4-17-2018

Land, Air, Sea, Rover (LASR) - Unmanned Vehicle

Gabriel Prescinotti Vivan
Western Michigan University, gabriel.vivan@yahoo.com

Follow this and additional works at: https://scholarworks.wmich.edu/honors_theses

Part of the Systems Engineering and Multidisciplinary Design Optimization Commons

Recommended Citation
https://scholarworks.wmich.edu/honors_theses/3014

This Honors Thesis-Open Access is brought to you for free and open access by the Lee Honors College at ScholarWorks at WMU. It has been accepted for inclusion in Honors Theses by an authorized administrator of ScholarWorks at WMU. For more information, please contact maira.bundza@wmich.edu.
Land, Air, Sea, Rover (LASR) - Unmanned Vehicle

Western Michigan University
Department of Mechanical and Aerospace Engineering

Joshua Gudenau
Corey Lee
Gabriel Prescinotti Vivan

Faculty Advisor:
Dr. William Liou

Spring 2018
Group: 04-18-17
DISCLAIMER

This project report was written by students at Western Michigan University to fulfill an engineering curriculum requirement. Western Michigan University makes no representation that the material contained in this report is error-free or complete in all respects. Persons or organizations who choose to use this material do so at their own risk.
ACKNOWLEDGEMENTS

We would like many people who helped us complete this project:

- Our families and friends for supporting us through the difficult times, and being understanding of our time commitments with the project.
- Dr. William Liou for providing feedback, advice, and helping us in many ways throughout the entire project.
- Dr. Damon Miller for helping us with power and electronic circuits understanding and feedback.
- Mr. Overberger for providing us access to the facility where we could work at.
- WMU’s IEEE members for helping us unsolder LASS’s power distribution board.
- WMU’s WALI and AIAA groups for allowing us use their facilities for different testing purposes.
- WMU’s Student Recreation Center staff for giving us access to their pool and tennis courts in order to perform different test procedures.
- WMU’s Computer Engineering students for allowing us to use their oscilloscopes for signal processing tests.
- All other students and friends we talked to throughout the project, who never failed to provide constructive feedback and new ideas towards the project.
ABSTRACT

This senior design project encompassed the optimization of a previously built quadcopter, as well as the design of new components for additional functions and increased range of operations. The previous vehicle was designed to operate as a helicopter, land rover, and submarine. Although the vehicle operates successfully in these three environments, it is not very successful on transitioning between them, i.e. cannot take off from underneath water. This year’s project goals included optimizing the current vehicle so that it could transition seamlessly between its functions and adding an additional function: to be able to rover at the bottom of a body of water, as a sea rover. The chosen name for the prototype is thus Land, Air, Sea, Rover (LASR) Unmanned Vehicle. The concept will allow researchers and professionals around the globe to significantly increase their range of operations using a single vehicle. LASR will have no limitations whether it is to be used under, on, or above earth.
# TABLE OF CONTENTS

## INTRODUCTION

Background ........................................................................................................... 9
Problem Posed and Need ....................................................................................... 9
Objective of Work ................................................................................................. 10
Scope and Limitation ............................................................................................ 10

## DESIGN PROCESS

Benchmarking ...................................................................................................... 11
Proposed Solution ................................................................................................. 12
  
  Land Locomotion and Control ............................................................................. 12
  Air Locomotion and Control ............................................................................... 13
  Sea Locomotion and Control ............................................................................... 14
  Underwater Rover Locomotion and Control ...................................................... 14

Methodology ........................................................................................................ 15
  Weight Reduction ............................................................................................... 15
  Drive Train ......................................................................................................... 16
  Radio Communication ........................................................................................ 19
  Electrical Systems .............................................................................................. 19
  Field of View ..................................................................................................... 23
  Waterproofing ..................................................................................................... 24
  Buoyancy ............................................................................................................ 24

## BUILD PROCESS

LASS Disassembly ............................................................................................... 26
Drive Train Assembly ........................................................................................... 27
Waterproof Container ........................................................................................... 28
Electrical Components ......................................................................................... 30

## TESTING

Weight Determination ............................................................................................ 32
Center of Gravity .................................................................................................. 34
Land Mode ............................................................................................................ 36
<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>LASS Design</td>
<td>9</td>
</tr>
<tr>
<td>2</td>
<td>LASS</td>
<td>12</td>
</tr>
<tr>
<td>3</td>
<td>LASR Land Mode</td>
<td>13</td>
</tr>
<tr>
<td>4</td>
<td>LASR Air Mode</td>
<td>13</td>
</tr>
<tr>
<td>5</td>
<td>LASR Depth Control</td>
<td>15</td>
</tr>
<tr>
<td>6</td>
<td>SolidWorks model of drive train used in Project LASR</td>
<td>16</td>
</tr>
<tr>
<td>7</td>
<td>SolidWorks model of tank chassis and tank wheel</td>
<td>17</td>
</tr>
<tr>
<td>8</td>
<td>Cartesian Coordinate to Differential Drive</td>
<td>18</td>
</tr>
<tr>
<td>9</td>
<td>LASS Signal Diagram</td>
<td>20</td>
</tr>
<tr>
<td>10</td>
<td>LASR Signal Diagram</td>
<td>21</td>
</tr>
<tr>
<td>11</td>
<td>LASS Power Systems Diagram</td>
<td>22</td>
</tr>
<tr>
<td>12</td>
<td>LASR Power Systems Diagram</td>
<td>23</td>
</tr>
<tr>
<td>13</td>
<td>GoPro in LASR</td>
<td>23</td>
</tr>
<tr>
<td>14</td>
<td>LASR Final Assembly</td>
<td>26</td>
</tr>
<tr>
<td>15</td>
<td>LASS Front Assembly</td>
<td>26</td>
</tr>
<tr>
<td>16</td>
<td>LASS Struts</td>
<td>27</td>
</tr>
<tr>
<td>17</td>
<td>Drive Train Assembly</td>
<td>28</td>
</tr>
<tr>
<td>18</td>
<td>Drive Train Mounting</td>
<td>28</td>
</tr>
<tr>
<td>19</td>
<td>Waterproof Container Mounting Brackets</td>
<td>29</td>
</tr>
<tr>
<td>20</td>
<td>LASS PDB Construction</td>
<td>30</td>
</tr>
<tr>
<td>21</td>
<td>LASR PDB Construction</td>
<td>30</td>
</tr>
<tr>
<td>22</td>
<td>Circuit Boards</td>
<td>31</td>
</tr>
<tr>
<td>23</td>
<td>Center of Gravity Testing Set-Up</td>
<td>34</td>
</tr>
<tr>
<td>24</td>
<td>Center of Gravity Roll Level</td>
<td>35</td>
</tr>
<tr>
<td>25</td>
<td>Center of Gravity Pitch Level</td>
<td>35</td>
</tr>
<tr>
<td>26</td>
<td>LASR Incline Test</td>
<td>37</td>
</tr>
<tr>
<td>27</td>
<td>PID Testing</td>
<td>38</td>
</tr>
<tr>
<td>28</td>
<td>Thrust Measuring Stand</td>
<td>39</td>
</tr>
<tr>
<td>29</td>
<td>LASR in Rover Mode</td>
<td>41</td>
</tr>
</tbody>
</table>
TABLE OF TABLES

Table 1: Benchmarking comparison .................................................................................. 11
Table 2: Channel Assignment .......................................................................................... 19
Table 3: Camera Decision Matrix .................................................................................... 24
Table 4: Weight Comparison .......................................................................................... 32
Table 5: LASR Component Weight .................................................................................. 33
Table 6: Arduino Pinouts ............................................................................................... 42
Table 7: LASS vs LASR Specifications ............................................................................ 43
Table 8: Performance Comparison .................................................................................. 44
INTRODUCTION

Background

Unmanned aerial vehicles (UAV), commonly known as drones, have become increasingly popular, and are relatively cheap considering the functionalities and practicalities they offer. Current research efforts at some higher education institutions such as Western Michigan University [3], Oakland University [6], and Rutgers University [2], revolve around optimizing these vehicles to increase range of operations. These research projects have common goals of utilizing drones as search, rescue, and patrol vehicles. When extending the operational capabilities of UAVs, they are simply called unmanned vehicles (UVs), as they are able to operate in all environments. This project is based on the previously designed multipurpose quadcopter– Land, Air, Surface, Submarine (LASS) aerial system, and focuses on optimization and improvements.

Problem Posed and Need

Considering LASS conclusions, the previous vehicle, shown in Figure 1, could operate successfully to some extent in the different environments but not transition between them [3]. Thus, the problem posed for the current project is an optimization one. The Land, Air, Sea, Rover (LASR) unmanned vehicle concept has to overcome weight and power limitations, improve the dive system, as well as have a newly designed underwater rover system.

Based on the needs of the previous vehicle research, there are no current UVs able to operate in a large range of environments. By proving the concept is viable and efficient, the team shows that a single vehicle can be used for actions that in today’s world would require multiple vehicles. These actions range from search and rescue missions, research jobs, cinematography, educational purposes, tourism and entertainment, sports, and many other functions only limited by the user’s imagination.
In addition to that, NASA’s Innovative Advanced Concepts program has recently funded 16 projects, $125,000 each, to develop a robot that is able to operate in land, air, and sea environments, in order to explore Titan, one of Saturn’s moons [1]. This shows that this project has a vast array of applications, not being limited by the needs posed solely on Earth.

**Objective of Work**

The objectives of the new design are to maintain all the previous vehicle’s accomplishments (further detailed in the benchmarking section), add an underwater rover capability, be able to transition seamlessly between modes, and more successfully operate in the different environments. Although the primary focus is optimization, the team is still proving a concept. Therefore, it is expected that there will still be room for optimization in each mode of operation. The prototype will confirm ability to operate in multiple environments with improvements from the previous model, and transition between them without changes in physical hardware. Additionally, a camera is required to assist in piloting the system, as well as collect situational data in the event of emergencies. Such camera should be able to transmit a live stream to the user.

**Scope and Limitation**

The scope of this project is to both prove that a single unmanned system can operate in multiple environments seamlessly, and to optimize previous accomplishments. The team does not expect to have ideal means of locomotion, maximum range or endurance, or the fastest propulsion capabilities in any environment. These would be goals for a future optimization project.

The solutions proposed in this concept are directly related to the team members’ technical skills, knowledge, and access to means of manufacturing. Again, an idealized model, including better aesthetics, would be considered future work.

Lastly, some limitations might come from a financial aspect. Considering aerial systems can be expensive and require precise machinery and electronics, the team will have to adjust solutions to what is within the reach of funds received from the university.
DESIGN PROCESS

Benchmarking

Benchmarking for LASR is completed based on the goals achieved by LASS. The team’s objectives are to maintain all of LASS’s achievements, in addition to new requirements put forth by the faculty advisor and team members of this project. For some specific modes of operation, benchmarking also is performed in comparison to other university’s unmanned systems.

1. 30 seconds of operation in each operational mode on a single charge of the battery.
2. Have the ability to wirelessly transition between all five operational modes, and from any individual mode to any other mode.
3. Have the ability to take off from underneath water.
4. On land, travel 360 degrees and on unfinished surfaces.
5. Have the ability to start locomotion on an incline.
6. In the air, be stable, able to hover, and respond quickly and accurately to input controls.
7. Have the ability to achieve altitudes of at least 10 feet.
8. On the surface of water, successfully float and travel 360 degrees without leaving the surface of the water.
9. As a submarine, submerge to a depth of at least 12 inches, travel 360 degrees, and be able to autonomously maintain a specified depth.
10. As an underwater rover, be able to travel 360 degrees, making contact with the bottom surface at all times.
11. Resurface in case there is loss of communication.
12. Video feed transmitted to either a phone, laptop, or computer.

The table below compares the different modes of operation of similar drones produced by other institutions [2,6,7].

<table>
<thead>
<tr>
<th>Vehicle</th>
<th>Flight</th>
<th>Land</th>
<th>Water Surface</th>
<th>Submarine</th>
<th>Underwater rover</th>
<th>Tethered</th>
</tr>
</thead>
<tbody>
<tr>
<td>X-TankCopter</td>
<td>✓</td>
<td>✓</td>
<td>❌</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LoonCopter</td>
<td>✓</td>
<td></td>
<td>✓</td>
<td>✓</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Naviator</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td></td>
<td>✓</td>
</tr>
</tbody>
</table>

*Table 1: Benchmarking comparison*
Proposed Solution

The optimization and redesign of LASS is an iterative process. Changes in one area will lead to either benefit or deficit in another, leading to changes across all platform systems. The following sections outline the solutions used to optimize LASS.

Land Locomotion and Control

This segment contains the most disparities to LASS’s design. LASS used a tricycle configuration to provide land locomotion, which lead to multiple problems. LASS could neither start from a stop, nor stop in a reasonable distance once moving. Figure 2 shows LASS before the design process. This team believed that completely replacing the tricycle mount by a continuous drivetrain would benefit the vehicle in various ways by reducing weight, increasing stability, improving the ability to reduce speed with a reverse command, and reducing the vehicle’s total volume.

![LASS](image)

*Figure 2: LASS*

The continuous track is made to be a multi-purpose propulsion system for land as well as water, similar to the AAV-P7/A1 amphibious assault vehicle. It consists of a Tamiya twin gearbox differential system powered by two regular 130 DC brushed motors. The motors are controlled by an Arduino Micro microprocessor. Shown in Figure 3, the continuous track is modeled after the SZDoit TP100. This model is made from an aluminum alloy and it was initially thought that this
would save weight, but is too heavy. To solve this, a 3D model is printed to cut the weight drastically.

![Figure 3: LASR Land Mode](image)

This type of drivetrain also allows for better directional control of the vehicle, as it is able to rotate about its vertical axis without horizontal displacement. This is achieved by moving the two tracks in opposite directions while the vehicle turns. However, a conventional brushed motor configuration that is directly connected to a receiver transmitting pulse width modulation (PWM) signals is not able to alternate directions. Therefore, an H-Bridge (or motor shield) system is necessary. This system is connected to a microcontroller that dictates the correct direction and speed for the two motors, as described in a later section.

**Air Locomotion and Control**

The air locomotion used by LASR does not differ much from that used by LASS. It consists of four electric brushless motors mounted on arms connected to a base, seen in Figure 4. The motors used are Tiger Motor MT2208-18 series brushless motor. Each motor is controlled using a Tiger Motor S12A Electric Speed Controller (ESC). The electrical diagrams and an in depth explanation of the electrical systems used to control the LASR are outlined in the methodology section of this report.

![Figure 4: LASR Air Mode](image)
In order to improve the air locomotion from last year’s vehicle, the team proposes a solution to cut overall weight, as well as raise thrust capability. Thrust is improved by replacing the 9x5 inch propeller for a 10x5 propeller, as analyzed further in the results section.

Sea Locomotion and Control

The continuous track drive train is a propulsion device in water as well as on land. Using the same controls as on land, the vehicle can maneuver with ease in water. Plastic covers are thermo-formed and placed above the tank treads so that the direction of the water is in one direction, allowing control. The vehicle is positively buoyant so in case of motor failure, it floats to the surface for recovery.

A relatively high line of flotation allows the flight propellers to be out of the water when the vehicle is in surface mode. This reduces drag when moving along the water surface and allows for an easier transition to air mode, as the vehicle does not have to break surface tension.

Underwater Rover Locomotion and Control

Two DYS BX1306 brushless motors are placed beneath opposite arms of the drone and are used for depth control. An Arduino code controls the propellers so that a desired depth can be reached when input into the controller, via a control system. When the vehicle needs to drive on a submerged surface, the depth propellers are set to full power so that contact with the surface can be maintained. The same microcontroller that operates land locomotion also operates all underwater systems, reducing the amount of separate parts for the different environments. As seen in Figure 5, the motors and propellers are moved to the arms of the LASR to increase the mass flow rate of water, increasing thrust.
Methodology

LASR is unique when compared to other aerial systems, leading to unique methods and solutions. The implementation of the proposed solutions is laid out in the following sections. Weight is the driving factor in all heavier-than-air flight, and will thus be discussed first.

Weight Reduction

Similar to other airborne systems, the weight of individual components is of utmost importance to the performance of LASR. Each component removed from LASS was subsequently weighed. This weight tracking method was used to find a target weight for the LASR as a whole. The goal was to reduce the weight of the LASR by a minimum of 100 grams in order to maintain an effective thrust to weight ratio of the system.

The primary source of weight in the LASS was the land locomotion and control system, and the waterproof container used to produce a buoyant force. Thus, the primary focus for reducing weight is a redesign of the drive train. The size of the waterproof container was reduced in order to minimize the weight as well as reduce the buoyancy. A small amount of weight was removed in the form of shorter wires, less marine grade heat shrink, more efficiently soldered connections, and less hot glue for waterproofing purposes.
Drive Train

As seen in Figure 6, the drivetrain represents the major change between LASS and LASR. Using hand calculations, the team verified that weight could be substantially reduced by replacing the long tricycle legs with a continuous track system.

The original design of the continuous track system was to use the SZDoit Mini T100 aluminum alloy tank tread. With a weight of 650g, this was heavier than the tricycle system used last year. To account for this, the motors were changed and two wheels removed. The group believed that with these changes, the tank track would be significantly lighter than the tricycle system. When the track was received and built, it was 428g, which was lighter than the tricycle system, but not light enough.

The tank chassis and wheel designs were then refined in SolidWorks so that they could be 3D printed. All parts were 3D printed using the third party company, Shapeways. The parts were printed in HP Nylon Plastic. While being more expensive than the other printing materials, this plastic is the most durable and has a low density of $1.01 \text{ g/cm}^3$. Before ordering the parts, an estimation of the weight of the chassis and wheels was calculated using the volume estimation from SolidWorks. The weight for the chassis and wheels was estimated to be 60 grams and 15 grams respectively. The actual weight of the chassis was 54 grams and the actual weight of the wheel was 13.4 grams. The difference in weight can be accounted for by irregularities in the printing process, and overestimation of the volume. The weight of the 3D printed parts was less than half of the weight of the aluminum alloy parts. The SolidWorks files of the 3D printed parts are displayed in Figure 7.
Hiltner and Pool mention the difficulty LASS had in starting locomotion, even on a flat surface [3]. This problem was due to a lack in torque provided by the only source of propulsion in land mode. The solution found was to increase the surface area of the tracks, and add one more motor for land propulsion.

Furthermore, a gearbox system was installed on a 203:1 ratio, in order to achieve the highest possible torque provided from the two 3V fed motors. The gearbox replaced the servo component from LASS, therefore it did not add any weight to the vehicle. It was placed on the aft portion, and connected to the back wheels on the tracks.
The electrical components and configuration for this new drivetrain represented the most challenging aspect of it. The two tracks had to be controlled simultaneously, while receiving coupled joystick inputs from a Cartesian plane. The algorithm implemented by the microcontroller had to perform functions as seen in Figure 8 below [5].

![Figure 8: Cartesian Coordinate to Differential Drive](image)

The solution represented in the above schematic was achieved using a map function, which converts the highest and lowest PWM values received from the receiver (988 – 2012 microseconds) to a proportional PWM for the motors, according to its own ranges (0 – 255). Forward and reverse directions are dictated by the H-bridge, which can reverse the way that current goes through the motors.

The code was written using Arduino’s software, and its output signal was tested using oscilloscopes, potentiometers, and a multimeter. Input and output signals for this algorithm are analog or digital, with four of them being PWM. The team had to carefully choose which board would be able to provide a good number of digital as well as PWM ports, while being compact. Therefore, the Arduino Micro was chosen.
Since underwater locomotion is done in the same manner as land locomotion, a single algorithm was composed by modifying the depth control code previously used by the LASS team. The separate and complete algorithms can be found in Appendix E.

Radio Communication

LASR uses the same radio communication device as LASS. A Taranis FrSky XD9 Plus transmitter that supports up to 16 channels was used to convey all of the desired inputs to LASR. An FrSky D8R-II Plus receiver was used in conjunction with the transmitter to relay flight data to the flight controller, and inputs to the Arduino for the land and sea configurations. The flight controller used is a Naze32 rev6. This flight controller has a built in gyroscope and accelerometer to maintain the stability of LASR. The Naze32 was programmed using the open source flight control software Cleanflight [4]. The process of programming the flight controller is outlined in Appendix G.

Electrical Systems

The electrical components of LASR had to be completely redesigned to account for the new drivetrain configuration. The vehicle is limited to having an 8-channel receiver, each of which cannot control more than one degree of freedom from the different modes. To solve this problem, the team decided to combine the operation of both the land and sea track movements. Even though it is not ideal to have the same track speed for both land and sea environments, this is a tradeoff inherent to the design process. It is important to note the different communication methods between LASS and LASR. Table 1 shows each channel assignment in both models.

<table>
<thead>
<tr>
<th>Channel No.</th>
<th>LASS</th>
<th>LASR</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Flying Thrust Setting</td>
<td>Flying Thrust Setting</td>
</tr>
<tr>
<td>2</td>
<td>Flying Roll Control</td>
<td>Flying Roll Control</td>
</tr>
<tr>
<td>3</td>
<td>Flying Pitch Control</td>
<td>Flying Pitch Control</td>
</tr>
<tr>
<td>4</td>
<td>Flying Yaw Control</td>
<td>Flying Yaw Control</td>
</tr>
<tr>
<td>5</td>
<td>Ducted Fan Power Setting</td>
<td>Differential Steering</td>
</tr>
<tr>
<td>6</td>
<td>Ducted Fan Control</td>
<td>Track Direction Control</td>
</tr>
<tr>
<td>7</td>
<td>Depth Control Setting</td>
<td>Depth Control Setting</td>
</tr>
<tr>
<td>8</td>
<td>Arming/Disarming Systems</td>
<td>Arming/Disarming Systems</td>
</tr>
</tbody>
</table>

Table 2: Channel Assignment

As seen in this table, and on LASS’s signal schematics in Figure 9, channels 1 through 4 are connected to the Naze32 Flight Controller, and control roll, pitch, throttle, and yaw,
respectively. Channel 5 controls the ducted fan ESC, and channel 6 controls the servo for directional control. Each ESC receives a signal from their respective sources, allowing for the control of the motors.

![Diagram of LASS signal diagram](image)

*Figure 9: LASS Signal Diagram*

LASR’s signal diagram is more complicated due to the addition of the continuous track. As one can see in Figure 10, channels 5 and 6 substituted the ducted fan motor and servo from LASS, and now control the horizontal and vertical components of land and underwater rover movement. Both the land and underwater signals are interpreted through a microcontroller on an Arduino Micro board, then sent to either a set of ESCs or the H-Bridge circuit. The H-Bridge is used to supply varying power to the 3V motors to achieve different speeds. Channel 7 sends PWM to signals to the Arduino for the depth control algorithm. Channel 8 changes the mode in which LASR is operating, and is connected to the flight controller as well.
A major portion of the design process for this vehicle was to program the microcontroller for both water and land operations. Initially, the team intended to have two Teensy LC Arduino compatible boards, one for the directional control of the tracks, and the other for the depth control algorithm. However, this solution immediately turned problematic, as the amount of extra wires, additional weight, and complexity for the electronics components showed problems that needed to be addressed. In addition to that, it is not efficient to have two boards operating on what a single, more capable, microcontroller can do on its own; hence, the team decided to implement both codes on a single Arduino Micro board. The algorithm used for depth control was unchanged, as LASS showed success in controlling the downward propellers [3]. Whenever a signal is received from Channel 7, the microcontroller understands that the vehicle is underwater, and therefore will send power to the propellers. The land and underwater directional control algorithm is described in detail in the methodology section above.
In addition to the redesign of the communication systems, the power distribution system had to be restructured. LASS used a Crazepony Power Distribution Board (PDB), which supplied power to seven total ESCs and implemented battery eliminator circuits (BEC) to power various systems. The flight controller used a BEC on the PDB while the FrSky receiver used a BEC on the ducted fan ESC. The ducted fan ESC also supplied power to the servo used in directional control. The original circuit diagram for power systems is shown in Figure 11.

![Figure 11: LASS Power Systems Diagram](image)

Comparing this diagram to the power systems of LASR, shown in Figure 12 there are significant differences. First, a Matek Systems HUBOSD PDB is used, which functions in a similar fashion to the Crazepony. A ducted fan is no longer used on LASR, and thus the ducted fan ESC has been removed. In its place is the Arduino Micro, which does not require the same voltage or current as the ESC. Due to the function of the Teensy being incorporated into the Arduino, a 5V BEC is used to supply ample power to the Arduino. The H-Bridge is powered through a 5V BEC on the PDB, as well as 3V through the Arduino. This is because the H-Bridge requires at least 8V to supply voltage to the 3V motors and its internal logic circuit. The FrSky receiver is now powered through a 5V BEC in the Naze32 Flight Controller, as it can no longer be powered by the ducted fan ESC.
Field of View

Conceptually, LASR can be used as an emergency response vehicle to evaluate an area in need of medical assistance. To do this, the system must not only be able to arrive at the affected area but transmit data as well. In accordance with this design requirement, a camera was chosen that could stream both video and audio to a phone, laptop, or PC. Based off the decision matrix in Table 3, the GoPro HERO5 Session was chosen. It can stream video and record audio, is inherently waterproof, and has an internal battery. As one can see in Figure 13, the HERO5 Session fit perfectly into an alcove designed for an ESC no longer in use, so additional space and fixtures were not required to mount the camera.
<table>
<thead>
<tr>
<th></th>
<th>HERO5 Black</th>
<th>HERO5 Session</th>
<th>HERO4 Black</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Dimensions</strong></td>
<td>61.7 x 44.4 x 24 mm</td>
<td>37.9 x 37.9 x 36.1 mm</td>
<td>41 x 59 x 30 mm</td>
</tr>
<tr>
<td><strong>Weight</strong></td>
<td>118g</td>
<td>73g</td>
<td>88/152 g</td>
</tr>
<tr>
<td><strong>Cost</strong></td>
<td>$399</td>
<td>$299</td>
<td>$299</td>
</tr>
<tr>
<td><strong>Wi-Fi</strong></td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td><strong>Streaming</strong></td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td><strong>Bluetooth</strong></td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td><strong>Waterproof</strong></td>
<td>33 ft</td>
<td>33 ft</td>
<td>Needs Housing</td>
</tr>
<tr>
<td><strong>Built in Battery</strong></td>
<td>No</td>
<td>Yes</td>
<td>No</td>
</tr>
</tbody>
</table>

*Table 3: Camera Decision Matrix*

**Waterproofing**

The process of waterproofing was taken in several steps. First, any exposed wire connections were either shrink wrapped with marine grade heat shrink or sprayed with a hydrophobic coating. Next, the primary electrical components were situated inside a plastic container. This container was waterproofed in a similar manner as exposed circuitry.

From the previous design, the ESCs and brushless motors have been waterproofed. The brushless motors are inherently waterproof as the coils are inside an airtight housing. They have been sprayed with a hydrophobic spray for extra security.

The most critical component to waterproof is the container housing all of the electrical circuit boards. To complete this, the wires were routed through several holes in the bottom of the container, then had the holes filled with silicone and hot glue. LASR was then be placed in a vat of water to find leaks, and the process was repeated until no leaks were present.

**Buoyancy**

Buoyancy is critical to the operation of LASR in water environments. If LASR is too buoyant, it will not be able to descend to a depth without completely redesigning the depth control system. The previous design group suggested that buoyancy be tested first, but with the redesign of the drive train, it was tested last. This was due to two factors: the design process and primary objectives. If the buoyancy of LASR was determined at the start of the design process, all subsequent decisions would be related to buoyancy. Considering LASR is first and foremost an optimization of an airborne system, weight is of primary concern, not buoyancy. Second, a fixed
buoyancy does not allow for weight creep. Any error in weight calculations would be disastrous, as the LASR is meant to have a slightly positive buoyancy.

Once the weight and displacement of LASR was known, the additional displacement of water was easily calculated, using the formula:

\[ F_B = \rho_F V_F g_0 \ [N] \]

where \( F_B \) is the buoyancy force, \( \rho_F \) is the density of the fluid, \( V_F \) is the volume of the fluid being displaced, and \( g_0 \) is gravitational acceleration. Dividing both sides by \( g_0 \) will relate the mass of the object to the required displaced volume in a certain fluid. For LASR, the fluid operated in is water. Using a MATLAB code found in Appendix F, and the estimated displacement of LASR in Solidworks, the buoyancy is found. This code outputs whether the LASR is over-buoyant, under-buoyant, or neutrally buoyant, and by how much. Based on this output, the additional displacement required to float was found. A waterproof container could then be selected to give LASR the desired buoyancy.
BUILD PROCESS

The build process of LASR is relatively straightforward. The following sections lay out the process used to assemble LASR. Figure 14 below shows the final assembly of LASR for reference.

![Figure 14: LASR Final Assembly](image1)

LASS Disassembly

LASS was received in a damaged state. The front strut had been pulled from its mount, and as a result, LASS could not support its own weight. The zip tie holding the axel was cut and then the support rod was pulled from the bearing, allowing for the entire assembly to be removed from LASS. The damaged state is shown in Figure 15, and the removed struts in Figure 16.

![Figure 15: LASS Front Assembly](image2)
Once the front strut had been disassembled, the weight of all components were taken and tabulated. Next, the rear struts were removed and weighed. The total weight of the three struts and their respective electrical components were noted and used as a benchmark for the development of the drive train. Next, the electrical systems were cataloged and removed. This process is described in a later section for easier comparison. Now that the unrequired components of LASS were removed, the assembly of LASR could begin.

**Drive Train Assembly**

The first major step in the build process was the assembly of the continuous track. The differential transmission was mounted on the 3D printed frame, and then metal wheels were attached. The aluminum wheels were used as the drive wheels as they are stronger than the 3D printed wheels, and have the required number of teeth for the track. Once the wheels had been mounted on the frame, the track was assembled and placed onto the wheels. The final assembly of the drive train is shown in Figure 17.
Next, the differential gearbox was attached to the drive train. The entire assembly was then mounted on the frame. In order to do this, two holes were drilled into the base of the quadcopter frame to coincide with holes present in the drive train frame. Nuts and bolts were then used to secure the drive train to the frame of the quadcopter, as seen in Figure 18.

**Waterproof Container**

Following the completion of the drive train, LASR was weighed and a waterproof container selected. Using nuts and bolts from LASS, the new waterproof container was mounted in an identical position on LASR, shown in Figure 19. Holes were then drilled into the bottom of the container to accommodate the wires that lead to the electrical systems. Next, spacers that were
included with the flight controller were used to lift any components off the bottom of the container. Electrical components were then placed onto the spacers to ensure a proper height while still being able to fit inside.

![Figure 19: Waterproof Container Mounting Brackets](image)

The LASS team had previously waterproofed all exposed electrical components. Other than the drive train components and GoPro, no other electronics were added to the exposed area of LASR and thus, no extra waterproofing measures were taken. The GoPro is waterproof on its own and required no extra measures. The electric motors used on the drive train are brushed and are inherently waterproof. As an added precaution, all holes leading to the internal components of the motor were filled with a moldable, self-hardening clay. All electrical connections were covered by a marine grade heat shrink to ensure a waterproof connection.

The final step of waterproofing was the container itself. Once the wires were fed through the holes into the container, hot glue was used to seal all possible avenues of water. It was imperative that no water be able to enter the container, so LASR was repeatedly dunked into a water filled vat to check for leaks. Once all leaks are stopped, a waterproof silicone gel is used to cover the inside base. This was an extra precaution to ensure no water was able to enter the container.
**Electrical Components**

To further reduce the weight of LASR, the electrical components are reconfigured. This was accomplished by removing unneeded wires and implementing a more efficient method of connecting wires and components together. LASS had irremovable wire connections on the PDB, seen in Figure 20. Due to this, any changes that needed to occur in the electrical components would require the complete disassembly of the circuit. This led to the addition of wire connections coming off of the new PDB, reducing the amount of wire needed. Using these connections, seen in Figure 21, LASR’s electrical systems were now more easily accessed and altered.

*Figure 20: LASS PDB Assembly*

*Figure 21: LASR PDB Assembly*
Once power was supplied to the components, communication signals were completed. The ESCs were connected to the flight controller, and their signals were verified using Cleanflight. Next, the channels of the receiver were connected to their respective pins on the flight controller and Arduino, and were verified again. After all signals were configured, the flight controller and PDB were mounted in the waterproof container, shown in Figure 22. LASR was then ready for testing.

![Circuit Boards]

*Figure 22: Circuit Boards*
TESTING

Weight Determination

The primary goal of this project was to optimize LASS. In order to do this, the weight of the system needed to be drastically reduced as it was too heavy to fly. According to last year’s report, LASS was 18 grams too heavy to fly [3]. LASR was designed to be at least 100 grams lighter to ensure a proper margin of error and available power for flight. Once completed, LASR was weighed and found to be 1612 grams, 222 grams less than the reported weight of LASS (1834 grams).

Since LASR uses essentially the same flight system as LASS, there were not many areas where weight could be saved in this function. The majority of the weight was saved in changing the tricycle configuration to a continuous track system. It can be seen in Table 4 that the Tricycle configuration on LASS had more complexity than the continuous track system on LASR. During the disassembly of LASS, every part was weighed and recorded. Additionally, every part of the continuous track on LASR was weighed and recorded. Comparing the two, this switch saved 181.9 grams. The overall weight of LASR and its individual components is found in Table 5.

<table>
<thead>
<tr>
<th>Part</th>
<th>Weight</th>
<th>Total (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wheels</td>
<td>20.2</td>
<td></td>
</tr>
<tr>
<td>Tread</td>
<td>35.2</td>
<td></td>
</tr>
<tr>
<td>Rear Strut Screws</td>
<td>6.4</td>
<td></td>
</tr>
<tr>
<td>Rear Strut Nuts</td>
<td>3.6</td>
<td></td>
</tr>
<tr>
<td>Rear Strut Cap</td>
<td>11.6</td>
<td></td>
</tr>
<tr>
<td>Right Rear Strut and Axle</td>
<td>64.6</td>
<td>541.4</td>
</tr>
<tr>
<td>Left Rear Strut and Axle</td>
<td>64.8</td>
<td></td>
</tr>
<tr>
<td>Front Turning Gear</td>
<td>3.5</td>
<td></td>
</tr>
<tr>
<td>Zip Tie in Front</td>
<td>0.6</td>
<td></td>
</tr>
<tr>
<td>Front Support + Wheel+ Tread</td>
<td>78.7</td>
<td></td>
</tr>
<tr>
<td>Front Motor and Wires</td>
<td>111</td>
<td></td>
</tr>
<tr>
<td>Turnigy</td>
<td>80.2</td>
<td></td>
</tr>
<tr>
<td>Servo</td>
<td>61</td>
<td></td>
</tr>
<tr>
<td>Wheel (Plastic) + Bearing</td>
<td>26.8</td>
<td></td>
</tr>
<tr>
<td>Chassis</td>
<td>54</td>
<td></td>
</tr>
<tr>
<td>Tread</td>
<td>114.4</td>
<td></td>
</tr>
<tr>
<td>H-Bridge</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>Bolt</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Differential +Motors</td>
<td>71.5</td>
<td></td>
</tr>
<tr>
<td>Driving Gear Wheel (Aluminum)</td>
<td>59.8</td>
<td></td>
</tr>
</tbody>
</table>

Table 4: Weight Comparison
<table>
<thead>
<tr>
<th>Part</th>
<th>Unit Weight (g)</th>
<th>Units</th>
<th>Total Weight (g)</th>
<th>Section Weight (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Flight Systems</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10 in. Propeller</td>
<td>27</td>
<td>4</td>
<td>108</td>
<td></td>
</tr>
<tr>
<td>10 in. Propeller cone</td>
<td>1.9</td>
<td>4</td>
<td>7.6</td>
<td></td>
</tr>
<tr>
<td>Electronic Speed Controllers</td>
<td>12</td>
<td>6</td>
<td>72</td>
<td></td>
</tr>
<tr>
<td>Receiver</td>
<td>8.2</td>
<td>1</td>
<td>8.2</td>
<td></td>
</tr>
<tr>
<td>Power Distribution Board</td>
<td>9.1</td>
<td>1</td>
<td>9.1</td>
<td></td>
</tr>
<tr>
<td>Arduino Micro</td>
<td>9</td>
<td>1</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>Flight Controller</td>
<td>8.5</td>
<td>1</td>
<td>8.5</td>
<td></td>
</tr>
<tr>
<td>1100 kV Motor</td>
<td>51</td>
<td>4</td>
<td>204</td>
<td></td>
</tr>
<tr>
<td>5 in. Propeller Cone</td>
<td>1.2</td>
<td>2</td>
<td>2.4</td>
<td></td>
</tr>
<tr>
<td>3100 kV Motor</td>
<td>12.3</td>
<td>2</td>
<td>24.6</td>
<td></td>
</tr>
<tr>
<td>5 in. Blade</td>
<td>2.8</td>
<td>2</td>
<td>5.6</td>
<td></td>
</tr>
<tr>
<td><strong>Drive Train</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wheel (plastic) + Bearing</td>
<td>13.4</td>
<td>2</td>
<td>26.8</td>
<td></td>
</tr>
<tr>
<td>Chassis</td>
<td>54</td>
<td>1</td>
<td>54</td>
<td></td>
</tr>
<tr>
<td>Tread</td>
<td>57.2</td>
<td>2</td>
<td>114.4</td>
<td></td>
</tr>
<tr>
<td>H-Bridge</td>
<td>30</td>
<td>1</td>
<td>30</td>
<td>359.5</td>
</tr>
<tr>
<td>Bolt</td>
<td>1.5</td>
<td>2</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Differential + Motors</td>
<td>71.5</td>
<td>1</td>
<td>71.5</td>
<td></td>
</tr>
<tr>
<td>Driving Gear Wheel (Aluminum)</td>
<td>29.9</td>
<td>2</td>
<td>59.8</td>
<td></td>
</tr>
<tr>
<td><strong>Frame Components</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Top Frame</td>
<td>200</td>
<td>1</td>
<td>200</td>
<td></td>
</tr>
<tr>
<td>Bottom Frame</td>
<td>55</td>
<td>1</td>
<td>55</td>
<td>295</td>
</tr>
<tr>
<td>Watertight container</td>
<td>40</td>
<td>1</td>
<td>40</td>
<td></td>
</tr>
<tr>
<td><strong>Miscellaneous Components</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3S30C Battery</td>
<td>204</td>
<td>1</td>
<td>204</td>
<td></td>
</tr>
<tr>
<td>Pressure Sensor + wires</td>
<td>16.1</td>
<td>1</td>
<td>16.1</td>
<td></td>
</tr>
<tr>
<td>Zip Ties added</td>
<td>1.1</td>
<td>8</td>
<td>8.8</td>
<td></td>
</tr>
<tr>
<td>Heat Shrink</td>
<td>15</td>
<td>2</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>Solder</td>
<td>15</td>
<td>1</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>Bullet Connectors</td>
<td>30</td>
<td>1</td>
<td>30</td>
<td>498.9</td>
</tr>
<tr>
<td>Roll of Wires</td>
<td>20</td>
<td>3</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td>Circuitry Mount</td>
<td>25</td>
<td>1</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>GoPro Camera</td>
<td>72</td>
<td>1</td>
<td>72</td>
<td></td>
</tr>
<tr>
<td>Stick of Hot Glue</td>
<td>6</td>
<td>3</td>
<td>18</td>
<td></td>
</tr>
<tr>
<td>Watertight Sealant</td>
<td>20</td>
<td>1</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td><strong>Total Estimation (g):</strong></td>
<td></td>
<td></td>
<td>1612.4</td>
<td></td>
</tr>
</tbody>
</table>

*Table 5: LASR Component Weight*
Center of Gravity

The center of gravity (CG) of LASR is essential to the stability of the system. In order to operate in each individual environment, the CG must meet the following criteria: be on or near the center of lift for flight; be underneath the center of buoyancy for water operations; be low to the ground for land operations. The reasoning behind these criteria is simple. If the CG is not within a reasonable distance of the center of lift, LASR will wobble in flight as the stability control of the flight controller tries to compensate. The CG should be under the center of buoyancy to avoid tipping over in the water. If it is not, due to the positive buoyancy of LASR, the system will flip over and no longer be able to operate. While not critically important to operations, a low CG will ensure stability in land mode. If it is not, a quick start, stop, or turn has the potential to tip LASR over, as seen in last year’s design [3].

In order to meet this criteria, it was determined that the CG should be at the center of LASR, below the waterproof container. To test this, LASR was held upside down by a pin, with all components attached. This allowed the system to freely pivot about the suspected CG, and weight could be added to all sides to determine where it needed to be added or removed if required. An app that uses the accelerometer of a smart phone was used to measure the levelness of LASR without placing weight on the system. Figure 23 shows the setup used, while Figures 24 and 25 show the front and side view, respectfully.

![Figure 23: Center of Gravity Testing Set-Up](image-url)
Using this method, it was found that the center of gravity was in the center of LASR. Comparing this to the predicted CG of the SolidWorks model, no alterations were required in either the model or physical system.
Land Mode

Testing of land mode was relatively complex. Once the code was written, the team did not immediately achieve success in control. Thus, it had to determine if the cause of the problem was hardware or software. A method to check this was to test different input and output signals through an oscilloscope and logic analyzer, in the Electrical Engineering Senior Design Lab at Western Michigan University. The team could then determine which input and output signals are analog, digital, or PWM, making the necessary changes on the code.

Next, correct but unsteady control was achieved when connecting a simple joystick circuit to the H-Bridge and motors. It was determined that the remaining problems were being caused by hardware. A solution was to feed the logic circuit of the H-Bridge from a different power source, and thus remove the jumper from it. In this setup, the motors were fed by a 5V output coming from the power distribution board, while the logic board on the motor shield was fed by a 3V output from the Arduino Microcontroller. This removed any erroneous feedback received from the motors to the logic board. With these changes, the vehicle achieved accurate, quick, and steady differential steering.

Once control was achieved, LASR was driven to tests all axes of movement. LASR has the ability to travel forward, backward, left, and right, as would be expected of a continuous track vehicle. There is no requirement to stop LASR to turn, as the motors for each side are operated independently of each other. This allows LASR to travel 360° while in land mode, and achieve pure rotational movement.

To meet benchmarking criteria, LASR must be able to start and stop on its own, start from an incline, and operate on unfinished surfaces. Due to the high torque of the differential gearbox, LASR was able to start on its own and on an incline of up to 20 degrees (measured with a protractor), shown in Figure 26.
The average speed was low due to the fact that the highest gear ratio possible was used. The gearbox also allowed for two other ratio configurations, which can be adjusted to achieve higher speeds. Another option to increase speed would be to upgrade the brushed motor.

To test on an unfinished surface, LASR was taken to a baseball field and driven around on the infield dirt. It operated successfully without a noticeable slow down. It was also able to operate on grass, and slippery surfaces, such as snow. Lastly, due to the large contact area of the tracks, LASR was able to overcome obstacles and unleveled surfaces (i.e. cracks and small steps) with ease. With the above mentioned test procedures, LASR achieved all goals posed on the benchmarking section related to land operation.

**Air Mode**

There are many steps involved in testing the flight capabilities of LASR. First, LASR must be able to achieve lift off. Next, it must be stable while in flight. Finally, LASR must be able to survive an impact with the ground to account for amateur pilots, unfavorable flight conditions, or loss of communication. Each of these must be tested in the order given, as stability cannot be
calibrated if flight is not achievable, and impact testing cannot be properly conducted if confidence in the stability of the LASR is in question.

To test the ability to fly, the following method was used. First, the weight of LASR was compared to the weight of LASS. LASR is 222 grams lighter than LASS, ensuring that the system could take off. Since LASR should theoretically fly, there was no other way to test this than to power the system and fly it. The first flight of LASR was a success, but limited. A height of only one foot was achieved to ensure no damage occurred before stability could be calibrated, and proper flight attained.

Stability was then tested using a combination of a test stand and Cleanflight. Cleanflight is the open source software used to program the flight controller. In addition to flight control, Cleanflight has the ability to program Proportional Integral Derivative (PID) control into the Naze32. This allows the Naze32 to stabilize LASR without user input. In order to test the effectiveness of the PID control, LASR was hung on a test stand that allowed for resistant free movement in all three axes. Figure 27 shows the test stand in use, with a concrete block to rest the LASR on while changes were made to the program. After multiple iterations to the PID control, a final setting was determined which allowed for proper stability while still maintaining maneuverability. The process for this is laid out in Appendix G and is included in the programing for the Naze32.

![Figure 27: PID Testing](image-url)
Following the integration of PID control, LASR was taken to a field outside to test flight and impact survivability. At full power settings LASR was able to achieve an altitude of 3 ft. Once at this height, the power was cut, and LASR was allowed to fall to the ground. All critical components survived, demonstrating that a system the size of LASR would survive a system failure when landing. The only component that broke was a 3D printed wheel whose spoke cracked. This part was easily replaced and was not critical to the functioning of LASR, as the system was still operable in both land and air mode.

Once it was determined that LASR would fly, it was beneficial to run a comparison of the propellers used on LASS, and a larger propeller bought by this design group. LASS used a three blade 9x5 propeller, meaning that the diameter of the three blades was 9 inches with a pitch of 5 inches. These propellers were compared to a three blade 10x5 propeller. Using a test stand, one of the motors from LASR was mounted, and the propellers attached during each test. Due to the difficulty of mounting the motor, only the test stand is shown in Figure 28. The results of the test are seen in Figure 29. On average, each 10x5 propeller produced one more Newton of thrust than the 9x5. While the 10x5 propeller weighed more than the 9x5, it did produce more thrust than the increase in weight, leading to the logical choice of using the 10x5 over the 9x5.

![Thrust Measuring Stand](Figure 28: Thrust Measuring Stand)
After the replacement of the propellers, LASR was taken outside to a field again, where the group performed sea, rover, and flight mode testing. As expected, the new propellers allowed the vehicle to gain altitude up to a point where ground effect is no longer considered. The vehicle could achieve heights of 20 ft. with ease on a full charge of battery.

With the large increase in available power, it was advantageous to perform a payload analysis. Payload positioning had to be given special consideration, as any major changes to the center of gravity location will affect flight stability. With that in mind, the team decided to strap National Collegiate Hockey Conference official hockey pucks to the top center of the waterproof container. This payload was chosen as the pucks are a regulation weight and easily mountable to LASR. Adding one puck a time, the team could achieve flight up to 6 ft. with a single puck on top of the vehicle. After adding a second puck, flight was not achieved. This proved the vehicle was able to carry at least 165 grams of payload.

Next, the transition between sea and air mode was tested. LASR started flight both when on surface mode, and when completely underwater. For surface mode, the vehicle was put to buoy, completely submerging the propellers. It was then given half throttle until the propellers were above the water, and then full throttle until LASR was completely out and flying. For the submarine to air mode transition, the vehicle was flown into the water, allowing it to fully
submerge. While completely underwater, the propellers spooled up to full throttle, until it reached the surface and took off without difficulties.

After performing all the above mentioned tests, the team could successfully achieve all of the goals posed on the benchmarking section, achieve other goals not initially expected, as well as transition seamlessly between the other two modes.

**Sea and Rover Mode**

Sea and rover capabilities were tested in conjunction with one another. To test rover capability without losing communication, LASR was placed into a shallow body of water. It was then put into either Sea or Rover mode, as they both allow the control of the drive train. Figure 29 shows the LASR in 3 inches of water to start. It was able to operate normally, with similar speed and directional control performance. This proved that the tracks were able to provide forward and backward propulsion for the underwater rover function, as well as showed that the brushed motors are waterproof.

![LASR in Rover Mode](image)

LASR was then driven into deeper water and allowed to float. Once floating, the continuous tracks were still able to provide directional control to the vehicle, although it was very slow. Next, the dynamic dive system was tested. All software components operated as usual, while one of the motors did not turn on. At this point, it was assessed that either the ESC or the motor
had a malfunction, and it could not be timely replaced due to waterproofing procedures and complexity of replacement. Nevertheless, the one operational propeller was able to diagonally pull LASR down. Therefore, the team concluded that if both propellers were operating, the vehicle would have been able to submerge. In addition, the pressure sensor output in connection to the Arduino algorithm was tested, and it operated successfully, similarly to LASS.

Another difference between the two vehicles is that LASR does not have an extended antenna. Since the transmitter used is in the 2.4 GHz frequency range, its radio waves do not penetrate water effectively. Because of that, the use of an extended antenna is unnecessary if it is going to be out of water. Upon testing, communications with LASR were lost at a depth of 6 inches. The team concluded that for the vehicle to operate at any depth lower than that, a new transmitter frequency should be considered, or an alternative way of making the vehicle tethered should be studied.

Lastly, the simultaneous control of the drivetrain and dive system algorithm was tested. The first Arduino microcontroller board (Nano) the team had purchased only provided six I/O PWM ports, while the vehicle required an extra PWM port for proper control. This translated into problems, as the microcontroller was not correctly interpreting one of the inputs. Therefore, the team upgraded to an Arduino Micro board. This corrected the issue of erroneous interpretations by the system. Table 6 below lays out the different ports used in each board.

<table>
<thead>
<tr>
<th>Output</th>
<th>Arduino Nano</th>
<th>Arduino Micro</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Port</td>
<td>Type</td>
</tr>
<tr>
<td>H-Bridge EnA</td>
<td>6</td>
<td>PWM</td>
</tr>
<tr>
<td>H-Bridge EnB</td>
<td>9</td>
<td>PWM</td>
</tr>
<tr>
<td>Receiver Channel 5</td>
<td>7</td>
<td>PWM</td>
</tr>
<tr>
<td>Receiver Channel 6</td>
<td>3</td>
<td>PWM</td>
</tr>
<tr>
<td>Receiver Channel 7</td>
<td>5</td>
<td>PWM</td>
</tr>
<tr>
<td>Depth Control Motor 1</td>
<td>10</td>
<td>PWM</td>
</tr>
<tr>
<td>Depth Control Motor 2</td>
<td>11</td>
<td>PWM</td>
</tr>
<tr>
<td>Pressure Sensor Serial</td>
<td>A4</td>
<td>SDA</td>
</tr>
<tr>
<td>Pressure Sensor Serial</td>
<td>A5</td>
<td>SCL</td>
</tr>
<tr>
<td>H-Bridge In1</td>
<td>2</td>
<td>Digital</td>
</tr>
<tr>
<td>H-Bridge In2</td>
<td>4</td>
<td>Digital</td>
</tr>
<tr>
<td>H-Bridge In3</td>
<td>8</td>
<td>Digital</td>
</tr>
<tr>
<td>H-Bridge In4</td>
<td>12</td>
<td>Digital</td>
</tr>
</tbody>
</table>

Table 6: Arduino Pinouts
After this change, both algorithms worked, although not as accurate as when independently set. Further work needs to be done when combining each independent code into a single one.

**Endurance**

Each mode was tested for endurance once the modes are verified and operational. To do this, LASR was operated in each mode for a set amount of time. The battery is then charged until full, with the charger displaying the amp-hours supplied. This number was then used to determine the percentage of the battery used, and how long LASR can operate while in that mode. LASR was operated at full throttle for 10 minutes in land mode, 4 minutes for flight time, and 5 minutes in sea mode.

**Results**

LASR performed above expectations for both land and air mode. Its specifications are compared to LASS, and can be found in Table 7.

<table>
<thead>
<tr>
<th>Specification</th>
<th>LASS</th>
<th>LASR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight (g)</td>
<td>1834</td>
<td>1612</td>
</tr>
<tr>
<td>Battery Life (min)</td>
<td>18</td>
<td>18</td>
</tr>
<tr>
<td>Top Speed (mph)</td>
<td>17</td>
<td>10</td>
</tr>
<tr>
<td>Max Altitude (ft)</td>
<td>1</td>
<td>20</td>
</tr>
<tr>
<td>Max Depth (in)</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Thrust (N)</td>
<td>17.66</td>
<td>28.25</td>
</tr>
<tr>
<td>Container Buoyancy Force (g)</td>
<td>2268</td>
<td>981</td>
</tr>
<tr>
<td>Wheel Torque (oz*in)</td>
<td>12</td>
<td>140</td>
</tr>
<tr>
<td>Servo Torque (oz*in)</td>
<td>157</td>
<td>N/A</td>
</tr>
<tr>
<td>Max Current Draw (A)</td>
<td>60</td>
<td>60</td>
</tr>
<tr>
<td>Max Burst Current (A)</td>
<td>150</td>
<td>150</td>
</tr>
<tr>
<td>Max Continuous Current Available (A)</td>
<td>80</td>
<td>80</td>
</tr>
<tr>
<td>Operating Voltage (V)</td>
<td>10.1-12.3</td>
<td>10.1-12.3</td>
</tr>
<tr>
<td>BEC Voltage (V)</td>
<td>5.6</td>
<td>5.12</td>
</tr>
<tr>
<td>Radio Signal Range (mi)</td>
<td>1.2</td>
<td>1.2</td>
</tr>
</tbody>
</table>

*Table 7: LASS vs LASR Specifications*
LASR outperforms LASS in land and air mode, but is deficient in sea and rover mode. Weight was reduced by 222 grams, and the thrust was increased by 10.59 N. With this decrease in weight and increase in thrust, LASR is able to outperform LASS in all air mode statistics. It is faster, more maneuverable, can carry more payload, and is able to achieve higher altitudes.

When it comes to current draw and voltage required, LASS and LASR are similar. They both use the same battery, flight controller, ESCs, and motors. While the BECs might be different, the current supplied is negligible when compared to that of the motors. Operating range is identical, as the same receiver and transmitter are used.

Servo torque is not applicable to LASR as the servo was removed. The controllability of LASR in sea mode is sub-standard. This can be attributed to the continuous track. In order to obtain movement from a standstill, as well as be able to start on an incline, a high torque was required. The high torque and low speed required to move LASR in land mode led to a slow moving and slow turning system. Despite this, LASR could still maneuver. The team concluded that implementing different settings for the track speed on land and sea mode could be beneficial. This can be achieved by modifying the algorithm used by the microcontroller.

Comparing LASR to LASS in endurance and speed, found in Table 8, one can see that there were trade-offs during the design process. In order to perform well in the land and surface modes, the top speed is dramatically reduced. This enabled LASR to start from a stop, as well as on an incline of 20°. During air operations, the increase in thrust lead to an increase in top speed for LASR. The battery life of LASR is higher than LASS for land, surface, and submarine modes. This is attributed to the smaller electric motors used for these modes, as less current is required.

<table>
<thead>
<tr>
<th>Mode</th>
<th>LASS</th>
<th>LASR</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Battery Life (min)</td>
<td>Top Speed (mph)</td>
</tr>
<tr>
<td>Land</td>
<td>45</td>
<td>17</td>
</tr>
<tr>
<td>Air</td>
<td>8</td>
<td>7</td>
</tr>
<tr>
<td>Surface</td>
<td>30</td>
<td>3</td>
</tr>
<tr>
<td>Submarine</td>
<td>25</td>
<td>2</td>
</tr>
<tr>
<td>Rover</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>

Table 8: Performance Comparison
The buoyancy was decreased by a factor of 2.3, which led to a more neutrally buoyant system. However, the decrease in buoyancy did not result in a decrease in depth, as the radio waves could not penetrate the water past a depth of six inches. Despite this, the team had a hard time controlling the depth of LASR. It was thought that with a reduction in weight and buoyancy LASR would be able to descend to depth. When testing, the left depth control motor failed, and the right motor could not compensate. However, the right motor was able to pull the right half of LASR under the surface, leading to the conclusion that with two fully operational motors, LASR will be able to submerge. The only limiting factor past this is the ability of radio waves to penetrate water, which is not in the scope of this project.

Eleven benchmarking parameters were put forth at the start of the project, with the addition of a twelfth at the halfway point. LASR was able to complete all but parameter 9, which can be attributed to the failure of a depth control motor. In the air, it responds accurately to input controls, is stable in flight, and can achieve an altitude of at least 15 feet. On land, LASR can start from a stop and on an incline, and travel in 360°. While in the water, LASR is buoyant, but not too buoyant to prevent submerging, all while traveling 360°. And most importantly, LASR has the ability to seamlessly transition between all modes of operation and have live video in each.
CONCLUSION

The development of unmanned vehicles is at a record high. Many higher education institutions and research organizations are increasing the amount of time and funds invested into the development of multipurpose drones. Western Michigan University can be considered to be on the vanguard on the research of these vehicles.

This senior design project was based on the optimization of a previous design project. The design process steps and characteristics, however, were still primordial for a successful completion of the project. The team acknowledged the need for optimization, set clear goals for the new vehicle, performed benchmarking analysis and explored solutions. Decisions on the vehicle’s main characteristics were then made as a group, followed by procurement of necessary parts, and assembly. Lastly, as with any new vehicle that is produced, extensive testing procedures were performed, and results were compared with the previous vehicle.

The optimization of LASS into a functional vehicle that has 5 operational modes represents an innovation not yet seen around the nation. At this time, a successful proof of concept has been achieved. Reflecting on all optimization goals stipulated for LASR, all but one have been completed.

Optimization accomplishments

This team was able to improve flight performance, by achieving takeoff, increasing flight speed, stability and accuracy. Land mode operations were also optimized in the sense that the vehicle can now start movement from a stopped position, as well as from an incline. Sea surface mode can also be considered to have been optimized, as a buoyancy is now more adequate to the other vehicle’s functions. A sea rover function has been added and successfully proven possible with the current drivetrain configuration. The only operational mode that has had neither improvement nor regression was the submarine mode.

All these were accomplished based on a successful selection of design choices, originated from basic calculations and simulations. The team had a clear idea that weight and buoyancy reduction, as well as power and torque improvements, were necessary. Since it has achieved all of these parameters, the optimization can be considered successful.
**Recommendations**

The development of a new vehicle is never considered fully complete, as there is always possibility of further improvements: these being performance traits, aesthetics, additional modes of operation, or more accurate instrumentation. Considering that, this team has a few recommendations that could be useful for future groups who intend to further develop this vehicle.

The design choice between a dynamic and static dive system can be considered the most important one. This is because all other modes of operation design choices will be made based on the use of a bilge system or propeller system. This team has been recommended to study the possibility of implementing a static system. This option was considered but discarded, as bilge systems are heavy, and the primary goal of optimization was weight reduction. After completing the project, the group still recommends that a future group assess the feasibility of pursuing a static solution, as submarine mode still seemed problematic. Another possible solution would be to explore different kinds of propellers and motors for underwater locomotion, considering the much lower rotation speed they achieve underwater.

The communication system also needs to be readdressed, since the high frequencies currently used do not allow for underwater control without the use of a tether. The team recommends that either a lower frequency transmitter is used, or a retractable antenna option is developed. This in itself could be considered an entire design project.

For video streaming capabilities, while the current configuration allows for a timely and high definition feed, its range is short, since it operates either on Wi-Fi or Bluetooth. Investigations on cameras or communication systems that can transmit a live video and audio feed via radio are therefore recommended. This also allows the option of adding First Person View (FPV) capabilities to the vehicle.

Lastly, although land mode operates successfully, it is not efficient. This is because the highest possible torque solution was chosen for this project, which resulted in very low speeds. The team believes that a good balance between the two can be achieved on manipulating the gear ratio of the drivetrain, as well as improving the land motors capabilities.
REFERENCES


APPENDICES

Appendix A: Acronyms Used

In order of appearance:
LASR – Land, Air, Sea, Rover
UAV – Unmanned Aerial Vehicle
UV – Unmanned Vehicle
LASS – Land, Air, Surface, Submarine
ESC – Electronic Speed Controller
PWM – Pulse Width Modulation
PDB – Power Distribution Board
BEC – Battery Eliminator Circuit
CG – Center of Gravity
PID – Proportional, Integral, Derivative
FPV – First Person View
## Appendix B: LASR Cost Spread Sheet

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost</th>
<th>Section Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Drive Train</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SZDoit Mini T100 Aluminum Alloy RC Tank</td>
<td>$49.85</td>
<td></td>
</tr>
<tr>
<td>Differential</td>
<td>$13.78</td>
<td></td>
</tr>
<tr>
<td>3D Printed Parts</td>
<td>$149.51</td>
<td></td>
</tr>
<tr>
<td>Extra 3D Printed Wheels</td>
<td>$62.48</td>
<td></td>
</tr>
<tr>
<td>Wood for Thermoform</td>
<td>$3.99</td>
<td></td>
</tr>
<tr>
<td><strong>Electronic Components</strong></td>
<td></td>
<td>$200.47</td>
</tr>
<tr>
<td>Teensy Microcontroller</td>
<td>$16.85</td>
<td></td>
</tr>
<tr>
<td>Flight Controller</td>
<td>$28.98</td>
<td></td>
</tr>
<tr>
<td>Power Distribution Board</td>
<td>$17.89</td>
<td></td>
</tr>
<tr>
<td>Arduino Micro with Headers</td>
<td>$33.97</td>
<td></td>
</tr>
<tr>
<td>Arduino Nano</td>
<td>$8.29</td>
<td></td>
</tr>
<tr>
<td>H Bridge</td>
<td>$6.89</td>
<td></td>
</tr>
<tr>
<td>Bullet Connectors</td>
<td>$34.61</td>
<td></td>
</tr>
<tr>
<td>3S LIPO Battery Pack</td>
<td>$52.99</td>
<td></td>
</tr>
<tr>
<td><strong>Flight Components</strong></td>
<td></td>
<td>$152.93</td>
</tr>
<tr>
<td>Brushless T-Motor MT2208</td>
<td>$45.18</td>
<td></td>
</tr>
<tr>
<td>10 inch Propellers</td>
<td>$39.08</td>
<td></td>
</tr>
<tr>
<td>FrSky D8R-II plus 8 Channel Receiver</td>
<td>$40.60</td>
<td></td>
</tr>
<tr>
<td>10 inch Propellers (Opposite direction)</td>
<td>$28.07</td>
<td></td>
</tr>
<tr>
<td><strong>Miscellaneous Components</strong></td>
<td></td>
<td>$295.33</td>
</tr>
<tr>
<td>Masking Tape</td>
<td>$3.59</td>
<td></td>
</tr>
<tr>
<td>Tupperware Containers</td>
<td>$2.12</td>
<td></td>
</tr>
<tr>
<td>GoPro Camera</td>
<td>$211.09</td>
<td></td>
</tr>
<tr>
<td>Fishing Line</td>
<td>$5.29</td>
<td></td>
</tr>
<tr>
<td>Hot Glue Gun</td>
<td>$5.29</td>
<td></td>
</tr>
<tr>
<td>Socket</td>
<td>$3.17</td>
<td></td>
</tr>
<tr>
<td>Drill Bit</td>
<td>$7.82</td>
<td></td>
</tr>
<tr>
<td>Wire Cutters</td>
<td>$15.93</td>
<td></td>
</tr>
<tr>
<td>Soldering Supplies</td>
<td>$3.37</td>
<td></td>
</tr>
<tr>
<td>Wire and Waterproof Supplies</td>
<td>$15.56</td>
<td></td>
</tr>
<tr>
<td>Western Michigan Decals</td>
<td>$22.10</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>Total Expenditures:</strong> $928.34</td>
</tr>
</tbody>
</table>


## Appendix C: Decision Matrix

<table>
<thead>
<tr>
<th>Needed Solution</th>
<th>Proposed Solution</th>
<th>Properties</th>
<th>Land Mode</th>
<th>Air Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mass</td>
<td>Dimensions</td>
<td>Cost</td>
</tr>
<tr>
<td>Drivetrain</td>
<td>Continuous Track</td>
<td>3</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Swivel</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Tripod</td>
<td>4</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>Fallsafes</td>
<td>Release Drive Train</td>
<td>5</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Pressurized Air Release System</td>
<td>3</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Pressure Depth Return System</td>
<td>5</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>Waterproof Housing</td>
<td>Separate Container</td>
<td>2</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Hydrophobic Spray</td>
<td>3</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Current System</td>
<td>4</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Vacuum Sealed Bag</td>
<td>5</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Depth Control</td>
<td>Bilge Pump</td>
<td>1</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Propeller System</td>
<td>5</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Current System</td>
<td>3</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Directional Control System</td>
<td>2</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Transition System</td>
<td>Static Dive System</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Dynamic Dive System</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Tracking System</td>
<td>GPS</td>
<td>4</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Tether</td>
<td>2</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Antenna for Sub. Com.</td>
<td>Fixed Antenna</td>
<td>3</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Retractable Antenna</td>
<td>2</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Custom Parts</td>
<td>3D Printed ABS</td>
<td>5</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Fabrication</td>
<td>Laser Cut Aluminum</td>
<td>3</td>
<td>1</td>
<td>3</td>
</tr>
</tbody>
</table>

## Criteria

<table>
<thead>
<tr>
<th>Surface Mode</th>
<th>Submerge</th>
<th>Remain at Surface Depth</th>
<th>Travel 360°</th>
<th>Communicate Without Use of Tether</th>
<th>Autonomously Maintain Specified Depth</th>
<th>Resurface After Failure</th>
<th>Total</th>
<th>Chosen Solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Float</td>
<td>Submerge</td>
<td>Remain at Surface Depth</td>
<td>Travel 360°</td>
<td>Communicate Without Use of Tether</td>
<td>Autonomously Maintain Specified Depth</td>
<td>Resurface After Failure</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>35</td>
<td>X</td>
</tr>
<tr>
<td>0</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>21</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>34</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>13</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>16</td>
<td>X</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>4</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>5</td>
<td>1</td>
<td>30 X</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>23</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>0</td>
<td>3</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>27</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>21</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>5</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>18</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>0</td>
<td>4</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>4</td>
<td>3</td>
<td>37 X</td>
</tr>
<tr>
<td>4</td>
<td>0</td>
<td>4</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>4</td>
<td>5</td>
<td>35</td>
</tr>
<tr>
<td>1</td>
<td>5</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>22</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>15</td>
<td>X</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>11</td>
<td>X</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>8</td>
<td></td>
</tr>
</tbody>
</table>
Appendix D: Gantt Chart
Appendix F: Buoyancy Calculation

{%
Buoyance Force Calculation
Author: Corey Lee

This code will calculate the buoyancy of an object based on its mass and displaced volume. If it is not buoyant, it will determine how much displacement is required to be buoyant.
%
}
g = 9.81;  %Gravitational constant  [m/s^2]

prompt1 = 'What is the mass of the object in kilograms? \n';
m = input(prompt1);  %Mass of the object  [kg]

prompt2 = 'What is the volume of the object [m^3]? \n';
V = input(prompt2);  %Volume of the object  [m^3]

rho = 1000;  %Density of water  [kg/m^3]

F = V*rho*g;  %Buoyancy Force required to float  [N]
F2 = m*g;  %Weight of the object  [N]

if F == F2
    fprintf ('The object is neutrally buoyant.\n')
    fprintf ('The buoyant force is %f [N]\n',F)
elseif F > F2
    F3 = (F-F2)/9.81;
    fprintf ('The object will float.\n')
    fprintf ('%f Liters of water displaced to sink.\n',F3)
else
    F4 = (F2-F)/9.81;
    fprintf ('The object will sink\n')
    fprintf ('%f Liters of water displaced to float.\n',F4)
end

Published with MATLAB® R2016b
Appendix G: Flight Controller Programming

To program the Naze32 rev6 flight controller, the Cleanflight opensource flight control program is used. The proper use of this program is highly dependent on the knowledge of the hardware used to fly, so ensure all technical specs are known. The steps to program a flight controller using this program are listed below.

1. Download Cleanflight. It is an open source app that uses Google Chrome to run.

2. If using a new flight controller, boot the controller. This is done by placing a wire between the two leads on the board labeled “boot,” With the wire still in place, plug the flight controller into the computer. Once the LEDs on the board are done blinking, the board is ready to download firmware.

3. Download the necessary firmware to operate the flight controller. Once this is done, Cleanflight can be used to program it.

4. Connect the flight controller and enter the set up tab. This is where the accelerometer will be calibrated, and is critical to the proper flight of the vehicle. Place the system on a flat surface and press the “Calibrate Accelerometer” button. Once complete, save and reboot.

5. Ports must now be configured to properly use all input and output pins of the flight controller. For the purpose of this project, UART1 Config/MSP is set to 115200, and UART2 is listed as Serial RX. This is different for every flight controller, so make sure to look up these inputs. Save and reboot.
6. The board can now be configured for the ESCs and motors used. Enter the “Configuration” tab and find the ESC/Motor Features tab. This tells the flight controller what type of signal is required to run the ESCs, and in turn, the motors. It will also let the minimum and maximum throttle be set. This project uses PWM to control all functions, so the protocol must be set to PWM. This could be different for other configurations. Next, the board alignment must be set. If the board is not placed with the arrow facing directly forward, the direction must be specified. If it is not, the system will try to fly in the direction of the arrow, even if it is sideways. For this project, a yaw correction of 315 ° was required.

7. The system will also need to be configured to match what devices are present on the flight controller. The NAze32 rev6 has an accelerometer and barometer, and were therefore indicated in the “System Configuration” section. The receiver type must also be specified, or inputs will not be read by the flight controller. The FrSky D8R-II Plus used in this project
has PWM outputs, with one output per channel. This setting should be found and input on
the “Receiver” section. Save and reboot the flight controller.

<table>
<thead>
<tr>
<th>System configuration</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Note:</strong> Make sure your FC is able to operate at these speeds! Check CPU and cycletime stability. Changing this may require PID re-tuning. TIP: Disable Accelerometer and other sensors to gain more performance.</td>
</tr>
<tr>
<td>Enable gyro 32kHz sampling mode</td>
</tr>
<tr>
<td>1 kHz ▼ Gyro update frequency</td>
</tr>
<tr>
<td>0.5 kHz ▼ PID loop frequency</td>
</tr>
<tr>
<td>Accelerometer</td>
</tr>
<tr>
<td>Barometer (if supported)</td>
</tr>
<tr>
<td>Magnetometer (if supported)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Personalization</th>
</tr>
</thead>
<tbody>
<tr>
<td>Craft name</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Camera</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 ▼ FPV Camera Angle [degrees]</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Receiver</th>
</tr>
</thead>
<tbody>
<tr>
<td>PWM RX input (one wire per chanr ▼ Receiver Mode</td>
</tr>
</tbody>
</table>

8. If the receiver/transmitter has the ability to relay battery information, it is necessary to input
the type of battery used. This project uses a 3-cell LiPo battery, and all subsequent
information was placed in the “Power and Battery” tab.

9. The receiver can now be connected to the flight controller and configured. Under this tab,
there are different settings that can be used for different brands. Taranis and FrSky are
listed as AETR1234, and this value is then selected. The stick min and max of the
transmitter can be input in this section as well. Once these values are input, save and reboot
the board. Cleanflight should now displace the proper number of channels for the receiver
used, as well as their current values. If the receiver and transmitter are linked and turned on, the channels will vary with the inputs of the transmitter. If they do not match, or no input is received, a wrong value was selected during previous steps. Review all manuals for the hardware used, and re-input the values. Save and reboot the flight controller.

10. If using an arming system, the modes of the flight controller must now be configured. Enter the “Modes” tab and review the options. “Arm” should correspond to Aux 4 (Channel 8) on the receiver used in this project. The value for arming should be only the input value desired to operate in flight mode. As such, the arming value is set between 1400 and 1600, corresponding to the arming switch on the transmitter being in the middle position. Any other value, and inputs will not be relayed to the ESCs. This project uses “Angle” for flight mode. This mode is for beginner to intermediate pilots, and does not allow for full channel inputs. This means that a full throttle will not correspond to a flip, which is desirable for a smooth and steady flight. The “Angle” mode is placed at the same value as the “Arm” mode, ensuring LASR will only fly if armed.

11. Now that the system can be armed, it is time to test the motors. Go to the “Motor” tab of Cleanflight. It is imperative that the battery be plugged in at this point. If it is not, any power required to run the motors will be supplied by the connected computer, and could easily damage both the board and computer. Once the battery is plugged in, override the
“Master Test Mode Notice,” With the transmitter off, manipulate each motor’s corresponding input to verify that a signal is being sent, and the motors work. Next, turn the transmitter on, and repeat the process using the transmitter. If the motors do not respond to the transmitter input, return to either the “Configuration” or “Receiver” and re-examine the properties.

12. Finally, PID tuning must be completed. Go to the “PID Tuning” tab, and examine all the available configurations. It is a good idea at this point to research what each value does, and its corresponding effect on the flight capabilities of the system. Set the desired values for PID in roll, pitch, and yaw, then test the flight stability of the system. Repeat this process until satisfied with the results. Save and reboot the flight controller. Disconnect, and the UAS is now configured for flight.
Appendix H: Transmitter Configuration

SB Switch:
Top - Air Mode active
Middle - Land Mode active
Bottom - Sea Mode active

SD Switch:
Top - System disarmed
Middle - Air Mode armed
Bottom - Land/Sea Modes armed

SH Switch:
Override Air Mode throttle to stabilize LASS in Submarine Mode

Left Slider:
Volume control

Left Stick:
Air Mode - Throttle & Yaw
Land Mode - N/A
Sea Mode - N/A

S1 Pot:
Depth control knob
Far Left - 0 inches deep
Far Right - 16 inches deep

Right Stick:
Air Mode - Pitch & Roll
Land Mode - Throttle & Dir.
Sea Mode - Throttle & Dir.
Appendix I: ABET Questionnaires

FORM 1

Evaluation of student outcome “An ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political ethical, health and safety, manufacturability, and sustainability”

1. This project involved the design of a: **System**
   **Description:** This project involved the design and optimization of a vehicle. The main goals were to improve performance and capabilities of the previous year’s design, as well as add a few other functions. The designed unmanned system is able to achieve flight, land, sea, and underwater locomotion, while transmitting a live feed through a camera connected via Wi-Fi or Bluetooth. [Pages 5, 12]

2. The need: Based on the needs of the previous vehicle research, there are no current UVs able to operate in a large range of environments. By proving the concept is viable and efficient, the team shows that a single vehicle can perform actions that in today’s world would require multiple vehicles. The vehicle can be used for search and rescue missions, research jobs, cinematography, educational purposes, entertainment, sports, and outer space exploration. NASA has currently funded many projects that are actively studying about multipurpose unmanned vehicles, to be used in the exploration of Saturn’s moon Titan. [Pages 11, 12]

3. The constraints:

   a. **Economic:** Advanced and modern unmanned vehicles can become a very expensive product. This team showed that an operational multipurpose drone could be produced with relatively low investments. However, if the need is to seek high performance in all operational modes, instruments that are more expensive, better quality materials, and manufacturing technologies are necessary, raising the total cost for production.

   b. **Social:** The rise of popularity of unmanned vehicles can pose a challenge to the privacy of the local population. As the range, endurance, and general performance of these vehicles grow, it becomes easy to take footage of private spaces or invade personal property. It is important that legislation and policies be developed in conjunction to the production of these vehicles.

   c. **Political:** With governmental agencies such as NASA starting to fund projects of the kind, political issues may arise. Different political views may alter the way projects are funded, and which vehicle capabilities will be given priority.

   d. **Ethical:** Referring to social constraints, the locations of where these vehicles will be operating may come back to being an ethical decision. Although there are current laws prohibiting the operation of drones next to airports, for example, enforcing these rules is a challenging task.

   e. **Health & Safety:** In addition to ethical constraints, operating these vehicles close to airports pose a threat to the health and safety of the public.
4. Is there a potential for a new patent in your design? Explain and compare to similar patents. Yes, to our knowledge there is no other vehicle of the kind that can perform in the same environments that LASR can. This represents there is a strong potential for a new patent. However, since this project was funded by Western Michigan University, its results are intellectual property of the university.

FORM 2
Evaluation of student outcome “A knowledge of contemporary issues”

1. Why is this project needed now?
The drone market has drastically expanded over the past five years. Over this time, they have become more diverse and stable in their design. However, few of these drones are able to transition between different modes, and none are able to function in land, air, and sea without being manually changed before the transition. Our model will allow researchers to further develop the feasibility of incorporating these features into commercialized drones. Where exactly this research will lead from there is hard to say, but with incorporating these unique capabilities, the opportunities are endless. [Pages 11 and 12]

2. Describe any new technologies and recent innovations utilized to complete this project and how will it improve satisfaction of the company’s existing customers?
Through our research, there are three research projects attempting to tackle this project at different universities. The B-Unstoppable (“Meet the TankCopter,” 2016), operates on land and in air, the Loon Copter (“Home Embedded,” 2016) which was made by a research team at Oakland University operates in air, on the surface of water, and underwater, and the Naviator (Blesch, 2015) which was made by a research team at Rutgers University which operates in the air and underwater. This project optimized an entirely new type of drone that is be able to function in all three environments: land, air, and sea. No new technology will be used in creating this drone, however the drone itself has become a new technology. [Page 13]

3. If this project is done for a company – how will it expand their potential markets?
This project is not being completed for a company.

How will it improve satisfaction of the company’s existing customers?
N/A

Identify the competitors for this kind of product, compare the proposal design with the company’s competitors’ products.
N/A

4. How did you address any safety and/or legal issues pertaining to this project? (e.g., OSHA, EPA, Human Factors, etc.)
We have all become familiar on Federal Aviation Administration (FAA) regulations pertaining to drones.

5. Are there any new standards or regulations on the horizon that could impact the development of the project?
With the drone market drastically expanding over the past five years, the FAA has added height restrictions as well as implemented new “no-fly zones,” and it is likely that they will continue to add new regulations as time progresses. However, we are unaware of any additional changes that will be taking place during the development of our drone at this time.

In recent patent searches, we were unable to find a patent related to a land, air, and sea vehicle that can also drive on submerged surfaces, so there is potential for a new patent on our overall design.

FORM 3

Evaluation of student outcome “An understanding of the impact of engineering solutions in a global, environmental and societal context”

1. Is this project useful outside of the United States? Describe why it is or not-provide details.  
This project is applicable anywhere in the world where drones are permitted to be operated. Multipurpose vehicles such as LASR will become the norm for search and rescue missions, as well as research operations. Different countries with different landscapes and geographies will not be limited to operate the vehicle as it offers a large range of capabilities and functionalities.

2. Does your project comply with U.S. and/or international standards or regulations? Which standards are applicable?  
The Federal Aviation Administration has some rules and regulations set in place currently for UAS systems weighting between 0.55 and 55 lbs. The UAS must be registered with the FAA, must not fly within a 5-mile radius of any airports, must always yield right of way to manned aircraft, and must follow community-based safety guidelines. The team made sure that all of these regulations were followed throughout the design, therefore LASR is within FAA requirements.

3. Is this project restricted in its application to specific markets or communities? To which markets or communities?  
The vehicle would only be restricted to communities in which drones are illegal to be used by the public. In all other cases, it can be used for recreation, research, education, and professional purposes. Some examples include analyzing and cleaning oil spills near underwater pipelines, monitoring migration patterns of animals, search and rescue missions, making aerial footage for companies, etc.

4. Design is focused on serving human needs. Design also can either negatively or positively influence quality of life. Address the impact of your project on the following areas. If the answer to any of the following is positive, explain how and, where relevant, what were your actions to address the issues?
Air Quality?
Air quality would not be affected by our project. LASR is powered by an electrical battery, therefore it does not expel harmful pollutants or gases.

Water Quality?
Our project may have different variations that might actually help improve water quality, such as cleaning oil spills in the ocean.

Food?
The quality of food and how it is harvested would not be negatively affected by our project. A possible application for the vehicle would be surveying crop areas to identify threats to the crops, or even scare animals that are harmful to the plants.

Noise Level?
This project is electrically powered using brushless motors. The vehicle, when operating, is relatively quiet compared to other drones and does not create noise pollution that is harmful to surrounding communities.

Does the project impact:

Human health?
This project would not affect human health.

Wildlife?
The vehicle has the potential of being used for research on migration patterns of local wildlife. The project could also be used to scare away predatory animals from crops or used by farmers to control herds of cattle.

Vegetation?
The vehicle could be used to analyze changes in the vegetation, assisting in research, or even helping localize and prevent wildfire.

Does this project improve:

Human interaction?
This project has no effect on human interaction, besides when used for recreational purposes.

Well-being?
This project has no effect on the well-being of others.

Safety?
This project could be used in search and rescue missions both in and out of water. It has the potential to make an impact in the search and rescue industry and potentially help search and rescue professionals save more lives, while experiencing less danger themselves.

Others?
The vehicle could be used in many other applications, only limited by governmental regulations and the user’s imagination.
The MAE faculty members have identified “A recognition of the need for, and ability to engage in life-long learning” as one of the student outcomes for both mechanical and aeronautical engineering programs.

NAME: Joshua Gudenau

1. List the skills you needed to execute your responsibilities on the project as outlined in ME 4790.
   
   I was organized through the process, keeping files for weight estimation and SolidWorks files on multiple drives to ensure they are not mistakenly deleted. My skills in Soldering and SolidWorks helped the team save of 200 grams of weight which ultimately allowed for flight and the transitions to be achieved.

2. Explain how you acquired or improved the skills needed for the completion the project.
   
   My skills in SolidWorks were improved by watching multiple videos online and doing various tutorials to become familiar with additional functions in the program. My time management skills were also improved as we had a set schedule of when we were going to work on LASR and this kept things moving forward in the project and allowed the team to complete it on time.

NAME: Corey Lee

1. List the skills you needed to execute your responsibilities on the project as outlined in ME 4790.
   
   I needed to be organized and stick to the scheduled laid out in the Gantt chart. This ensured that as a team, we accomplished all the tasks on time and progress proceeded as planned. I also needed to be motivating, as certain aspects of the project are new to the team, and we had to learn these new concepts. Learning these new concepts was challenging, but with the proper motivation, they were accomplished. I also needed to be prepared to write every week. I created structured test procedures so data is produced in the same manner every time.

2. Explain how you acquired or improved the skills needed for the completion the project.
   
   The main skills I had to acquire are related to electronics. I needed to learn how to solder, manage signals, and read circuit diagrams. I spent time reading the manuals for the circuit elements present to learn how they operated and what their functions were. To improve my soldering skills, I practiced on old boards over the course of several days. I also had to learn what different types of signals are and how they are interpreted. This allowed for the proper programming of flight control systems.
NAME: Gabriel Prescinotti Vivan

1. List the skills you needed to execute your responsibilities on the project as outlined in ME 4790.

   I have had multiple experiences with professional research during my undergraduate studies. In all of these different projects, the subject of work was of innovation character, and therefore required the same mindset the team needed for this senior design project. Additionally, I have experience with working in control systems design, and simulations, which was helpful for coding the depth control system as well as the drivetrain locomotion algorithm. However, I did have to become proficient with Arduino coding and electronics, which was a great outcome of this project. Lastly, I have had many leadership positions within the University that gave me opportunities to develop communication and team working skills, which are very helpful for maintaining good team relationship.

2. Explain how you acquired or improved the skills needed for the completion the project.

   The main skill that I had to acquire and become proficient at was related to electronics, signal processing and Arduino coding. I have spent a considerable amount of time doing research, practicing online tutorials, exploring how other users solved similar problems. Since Arduino is an open source software, online resources are plentiful, and the community is very helpful towards new learners. For signal processing, I have had help from the Computer Engineering department students, who allowed me to use their hardware to make tests and provided me with feedback on what needed to be done for proper interpretation of the different kinds of signals.
Appendix J: Resumes

Josh Gudenau’s Resume

JOSHUA GUDENAU
41154 Belvidere Street
Harrison Charter Township, MI 48045
(586) 879-7653
josh_gudenau@yahoo.com

Objective
Self-directed and goal-oriented aerospace engineering student with an understanding of design process with exceptional creativity and interpersonal skills seeking employment.

Education
Western Michigan University
Major: Aerospace Engineering Minor: Mathematics
☐ Received the Excellence Scholarship
☐ Acquired over 100 hours of community service in events such as blood drives, the relay for life
   and Habitat for Humanity fundraisers.
☐ Expected Graduation: Spring 2018

Skills
☐ Complex problem solving ☐ Microsoft Office
☐ SolidWorks ☐ Quick Learner
☐ AutoCAD ☐ Team Leadership
☐ Superior Communication ☐ Soldering

Work Experience
2nd Shift Recycling Associate at Imperial Beverage, April 2017- Present
☐ Responsible for maintenance and organization of empty keg room.
☐ Lead weekly meetings discussing the status of the recycling department.

Crew Member at Valley Dining Services in Kalamazoo, September 2014- April 2017
☐ Work well in a team oriented environment in order to maintain smooth and timely operations in
   kitchen sanitation.

Maintenance at MacRay Harbor in Harrison Charter Township, April 2014-August 2016
☐ Utilize problem solving skills to execute dock repairs, pump repairs, and other minor repairs around
   the marina.
☐ Received multiple reviews that point out dedication to superior customer service.
☐ Operate heavy machinery with caution and safety.

Customer Acquisition at MTS Sales, July 2005- August 2013
☐ Showed leadership qualities in training potential new employees.
☐ Acquired new customers for the Macomb Daily, Daily Tribune, and Oakland Press.
☐ Was trusted in handling money for new customers.

Honors and Achievements
Land, Air, Sea, Rover (LASR)- Unmanned Vehicle, member Fall 2017- Present
☐ Received the Undergraduate Research Excellence Award from Western Michigan university.
☐ Design a quadcopter that can seamlessly transition from air, land, and sea modes of transportation.

American Institute of Aeronautics and Astronautics (AIAA), member
☐ Assist in the design and build of rockets used in competition.

Alpha Tau Omega Fraternity, community service chair Fall 2013- Spring 2017
☐ Attending the Emerging Leadership Council in Indianapolis.

Western Aerospace Launch Initiative (WALI), communication systems team member
☐ Assist in designing and building the communication system for a two-part satellite.

Charity Event for Habitat for Humanity, February 22-24, 2015
☐ Lead an organization (40+ members) to help raise money for Habitat for Humanity.
☐ Was in charge of all the money people donated to Habitat for Humanity. ($5,000)
Corey J. Lee
Corey.j.lee@wmich.edu – Cell: 810-869-2733

Effective leader who can motivate a team to accomplish difficult goals through military leadership and strong communication and organizational skills.

Education
Western Michigan University
Bachelors of Science in Aerospace Engineering
Expected Spring 2018
GPA: Overall 3.67, Major 3.59

Experience
Air Force Reserve Officer Training Corps
Michigan State University
Cadet/Vice Wing Commander

Fall 2013-Present

- Attend weekly training under active duty Air Force Personnel
- Develop skills required to be an effective Air Force Officer such as leadership, communication, teamwork, and time management.
- Responsible for executing training plan directed at 100+ cadets
- Supported all operations of the Cadet Wing including weekly planning, mission support, and cadet development

Student Success Center
Western Michigan University
Student Programs Assistant/Teachers Assistant

Summer 2017-Present

- Tutor freshmen in application of algebra to science, technology, and mathematics problems
- Grade completed work
- Assist in the education of students in a classroom setting
- Hold early intervention meetings to help students develop necessary study skills to succeed in an academic environment

Applebee’s Family Restaurant
Burton, Michigan
Host

Summer 2014

- Ensure customers had a decent experience
- Assist servers with serving food and taking orders
- Developed teamwork and communication skills

Honors and Awards

- Dean’s List – Fall 2013, Spring 2014, Fall 2015, Fall 2016, Spring 2017
- Mechanical and Aerospace Engineering Merit Scholarship – Fall 2015-Present
- ROTC Veteran’s Educational Benefits Scholarship – Spring 2015-Present
- The “M” Scholar Scholarship – Spring 2017
- AFROTC Commendation Award – Spring Semester 2014
- AFROTC Meritorious Service Award – Fall Semester 2014, Spring Semester 2015
- AFROTC Achievement Award – Fall Semester 2016
- National Defense Industrial Association Award – Spring Semester 2017
- The Order of the Founders and Patriots of America Award – Spring Semester 2017
- The American Legion ROTC Program Military Excellence Award – Spring Semester 2017

Membership

Tau Beta Pi, Michigan-Kappa Chapter

Fall 2016- Present
Chapter President: Spring 2017-Present
Gabriel Vivan’s Resume

Gabriel P. Vivan  
gabrielprescin.vivan@wmich.edu  
5200 Croyden Ave, Apt 23104  
Kalamazoo, MI 49009 – USA  
(269) 271 - 6680

OBJECTIVE: A highly motivated student seeking an entry-level position that will provide an opportunity for me to apply my engineering skills and enhance my education, while contributing to a company with a high-paced work environment.

EDUCATION:  
Western Michigan University  
Bachelor of Science in Aerospace Engineering  
Minors in International Business and Mathematics  
GPA: 3.95 / 4.00  
Lee Honors College  
Expected graduation date: April 2018

PROJECTS:  
Ford Motor Co. URP, Michigan  
Research assistant  
May 2017 – July 2017  
- Researched about improvements in control algorithms for shift and lock-up schedules in CVT transmissions coupled with downsized gasoline turbocharged direct injection (GTDI) engines.  
- Presented bi-weekly reports to the engineering team at Ford Motor Co.  
- Ran simulations based on the federal test procedure (FTP) cycle on Simulink and MATLAB

Unilever / Amazon / IKEA Case Studies, Netherlands  
Team member  
- Conducted research and provided reports on specific areas of select companies  
- Developed products to be introduced in new markets in the European Union  
- Worked with diverse groups of students from multiple countries in Europe

Advanced Studies Institute, SP, Brazil  
Research intern  
June 2014 – July 2014  
- Investigated about scramjet vehicles on transonic and hypersonic flows  
- Participated in shock tunnels experiments and performed CFD simulations through Ansys Fluent

SAE Aerodesign Group, Brazil  
Stability and control assistant  
March 2013 – July 2013  
- Ran reports on stability and control of small airplane models  
- Provided feedback to the aerodynamics and performance teams to design the best model for competition

WORK EXPERIENCE:  
International Student Activities, WMU, MI  
Activities assistant  
May 2017 – Present  
- Coordinate international orientation throughout the year, being responsible for a team of 30+ orientation leaders  
- Schedule, organize, and promote events on campus, encouraging interaction between domestic and international students  
- Manage all social media interaction and content for WMU International Student Activities office

International Admissions and Services, WMU, MI  
Student ambassador  
Feb. 2014 – May 2017  
- Contacted prospective international students regarding any difficulties they have with transitioning to university life  
- Contributed to an 11% increase in international enrollment  
- Established international relations between people from several different countries in the world

ACTIVITIES / AWARDS / LEADERSHIP:  
- Tau Beta Pi National Scholarship  
  Recipient  
  Sep. 2017 – Present
- Tau Beta Pi MI Kappa Chapter  
  Vice – President  
  April 2017 – Present
- Climbing team at WMU  
  Instructor / Secretary  
  Sep. 2016 – Present
- MAE Merit Scholarship  
  Recipient  
  Aug. 2014 – Present
- Brazilian Students Association at WMU  
  Founder and President  
  Aug. 2014 – Present
- Dietrich H. Haenické Scholarship  
  Recipient  
  Aug. 2013 – Present
- Western Student Association  
  Associate Justice  
  Oct. 2016 – April 2017
- Omicron Sigma Lambda  
  Fundraising Chair  
  Sep. 2016 – April 2017

SKILLS:  
- Non-technical: Fluent in English and Portuguese; Intermediate Spanish; Basic French and Dutch
- Technical: Microsoft Word, Excel, Access, PowerPoint; Ansys Fluent; MATLAB, Simulink; C++; AutoCAD; LabVIEW; Abaqus; BiZZdesign; Romax; IBM Cognos