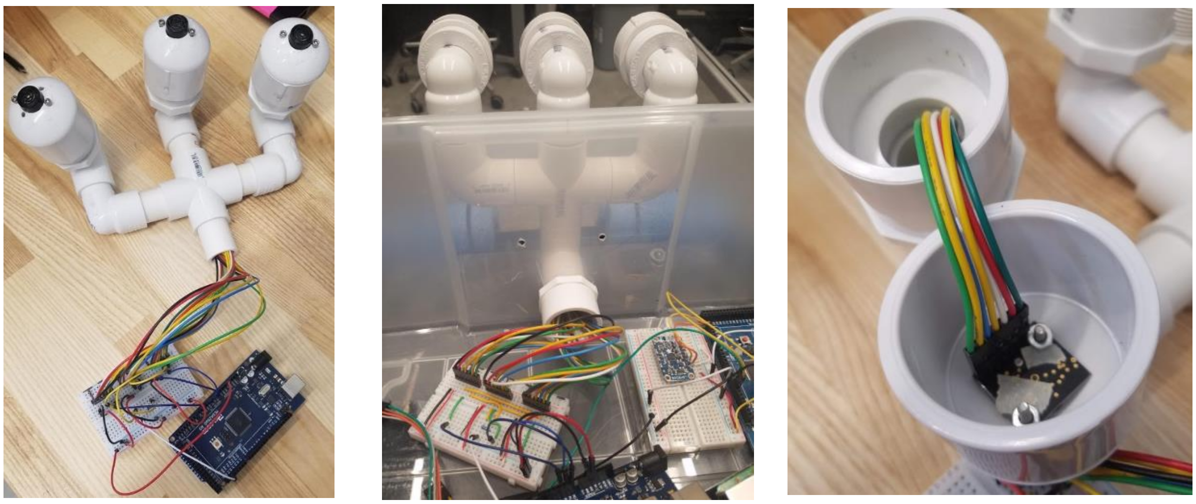

Figure 13: Ultrasonic sensors setup in PVC mount

Each ultrasonic sensor has 7 pins, described in the table and images below.

Table 2: Ultrasonic sensor pins

Pin	Pin Out Description
1	Temperature Sensor Connection
2	Pulse Width Output
3	Analog Voltage Output
4	Ranging Start/Stop
5	Serial Output
6	Positive Power, Vcc
7	Sensor ground pin

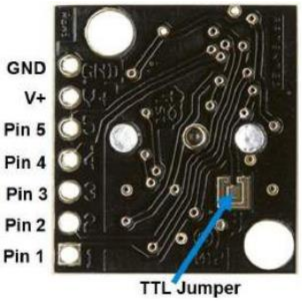

Figure 14: Ultrasonic sensor pin diagram

Figure 15: Ultrasonic sensor

One of the concerns with using multiple ultrasonic sensors is interference between them, called “cross-talk”. In order to account for this, the sensors are chained together using a AN Output Constant Loop. With this method, the first sensor will range to detect an object, then signal for the second sensor to range. After the second sensor has ranged, the third sensor will be signaled to do the same thing. Once this loop has been completed, it will repeat infinitely to constantly be ranging to detect for objects. This can be seen in the below images.

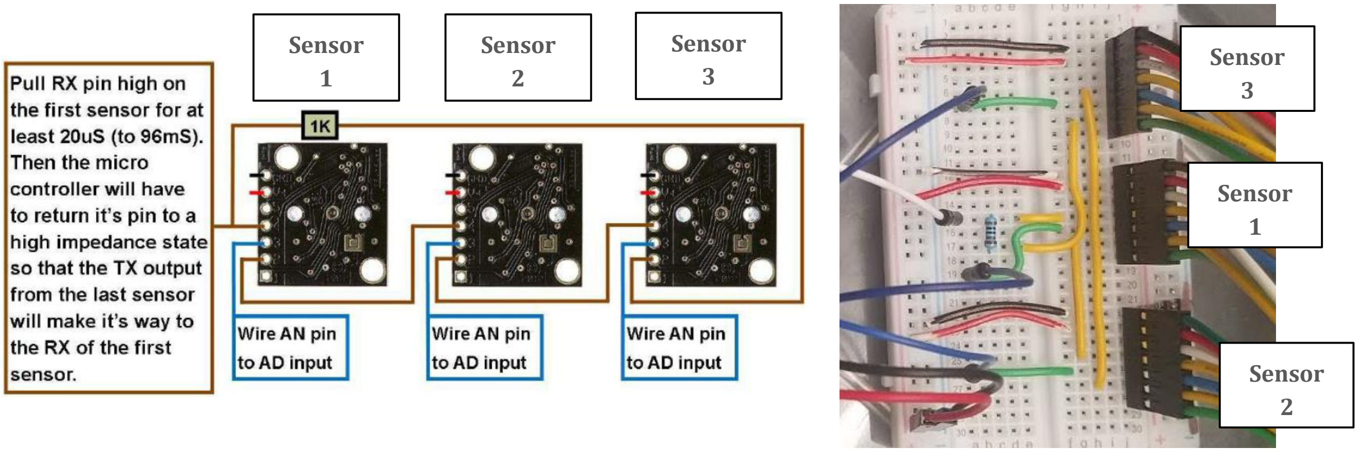

Figure 16: AN Output Constant Loop Method for Wiring Ultrasonic Sensors

The frame of TUPPS was created using 8020 T-Slot Aluminum bars, which provided a sturdy surface for the motors to be attached. The frame was then fixed to the hull (rectangular bucket lid) and pool noodles were zip tied to the bottom for flotation. Multiple tests had to be run in order to determine the best location for the noodles, and the exact quantity. The electronics box was chosen due to its size and lid seal. It was secured to the hull using Velcro to allow for removal if necessary, but is sturdily attached. The larger electronics box is an improvement from the first TUPPS, which utilized a plastic oil pan. While that kept water out, it was difficult to work on the electrical components with such a small lid.

Figure 17: Underside view of TUPPS 2

Figure 18: Side-view of TUPPS 2 without electronics

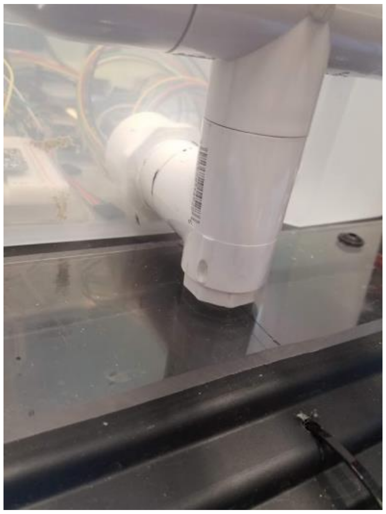

Figure 19: PVC sensor tower with acrylic support

Figure 20: Sensor tower tube with ultrasonic sensor wires going through it

In order to attach the ultrasonic sensor tower to TUPPS, a sturdy base was needed. The bucket lid was too flimsy to allow for a rigid sensor tower. To solve this problem, a piece of plastic acrylic was bolted to the front of TUPPS to provide that stable platform. The sensor tower was then bolted to the acrylic, through the use of a T-shape PVC connector. An epoxy was used to seal any gaps around the bolt to prevent water from entering the system and causing damage. To bridge the gap between the sensor tower and electronics box, a hole was drilled in the box and a PVC pipe was passed through it. The connector on the inside of the box has a threaded adapter to allow for the pipe to be sealed, if the sensor tower is to be removed. Epoxy will also be applied around the hole in the electronics box to prevent water from getting inside. The rest of the PVC pipes in the sensor tower will not use any epoxy. While this would provide a waterproof seal, the ability to adjust the tower would be taken away.

TUPPS 2 is a platform that has far surpassed the expectations for what it was originally thought to be capable of. With its modular construction, any component can easily be replaced at a low cost. The platform will hopefully see continued use over the summertime and next year by undergrad and graduate students.

Stability and Buoyancy Analysis

Figure 21: ASV in engineering tank

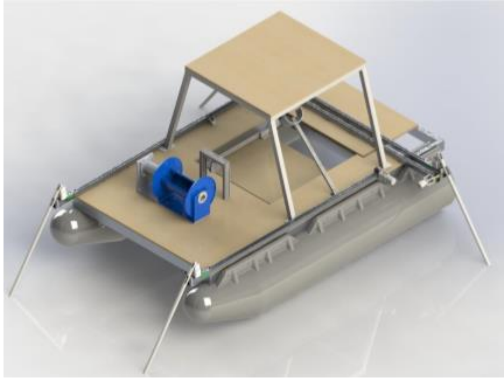

Figure 22: ASV model

A stability and buoyancy analysis was initiated to better understand the performance, limitations, and proper location of onboard components and how the ASV will be impacted. Poor equipment placement will result in an improperly balanced platform, leading to severe tilt, instability, increased risk of tipping, equipment damage, and a safety hazard. To start, the ASV was put into the Engineering Tank as is to take note of the current stability of the platform. It was determined that the stern of the ASV was lower than the bow, and the plywood covering the trapdoor was unnecessary and adding extra weight to the rear, and must be removed. Working with other team members and taking into consideration their projects and how they will be implemented onto the ASV, a solution to accommodate all changes was reached. The GPS deployment system and its four sections will have two arms mounted in the back, perpendicular to the pontoons. The other two arms will be mounted on either side of the ASV directly over the pontoons. The ROV deployment reel will be mounted onto the front deck of the ASV, with the ROV to be stored on the trap door in the center under the penthouse. The two batteries would be in the back of the ASV, along with the motors. All of the electronic components will be on top of the penthouse. With this current setup, the ASV is still tilting towards the stern. In order to correct this, the front will have to be weighed down. During preliminary testing, a 45-pound weight was placed on the bow. This effectively fixed most of the tilt, but still left a few degrees of rearward tilt. Ideally, the platform should be level. However, the slight tilt will help counteract any forward tilt that would cause the ASV to nosedive.

The overall analysis will continue into the summer and next year. The design of onboard components will constantly change, making it difficult to have a definitive model of the ASV stability. Data collection for different weights and lengths of onboard equipment and parts have started to be collected. Not much documentation from the construction of the ASV remains, which makes it difficult to determine the origin of some of the parts. This also leads to an inaccurate SolidWorks model, since the dimensions and materials are unknown.

After hours of online research and emailing companies, the origin of the pontoons was discovered. The pontoons are made of High Density Polyethylene (HDPE) ExxonMobile HD 8660. The internal foam is polyurethane based, with a density of 2 lb./ft^3. Each pontoon body section has a load capacity of 130 lbs., while the nose cone has a limit of 45 lbs. With four body sections and two nose cones, the maximum capacity for the pontoons is 610 lbs. These limits are determined based on the pontoons being submerged 50%. Knowing this, everything onboard the ASV must weigh less than 610 lbs. More pontoon data can be seen in the table below. The schematics of the pontoon sections can be seen in Appendix B.

STABILITY AND BUOYANCY ANALYSIS

Table 3: Pontoon information

Description	Length [in]	Width [in]	Weight [lbs]	Recommended Capacity* [lbs.]	Inner Diameter [in]	Inner Volume [in^2]
Body	35	17	23	130	16.1623	7276.7
Nose Cone	25	17	14	45	15.9	3053.84

Figure 23: Sideview of pontoon in ASV assembly

The stability and buoyancy analysis will be continued with next year's team and will focus on more calculations. What has been completed so far included properly balancing the ASV, along with initial background research to gather the necessary information for calculations. Since the intent of the ASV is to be self-driving, there will no longer be a person onboard, since there will be no space. In addition to this, a person standing on the ASV will drastically alter its stability.

ASV/TUPPS Theoretical Model

Table 4: Nomenclature

Nomenclature	
Variable Name	Variable Symbol
External forces	X, Y, Z
Moment of external forces about origin (secondary coordinates)	K, M, N
Linear velocity of x,y,z (secondary coordinates)	u, v, w
Angular velocity of x,y,z (secondary coordinates)	p, q, r
Center of gravity	x_G, y_G, z_G
Mass	m
Moment of inertia along principal axes	I_x, I_y, I_z
Product of Inertia	I_{xy}, I_{yz}, I_{zx}

In order to successfully model the ASV, there are four aspects of the system that are considered:

1. The Secondary Coordinate System
2. Earth-Fixed Dynamics and Kinematics
3. External Forces
4. Controller

THE SECONDARY COORDINATE SYSTEM

When the ASV is moving, it is important to know both where it is in the world, and which direction it is facing. The secondary and global coordinate systems are used together in order to gather this information related to a fixed point (the shore station). In the figure below, the secondary coordinate system is denoted using (x,y), while the global coordinate system is denoted using (X,Y).

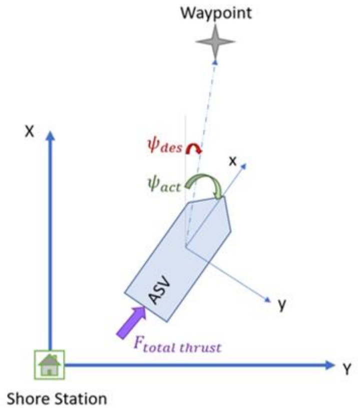

Figure 24: ASV global and local coordinate systems

As can be seen in the figure above, the secondary coordinate system originates from the ASV. In our calculations, the body-fixed coordinate system lies on the principle axes of inertia. (The z-axis is going into the paper/water for easier relation to the ROV and its position and orientation information).

The ASV can move in three degrees of freedom (assuming still water). The ASV can move forward in the x-direction ("*u*", surge), sideways in the y-direction ("*v*", sway), and rotate about the z-axis (“r”, yaw). The other three degrees of freedom (roll, pitch, and heave) are assumed to be negligible. The motors cannot make the ASV move in these three directions, and if the ASV was moving in any of them a significant amount, it would be because the ASV was in some way getting submerged. Any submergence of the ASV past the pontoons can result in the ASV tipping over; as a result, it is safe to assume that these three degrees of freedom do not need to be considered for the ASV theoretical model.

In order to model the motion for the ASV, Thor I. Fossen’s “General 6 DOF Rigid-Body Equations of Motion” were used (Equations 1-6) [4].

$$m[\dot{u} - vr + wq - x_G(q^2 + r^2) + y_G(pq - \dot{r}) + z_G(pr + \dot{q})] = X \tag{1}$$

$$m[\dot{v} - wp + ur - y_G(r^2 + p^2) + z_G(qr - \dot{p}) + x_G(qp + \dot{r})] = Y \tag{2}$$

$$m[\dot{w} - uq + vp - z_G(p^2 + q^2) + x_G(rp - \dot{q}) + y_G(rq + \dot{p})] = Z \tag{3}$$

$$\begin{aligned} I_x\dot{p} + \left(I_z - I_y\right)qr - (\dot{r} + pq)I_{xz} + (r^2 - q^2)I_{yz} + (pr - \dot{q})I_{xy} \\ + m[y_G(\dot{w} - uq + vp) - z_G(\dot{v} - wp + ur)] = K \end{aligned} \tag{4}$$

$$\begin{aligned} I_y\dot{q} + (I_x - I_z)rp - (\dot{p} + qr)I_{xy} + (p^2 - r^2)I_{zx} + (qp - \dot{r})I_{yz} \\ + m[z_G(\dot{u} - vr + wq) - x_G(\dot{w} - uq + vp)] = M \end{aligned} \tag{5}$$

$$\begin{aligned} I_z\dot{r} + \left(I_y - I_x\right)pq - (\dot{q} + rp)I_{yz} + (q^2 - p^2)I_{xy} + (rq - \dot{p})I_{zx} \\ + m[x_G(\dot{v} - wp + ur) - y_G(\dot{u} - vr + wq)] = N \end{aligned} \tag{6}$$

Since it was assumed that there is no heave, the vertical component is irrelevant and can be set to zero.

$$z_G = 0 \tag{7}$$

As mentioned before, in this model, the secondary coordinate system lies on the principle axes of inertia.

$$I_{xy} = I_{yz} = I_{zx} = 0 \tag{8}$$

Finally, since it has been determined that the significant ASV dynamics are surge, sway, and yaw, we can assume the motion in the other three degrees of freedom is zero.

$$w = p = q = 0 \tag{9}$$

These assumptions completely remove Equations 3,4, and 5. Equations 1, 2, and 6 remain in a simpler form.

$$m[\dot{u} - vr + \cancel{wq} - x_G(\cancel{q^2} + r^2) + y_G(\cancel{pq} - \dot{r}) + \cancel{z_G(pr + \dot{q})}] = X \tag{10}$$

$$m[\dot{v} - \cancel{wp} + ur - y_G(r^2 + \cancel{p^2}) + \cancel{z_G(qr - \dot{p})} + x_G(\cancel{qp} + \dot{r})] = Y \tag{11}$$

$$m[\cancel{\dot{w}} - \cancel{uq} + \cancel{vp} - \cancel{z_G(p^2 + q^2)} + x_G(\cancel{rp} - \cancel{\dot{q}}) + y_G(\cancel{rq} + \cancel{\dot{p}})] = Z \tag{12}$$

$$\begin{aligned} \cancel{I_x\dot{p}} + \left(I_z - I_y\right)\cancel{qr} - \cancel{(\dot{r} + pq)I_{xz}} + \cancel{(r^2 - q^2)I_{yz}} + \cancel{(pr - \dot{q})I_{xy}} \\ + m[y_G(\cancel{\dot{w}} - \cancel{uq} + \cancel{vp}) - \cancel{z_G(\dot{v} - wp + ur)}] = K \end{aligned} \tag{13}$$

$$\begin{aligned} \cancel{I_y\dot{q}} + \cancel{(I_x - I_z)rp} - \cancel{(\dot{p} + qr)I_{xy}} + \cancel{(p^2 - r^2)I_{zx}} + \cancel{(qp - \dot{r})I_{yz}} \\ + m[\cancel{z_G(\dot{u} - vr + wq)} - x_G(\cancel{\dot{w}} - \cancel{uq} + \cancel{vp})] = M \end{aligned} \tag{14}$$

$$\begin{aligned} I_z\dot{r} + \cancel{(I_y - I_x)pq} - \cancel{(\dot{q} + rp)I_{yz}} + \cancel{(q^2 - p^2)I_{xy}} + \cancel{(rq - \dot{p})I_{zx}} \\ + m[x_G(\dot{v} - \cancel{wp} + ur) - y_G(\dot{u} - vr + \cancel{wq})] = N \end{aligned} \tag{15}$$

Equations 1, 2, and 6 can now be rewritten as Equations 16, 17, and 18.

$$m(\dot{u} - vr - x_G r^2 - y_G\dot{r}) = X \tag{16}$$

$$m(\dot{v} + ur - y_G r^2 + x_G\dot{r}) = Y \tag{17}$$

$$I_z\dot{r} + m[x_G(\dot{v} + ur) - y_G(\dot{u} - vr)] = N \tag{18}$$

For later use in a graphical programming environment, Equations 16-18 are rewritten in matrix form.

$$\begin{bmatrix} m & 0 & -y_G \\ 0 & m & x_G \\ -y_G & x_G & I_z \end{bmatrix} \begin{Bmatrix} \dot{u} \\ \dot{v} \\ \dot{r} \end{Bmatrix} = \begin{Bmatrix} X + mvr + mx_G r^2 \\ Y - mur + my_G r^2 \\ N - mx_G ur - my_G vr \end{Bmatrix} \tag{19}$$

EARTH-FIXED DYNAMICS AND KINEMATICS

In order to relate the secondary coordinate system to the global coordinate system, the following coordinate transformation matrix must be used [4]. The angle is defined in Figure 24.

$$J_\eta = \begin{bmatrix} \cos(\psi) & -\sin(\psi) & 0 \\ \sin(\psi) & \cos(\psi) & 0 \\ 0 & 0 & 1 \end{bmatrix} \tag{20}$$

This matrix can then be used in Equation 21. The secondary coordinate system velocities (ν) are multiplied by the coordinate transformation matrix to get the global coordinate system velocities $(\dot{\eta})$. This can then be integrated to get the position and heading of the ASV related to the global coordinate system.

$$\dot{\eta} = J_\eta \nu \tag{21}$$

EXTERNAL FORCES

This year, the only external force being considered is skin friction from the water. The coefficient to use to represent this friction is going to be investigated more thoroughly by next year's team. At the moment, it is set as 0.1 and the equations to represent skin friction are being finalized.

Skin friction will be evaluated more thoroughly next year. Next year's team may also add forces from wind and waves into the model.

CONTROLLER

The ASV's controlled movement comes from the two thrusters located at the back of the vehicle, as shown in the figure. Since there are only two inputs, there is no way for each degree of freedom to be directly controlled. As a result, the ASV is an underactuated system. This presents some additional challenges and requires that the left and right thruster inputs be related to the center of mass in order to approximate how they move the system.

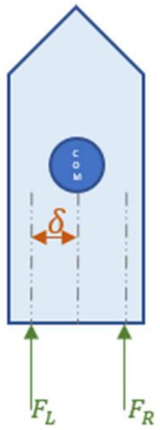

Figure 25: ASV inputs

There are two controllers being used: one is to control the ASV's speed, and one is to control its heading. "PID" control is being used to control both of these parameters. PID stands for "Proportional, Integral, and Derivative" control, and is widely used. The process for designing the two controllers is largely the same. In order to control the heading, the difference between the measured and desired heading is calculated. This difference is usually referred to as the "error", or *e(t)*. The equation to represent PID control is shown below. In this case, u(t) refers to the output of the system, not surge.

$$u(t) = K_p e(t) + K_i \int_0^t e(t)dt + K_d \frac{d}{dt} e(t) \qquad (22)$$

There are three constants that are needed to use the PID controller. These constants, referred to as K_p, K_i and K_d are part of the proportional, integral, and derivative parts of the controller, respectively. In order for the PID controller to be effective, it must be "tuned" (have the gains set to appropriate values). The PID controller has not yet been tuned, as the relationship between the motors and the motion of the ASV/TUPPS is still being determined. The same process occurs for the speed PID controller.

THE OVERALL SYSTEM

The complete model of the system combines these four sections, interconnecting them through like variables and terms. The visual model of this system can be seen in the figure below.

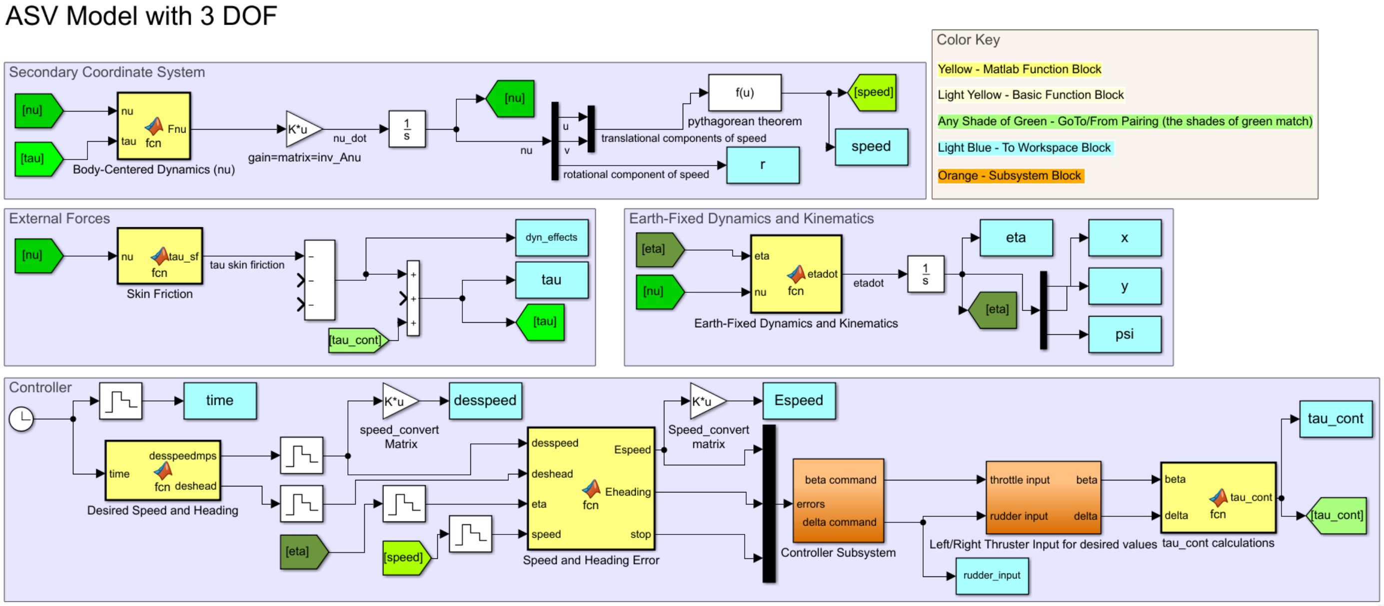

Figure 26: Model of ASV in 3 degrees of freedom

As can be seen in the figure, there has been room left available for additional external forces to be accounted for in the model. Additionally, the PID controllers are located within a controller subsystem, so they can be switched out for other controllers at any time. This model is usable by future years, so that they can add to the analysis and create a more accurate representation of the system.

APPLYING CONTROLLERS TO TUPPS

Applying Controllers to TUPPS

The controllers are first being applied to TUPPS, because it is easier to rapidly troubleshoot and test controls on the smaller platform. The controller is following the same theory as the theoretical model.

Some of the challenges encountered while currently incorporating the controllers onto TUPPS is accurately relating the direction (heading) to the thruster outputs. Currently, some ideas are being considered on how to resolve this issue, though a definitive answer has not yet been reached.

A segment of the Arduino code on TUPPS that is trying to be implemented to control heading using only one motor is shown below. As can be seen here, the derivative and integral terms are calculated using the error and time difference information.

```
time_=millis;
PID_prop_left=Kp*error_left;
PID_int_left=PID_int_left+(Ki*error_left);
integrate_left=Ki*(integrate_left+error_left*(time_-prev_time));
prev_time=time_;
PID_der_left=Kd*((error_left-prev_error_left)/(time_-prev_time);)
prev_error_left=error_left;
control_left=PID_prop_left+PID_int_left+PID_der_left;
```

ELECTRICAL AND COMPUTER ENGINEERING SUMMARY

Electrical and Computer Engineering Summary

Since there are Electrical and Computer Engineering (ECE) students who also participate on the project, a summary of the tasks that they supervised has been included below.

The ECE students had four main projects that they worked on: Using an Arduino to open and close the trapdoor, implementing LIDAR, implementing a new motor driver, and implementing a MICTUNING DC Energy Meter.

CONTROLLING THE TRAPDOOR

The ASV's trapdoor (used in ROV deployment), needed to be able to be opened by an Arduino. The ECE students developed code to control the trapdoor and ensured the necessary connections between the actuator and the trapdoor for it to open and close.

IMPLEMENTING LIDAR ("LIGHT DETECTION AND RANGING")

Figure 27: LIDAR purchased (Photo by Velodyne [5])

A LIDAR sends pulses of light in the direction it is pointed in, and then detects the moment when the light returns from "bouncing off" of a surface. Using this information, the LIDAR can use the time difference between when it sent out a pulse of light and when it detected the "bounced-back" pulse of light to determine how far away an object is in front of the sensor [6]. This sensor has been ordered but has not yet arrived to be implemented on the ASV. The LIDAR will be used so that the ASV can detect obstacles in its path and implement an obstacle-avoidance algorithm to be able to drive around these objects.

It was selected because it is computationally cheaper than stereo cameras (the other option being considered for obstacle avoidance).

IMPLEMENTED A NEW MOTOR DRIVER AND MICTUNING DC ENERGY METER

The ECE students of the 2018-2019 team realized that the electronics setup from the 2017-2018 team prevented the ASV's motors from reaching their fastest speed. As a result, they implemented the Cytron Smart Drive Duo-60 MDDS6 motor driver. This was able to increase the amount of power going to the motors.

Figure 28: Motor driver (photo by Cytron [7])

Figure 29: DC Energy Meter (Photo by Mictuning [8])

The effect this had on the system was quantified using a MICTUNING DC Energy Meter. Using this setup, it was determined that using the new setup, there was a 93.07% increase in power going straight, 90.03% increase in power in left turns, and 91.8% increase in power in right turns.

COMPUTER SCIENCE SUMMARY

Computer Science Summary

Since there is a Computer Science student who also participates on the project, a summary of the work that they supervised has been included below.

Excerpts from “Reflection of Work Done” by Bret Dusseault (the Computer Science student working on the ASV) [9]:

ON OVERALL COMPUTER SCIENCE GOALS FOR THE 2018-2019 YEAR:

“This year I have worked on several different tasks for ASV and ROV. My primary goal has been to improve the autonomous controls of the ASV, through testing and building new software for the TUPPS platform. That task is split into two sub-goals. First, is that we have to take control of the communications so that we can design our own system in totality. Secondly, we had to move our control logic over to a back-seat and front-seat model.”

ON THE TRANSFER FROM MOOS-IVP TO ROS:

Please note: both MOOS-IvP and ROS are communication platforms that are coded to implement autonomy. MOOS-IVP is a platform developed at the Massachusetts Institute of Technology, and according to its website is “a set of open source C++ modules for providing autonomy on robotic platforms, in particular autonomous marine vehicles [10].” ROS (Robot Operating System) is a different open-source system, which is similar to MOOS-IvP. ROS is more widely used, due to its broader range of applications. After the student teams from both summer research and the 2018-2019 academic year identified issues with replicability of tests when using MOOS-IvP, the decision was made to switch both the ASV and TUPPS to ROS.

“ROS, while less mature [than MOOS-IVP], allows for total control over the network and communication layout between devices. It also comes with a large repository of tools and libraries for rapidly developing the platforms we need. Therefore, we decided to proceed with ROS and write our own applications using it.”

ON THE IMPLEMENTATION OF A FRONT SEAT-BACK SEAT COMBINATION ON TUPPS:

“There are two competing designs for controlling complex autonomous systems like the ASV: a synchronized singular controller where each component has full (or close to) information of the mission, or a front seat and back seat that compartmentalizes tasks. From suggestions given by Dr. Renken we have proceeded with a front seat and back seat approach. The hope is that by splitting up responsibilities between the different areas of control, we can rapidly develop and tune each of them before ‘gluing’ them together with ROS. We also hope that it allows moving the software between different platforms and configurations significantly easier. For example, the team is testing IR range sensors for object detection on TUPPS, which only requires an Arduino board to translate and send those values through Ros to the back seat. If that system is moved onto the ASV or if different sensors are used, then the back seat will not have to change at all, only the front seat translator will have to be adjusted.”

COMPUTER SCIENCE SUMMARY

“Front seat controls are implemented with a minimal amount of data being sent between the front and back seat. The front seat does not need to know about any of the mission goals, only how fast it should move and at what heading. It then reads sensor values from its IMU [Inertial Measurement Unit] and moves according to the theoretical control models that have been designed. At the same time, it will send back some telemetry, like current speed and heading, along with any sort of error message, to the back seat for diagnostic purposes. This communication channel is flexible and permits future changes to not hamper older versions of controllers as long as they are not dependent on any new data channels. Once the TUPPS testing is complete, the front seat will be adapted to the ASV’s electronics layout and tested with the same back seat and communications. It is even possible to create ‘mock drivers’ to simulate values and outputs for testing components if their corresponding components are not ready. Ultimately, this strict division of responsibilities will make testing our platforms significantly easier and faster.”

WORK TO BE COMPLETED BY NEXT YEAR’S TEAM

Work to be Completed by Next Year’s Team

This project is continuing into its third and final year. As stated in the introduction, the goal of this project is autonomous ocean floor mapping using ASV-ROV pairs. The 2018-2019 team has set up a good platform for next year’s team to take over. The project this year emphasized documentation and continuity.

Next year’s ASV team will need to program the ASV so that it deploys all sensors and the ROV autonomously when the sonar detects something on the ocean floor, using the setup established this year.

The team will also need to switch the ASV autonomy over to ROS instead of MOOS (as is being done with TUPPS). The PID controllers will need to be tuned on TUPPS, and tuned and implemented on the ASV. Next year’s ASV team may also account for additional external forces in the theoretical model, such as wind and waves, if there is the opportunity to do so. The theoretical model should also be compared to actual results collected using a GPS and IMU data.

The team will need to finalize the placement of all components on the ASV, so that the final buoyancy and stability calculations can be completed.

WORK TO BE COMPLETED BY NEXT YEAR’S TEAM

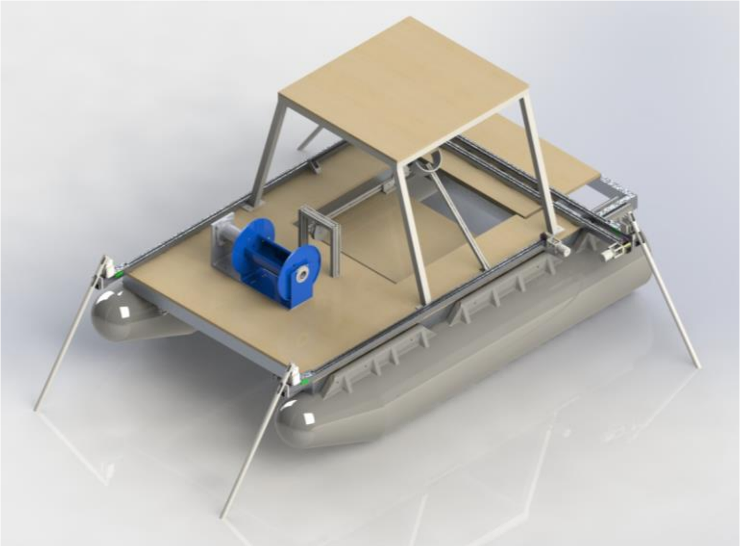

Figure 30: Model of Autonomous Surface Vehicle (ASV)

ACKNOWLEDGMENTS

Acknowledgments

Thank you to all those who have funded this project (see Financial Summary).

Thank you to John Ahern, for his assistance getting the team crane certified and giving valuable input.

Thank you to Dr. Martin Renken from Keyport, WA Naval Base, for his support and insight.

Thank you to the ROV team for their collaboration.

Thank you to Laura Gustafson for helping organize our time for testing and providing us with outreach opportunities.

Appendices

APPENDIX A: REFERENCES

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"Computer Science Member of ASV team"

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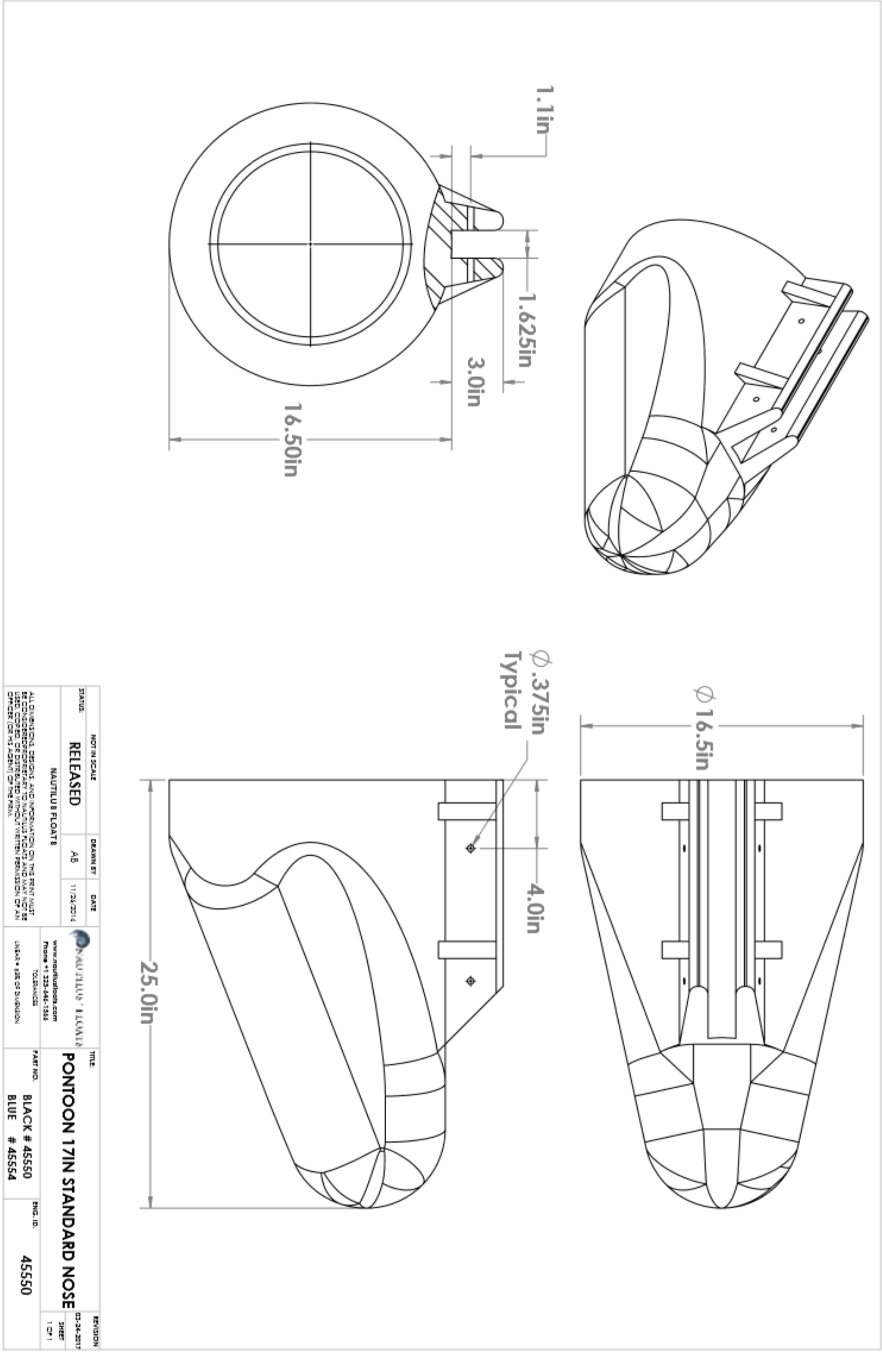
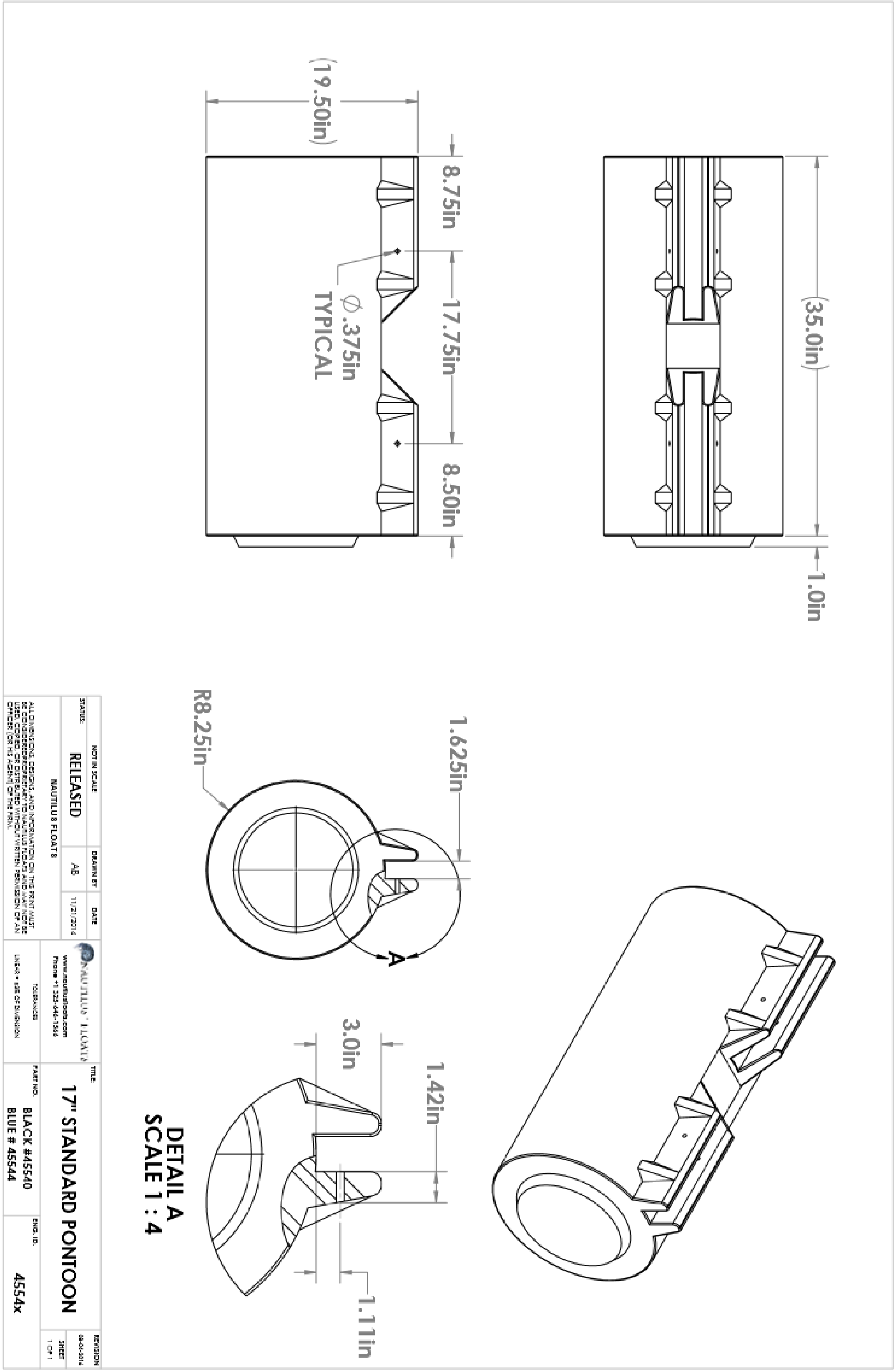
APPENDICES

APPENDIX B: PONTOON DRAWINGS



APPENDICES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1 OF 1

Date	Vendor	Items	Deposits	Withdrawals	Balance
		Balance Forward (As of July 12, 2018)	$ 1,581.71		$ 1,581.71
		Dean's Office Contribution	$ 1,500.00		$ 3,081.71
		ME Events - Ocean Discovery; ME441; ASD; Mini ASD 1&2	$ -		$ 3,081.71
		COLSA Contribution	$ 1,500.00		$ 4,581.71
		Computer Science contribution	$ -		$ 4,581.71
7/12/2018	Amazon	lipo packs		$ 66.68	$ 4,515.03
7/12/2018	Home Depot	project supplies		$ 26.23	$ 4,488.80
7/12/2018	Blue Robotics	basic ESC		$ 56.00	$ 4,432.80
7/19/2018	Walmart	project supplies		$ 15.88	$ 4,416.92
7/19/2018	Walmart	project supplies		$ 39.55	$ 4,377.37
7/19/2018	Sparkfun	dongles		$ 56.21	$ 4,321.16
7/19/2018	Amazon	breakout board/antenna		$ 129.71	$ 4,191.45
7/24/2018	Walmart	project supplies		$ 3.98	$ 4,187.47
7/27/2018	Robot Shop	GPS/Navigation kit		$ 488.00	$ 3,699.47
8/1/2018	Amazon	electronics - breadboards/breakout		$ 81.17	$ 3,618.30
7/27/2018	Amazon	usb cables		$ 19.98	$ 3,598.32
7/27/2018	Amazon	disconnect kit		$ 15.49	$ 3,582.83
7/30/2018	Amazon	power supply		$ 49.18	$ 3,533.65
7/12/2018	Walmart	noodle/straps		$ 17.81	$ 3,515.84
8/5/2018	Amazon	connector plugs		$ 7.49	$ 3,508.35
7/31/2018	Amazon	lipo packs		$ 51.20	$ 3,457.15
10/17/2018	Amazon	Raspberry pi & micro SD cards		$ 73.35	$ 3,383.80
10/17/2018	Amazon	power supply		$ 51.18	$ 3,332.62
10/18/2018	Amazon	batteries/label maker tape		$ 27.60	$ 3,305.02
10/18/2018	Walmart	battery charger		$ 39.76	$ 3,265.26
10/17/2018	Adafruit	arduino IR sensors		$ 143.36	$ 3,121.90
11/13/2018	Amazon	3x Arduino Mega 2560		$ 43.69	$ 3,078.21
11/13/2018	Amazon	DC Motor Driver		$ 149.90	$ 2,928.31
11/26/2010	Amazon	Pulley, pulley wheel, round rod		$ 37.52	$ 2,890.79
11/27/2018	Amazon	100A multimeter		$ 16.99	$ 2,873.80
11/27/2018	Walmart	Latch box & latch tote		$ 14.95	$ 2,858.85
12/11/2018	McMaster	PVC 3/4" x 10ft, socket head screws, stainless hex nuts		$ 107.67	$ 2,751.18
12/14/2018	McMaster	Carbon steel rod, shaft collar, 6061 Aluminum stock		$ 41.51	$ 2,709.67

12/14/2018	Robot Shop	LiDAR sensor		$ 1,775.00	$ 934.67
1/7/2019	Walmart	Tupps supplies		$ 78.91	$ 855.76
1/8/2019	Unknown	Laptop		$ 368.00	$ 487.76
1/25/2019	Amazon	3D printer filament		$ 19.99	$ 467.77
1/25/2019	McMaster	Screws & set screws		$ 27.75	$ 440.02
1/3/2019	Amazon	Lenovo water resistant keyboard		$ 169.94	$ 270.08
1/9/2019	Amazon	Lenovo keyboard return		$ (161.21)	$ 431.29
1/29/2019	Amazon	6v DC Motors		$ 59.92	$ 371.37
2/4/2019	Lowe's	PVC pipe & adapters		$ 25.94	$ 345.43
2/4/2019	Amazon	Multimeter & wire		$ 27.59	$ 317.84
2/5/2019	Lowe's	PVC pipe, wood dowel, machine screws		$ 16.56	$ 301.28
2/6/2019		Parents Association	$ 2,000.00		$ 2,301.28
2/18/2019	McMaster	Socket Head Screws 2-1/2" (Shipping not yet included)		$ 17.61	$ 2,283.67
2/27/2019	Amazon	Scale/angle finder		$ 58.95	$ 2,224.72
4/3/2019	Amazon	wires, DC power cords, connectors		$ 51.94	$ 2,172.78
4/3/2019	Adafruit	Ultrasonic rangefinders		$ 109.68	$ 2,063.10
3/13/2019	Robot Shop	Return - LiDAR Sensor		$ (1,775.00)	$ 3,838.10
4/16/2019	Amazon	Right angle USB adapter X2		$ 12.54	$ 3,825.56
4/16/2019	Amazon	Arduion Relay Module		$ 13.98	$ 3,811.58
4/13/2019	Walmart	Whistle, fire extinguisher, rope Type IV PFD		$ 36.34	$ 3,775.24
4/7/2019	Lowe's	TUPPs PVC elbows		$ 16.25	$ 3,758.99
4/17/2019	Amazon	ball bearings, X3 timing belts & pulley wheels		$ 61.95	$ 3,697.04
4/17/2019	Amazon	X1 timing belt & pulley wheel		$ 13.99	$ 3,683.05
4/17/2019	McMaster	shaft couplings, aluminum sheet, steel rod		$ 150.01	$ 3,533.04
4/9/2019	Amazon	X2 wire strippers, X2 tape measures		$ 29.41	$ 3,503.63
					$ 3,503.63
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