ECE 455 Capstone Design in Electrical and Computer Engineering
Project Report

LOW-FREQUENCY ELECTROMAGNETIC EMITTING AUTONOMOUS BOAT FOR OFFSHORE PLANE RECKAGE RECOVERY

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1 Introduction

This project was developed to support the University of Wisconsin Missing in Action Recovery and Identification Project (UW MIA RIP), a program focused on locating and recovering U.S. service members who went missing during past wars. Many of these service members were lost when aircraft crashed in shallow coastal waters, especially in regions like Southeast Asia. Recovering their remains is difficult because traditional search methods are expensive and not always effective in those environments. Our team set out to design a low-cost, self-powered system that could help identify locations of underwater wreckage and assist with future recovery efforts.

The goal was to build an autonomous surface vehicle (ASV) that could generate a magnetic signal detectable by underwater equipment. The ASV works in tandem with an underwater autonomous vehicle (AUV), which has a 3-axis magnetometer on it that can sense the magnetic field generated by the ASV. This signal can help guide recovery teams to areas where aircraft debris might be buried or difficult to locate visually. We were challenged to build an ASV that could be built on a budget a budget of $500, uses accessible materials, fits in a suitcase, and could operate independently in the field.

To meet these goals, we constructed the boat using affordable components like PVC pipes for flotation, foam for stability, and a combination of wooden and polycarbonate boards for mounting electronics. A solar panel powers the system by charging two batteries, which then provide energy to the onboard electronics. These electronics include a flight controller for navigation, a Raspberry Pi for control, and a signal generator and amplifier to drive a coil that emits the magnetic field.

The boat is designed to follow GPS waypoints on its own, while also allowing manual control if needed. Electronics are enclosed in a waterproof box to keep them safe during outdoor testing. We used prebuilt circuit boards where possible to reduce development time and focus on integrating everything into a working prototype.

This report describes the design process, how the system works, and what we learned throughout the semester. We also discuss the challenges we faced and how future teams can continue building on this foundation to improve the technology and support the mission of recovering those who served.

2 Bill of Materials

Include a table with a list of all the materials. Include a description, quantity, cost/unit, total, and URL link for each item.

3 Circuit Schematics

The circuits we designed focused on power distribution. Specifically, how were we going to bring the 12V battery supply down to a usable voltage while still supplying enough current for our load? To solve this issue, we designed a voltage regulator using a L7805CV and a DC-DC buck converter using a TPS563200. the buck converter provides a stable 5V to devices like the servo and the Raspberry pi. The buck converter allows us to select a desired output voltage and will supply up to 3A of current to the load.

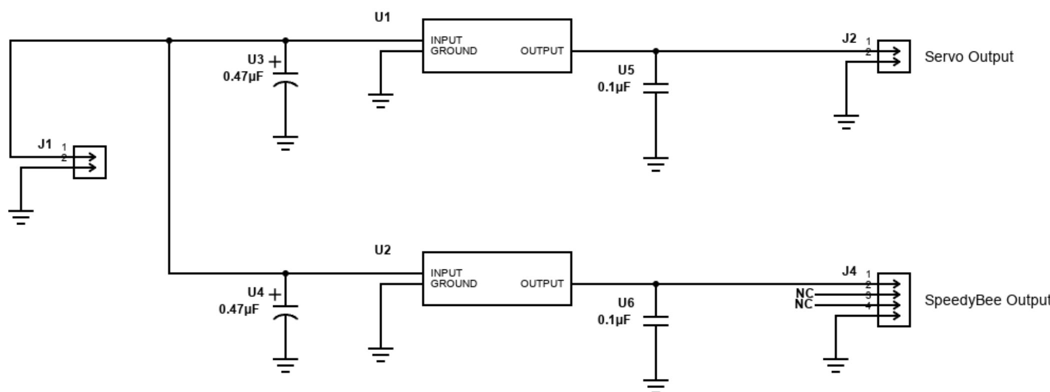

Figure 1: 12V-5V Voltage Regulator

Fig. 1 shows the schematic for the voltage regulator used to power both the servo motor and the Raspberry Pi. This circuit is centered around the L7805CV linear voltage regulator, which steps the 12V battery down to a stable 5V output and is capable of supplying up to 1.5A of current. The input and output capacitors are selected based on the recommendations provided in the datasheet to ensure optimal performance in DC applications.

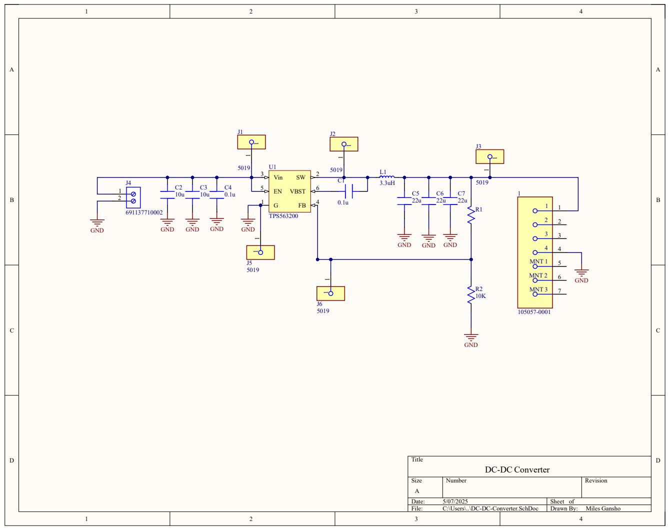

Figure 2: DC-DC converter

Fig. 2 is the second of our two designed circuits. this circuit also allows us to bring 12V down to a voltage we can use, however the TPS563200 has a feedback on pin 4 which allows us to select a desired output voltage with the voltage divider constructed with R1 and R2. The output capacitors and inductors are selected based on datasheet recommendations for 5-7.5V outputs and R1 is selected using the equation $V_{\text{out}} = 0.765 \times \left(1 + \frac{R_1}{R_2}\right)$. this chip also gives us a output current max of 3A which is much higher then the voltage regulator so better for larger loads.

4 Simulation and Circuit Board Design

Include URL links to any circuit simulation or PCB design files. You can store them on a folder in OneDrive. **Please add me as an owner so I can access the files after your account closes.**

5 Physical Design

5.1 Frame and Flotation

The ASV's frame is built from two 4" PVC pipes, each 30" long, mounted in parallel to provide flotation and structural support. A block of closed-cell EPS foam is secured beneath the pipes to improve buoyancy and overall water stability, as well as introducing some rigidity to the system. Closed-cell foam was required for underwater use, as open-cell foam would absorb water and lose buoyancy. The foam was cut to fit the frame and held in place with eight (1/4") bolts.

To calculate the buoyancy required by the ASV, we first calculated the ASV's mass to be approximately 14.4 kg. With a 25% safety factor, our target buoyancy is 18 kg. Buoyancy in kilograms is calculated by Buoyancy = Weight of water displaced × Volume of submerged object. For our geometry, the two PVC pipes displace 15.64 L and the EPS foam displaces 19.66 L, for a total volume of 35.3 L. With a saltwater density of 1.025 kg/liter, the total buoyancy of the ASV is $1.025 \times 35.3 = 36.2$ kg, well above our 18 kg requirement.

5.2 Platform Structure

A 24" wide platform sits atop the PVC pipes, consisting of two 1/8" MDF wooden struts for rigidity and a polycarbonate sheet for mounting structural components. Polycarbonate was chosen for its strength and durability, but it is very flexible; the MDF and EPS foam serve to stiffen the base while the polycarbonate provides a strong, flat mounting surface.

A waterproof enclosure is mounted at the center of the platform to protect onboard systems. Above it, a 100 W solar panel is held in place by four pairs of custom 3D-printed brackets. The brackets attach to the panel's corners and interface with 10" long, (1/2") fiberglass composite rods seated in mating mounts. These brackets allow for easy removal of the solar panel for ease of transportation. The brackets proved strong enough to hold the panel, but future iterations could add captive set-screws to lock the rods in place rather than relying solely on friction and weight. An assembly view is shown in Figure 3.

5.3 Motor Mounting and Flange Design

The motor is mounted at the stern using a custom 3D-printed flange. The flange fits a 1" PVC shaft that connects the motor to the servo and keeps the shaft vertical during operation. To keep the motor in place, two 3D printed bushing were designed to fit the PVC shaft, which hold the motor at a constant depth. The bushing rotate above the flange, but the coefficient of friction between the two is low enough to allow the motor to rotate freely. This design choice ensures that the motor remains securely in place during operation, even in rough water conditions. The choice of a friction based bushing and flange system was chosen over a bearing system to reduce cost and complexity, as well as to allow for easy replacement of parts if needed. In Figure 4, an assembly view of the flange can be seen, where the servo sits in a recess to protect it from the elements. The servo's axis is aligned to the PVC pipe so both rotate together.

Material choice for 3D printed parts was given careful consideration to ensure the ASV is lightweight, low cost, but also resistant to wear. The 3D printed flange is made from ASA, a material known for its excellent UV resistance and mechanical properties. All other parts were made from PETG, which is a strong and durable material that maintains its structure

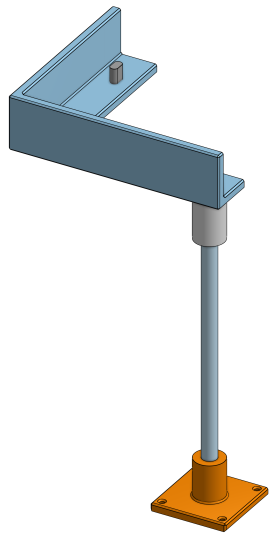

Figure 3: Solar panel assembly view.

underwater, making it suitable for the ASV's environment. The use of these materials ensures that the ASV can withstand the rigors of outdoor use while remaining lightweight and cost-effective. Structural parts were printed using 5 perimeters and 25% gyroid infill, which provided a good balance of strength and weight, while also keeping costs relatively low. The entire project used under 750g of PETG, and around 250g of ASA, which can be purchased for around $15. Further iterations could likely halve this number. Refer to the appendix for all isometric views of 3D printed parts.

6 Electrical

6.1 Power Distribution

The ASV is powered by two 12.8V 8Ah LiFePO4 batteries connected in parallel. A 100 W solar panel mounted above the electronics enclosure outputs power to an MPPT controller, which continuously regulates the voltage and current to maximize the power output from the solar panel. The charge controller adjusts the variable DC that comes in from the solar panel to a constant voltage and current that is suitable for charging the batteries. The MPPT controller outputs the current through Anderson Powerpole connectors, which are tied into the circuit via a 12p junction terminal block, which distributes power to the rest of the system. The use of Anderson connectors allows for easy connection and disconnection of the solar panel. The batteries are connected with F2 spade connectors, also allowing for

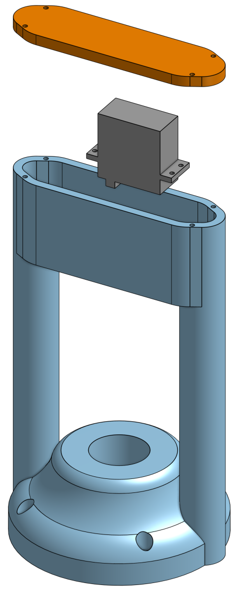

Figure 4: Flange assembly view.

easy connection and disconnection.

Power is distributed through two voltage regulators that step the 12.8V battery voltage down to 5V. One converter supplies the SpeedyBee F405 V4 flight controller and GPS, and the other is dedicated to the servo motor. All components are placed inside a waterproof enclosure without mounting hardware. Initially, the voltage regulator was a buck converter on a PCB, but was replaced with a voltage regulator on a protoboard. The buck converter was not able to handle the current draw of the Speedybee, which caused it to overheat and fail.

6.2 Flight Controller and GPS

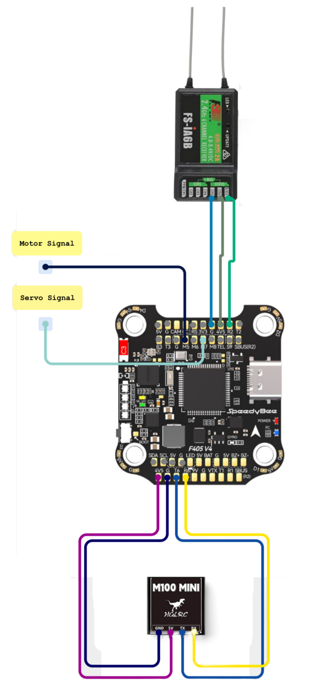

Figure 5: Schematic of the SpeedyBee F405 V4 flight controller and its connections.

The SpeedyBee F405 V4 flight controller runs iNav firmware and handles both GPS waypoint navigation and motor control. It outputs PWM signals to the brushed DC motor and rudder servo and receives location data from a GPS module. The GPS is soldered directly to UART6 on the flight controller: TX from the GPS is connected to RX6, and RX from the GPS is connected to TX6. A FlySky FS-iA6B receiver is soldered directly to the RX2 pad on the flight controller for SBUS communication, enabling manual RC override when needed.

To generate a magnetic field, a 40 Hz sine wave is created by a prebuilt signal generator and passed through a power amplifier. The amplified signal drives a large copper coil wrapped around the boat's structure, producing a low-frequency magnetic field detectable by submerged sensors.

The magnetic field B at the center of a circular coil is given by:

$$B = \frac{\mu_0 N I}{2R} \tag{1}$$

where:

- $\mu_0 = 4\pi \times 10^{-7}\,\mathrm{T \cdot m/A}$ is the permeability of free space,
- N is the number of turns in the coil,
- I is the current through the coil,
- R is the radius of the coil.

This equation demonstrates that the magnetic field strength increases with more turns or higher current and decreases with a larger coil radius. The 40 Hz frequency was chosen to ensure good penetration through water with minimal signal loss, making it suitable for detection by submerged sensors.

All electrical connections are made using soldered wires. Power and signal lines are routed manually inside the enclosure. Signal and high-current paths are physically separated to minimize noise. Fuses are installed on the battery output lines to protect critical components from short circuits.

The electrical system is simple, modular, and designed for ease of repair and future upgrades. Components can be swapped or rewired without requiring full system disassembly. mi

7 Coding

In this section, we will include the programming aspects of our design.

7.1 Buoyancy Calculations

A crucial aspect of the RMS Titanic 2 autonomous surface vehicle is its ability to remain buoyant and stable while carrying all mission-critical components, including the electromagnetic coil of wire, electronic components, batteries, and solar panel. To ensure this, a comprehensive structural and buoyancy analysis was performed using a Python-based workflow.

7.1.1 Pipe and Material Specifications

The vessel's primary flotation is provided by two large-diameter PVC pipes, each with an inner diameter of 4 inches and a length of 30 inches. The density of polycarbonate (1210 $\mathrm{kg/m^3}$) and seawater (1025 $\mathrm{kg/m^3}$) were used as reference values for calculations. The mass of each PVC pipe was calculated using the manufacturer's specified weight per foot, converted to metric units for consistency.

7.1.2 Component Mass Budget

The total system weight includes all major components: electromagnetic coil (2.95 kg), servo, propulsion motor, $LiFePO_4$ battery, PVC housing, and a 6 kg solar panel. A 5% contingency margin was added to account for mounting hardware, fasteners, and unforeseen additions.

7.1.3 The Analysis

The internal volume of each PVC pipe was computed and multiplied by the number of pipes to determine the total displaced volume. The buoyant force was calculated as the product of displaced seawater volume and seawater density. The total required buoyancy was set to the system's weight multiplied by a 1.25 safety factor, ensuring a 25% margin for dynamic loads and environmental uncertainties. The difference between required buoyancy and the buoyancy provided by the PVC pipes determined the additional lift needed from closed-cell foam—we use Pink foam.

7.1.4 Foam Material Evaluation

Several foam options were considered, including marine-grade polyethylene, polyurethane, PVC foam, syntactic foam, and pink EPS foam- the latter being the most accessible and convenient whilst maintaining the properties required for floatation For each material, the required foam volume and example thickness (assuming a 30×15 cm base area) were calculated, aiding in rapid material selection and prototyping.

7.1.5 Summary of Results

The analysis provided a clear breakdown of the vessel's mass, the buoyancy contribution of the PVC pipes, and the precise amount of additional foam required for safe operation. This approach allowed for iterative design, supporting quick assessment of the impact of component changes or material substitutions on vessel stability. The resulting design ensures that the ASV is robust and is capable of supporting all hardware without risk of sinking or instability, even under varying environmental conditions. This structural and buoyancy analysis was essential for validating the design of the RMS Titanic 2 platform, ensuring reliable operation during autonomous missions in coastal waters.

7.1.6 Python Code for Buoyancy Analysis

```
import math

# --- MATERIAL PROPERTIES ---
POLYCARB_DENSITY = 1210      # kg/m³, density of polycarbonate
SALTWATER_DENSITY = 1025     # kg/m³, typical density of seawater
```

```
# --- PIPE SPECIFICATIONS ---
NUM_PIPES = 2
INNER_DIAMETER_IN = 4.0      # Inner diameter in inches
LENGTH_IN = 30               # Length in inches
WEIGHT_PER_FOOT_PVC = 2.01

def in_to_m(inches):
    """Convert inches to meters."""
    return inches * 0.0254

# --- COMPONENT WEIGHTS (UPDATED WITH SOLAR PANEL) ---
components = {
    'em_coil': 2.95,         # Electromagnetic coil
    'servo': 0.068,          # Servo motor
    'motor': 0.500,          # Propulsion motor
    'battery': 1.80,         # LiFePO4 battery
    'small_pvc': 0.227,      # PVC housing
    'solar_panel': 6.00      # 6kg solar panel
}

# --- CALCULATE PIPE MASS USING INNER DIAMETER ---
inner_radius = in_to_m(INNER_DIAMETER_IN) / 2
length_m = in_to_m(LENGTH_IN)
single_pipe_volume = math.pi * (inner_radius ** 2) * length_m
total_pipe_volume = single_pipe_volume * NUM_PIPES

pipe_mass = (WEIGHT_PER_FOOT_PVC * LENGTH_IN / 12) # add lb to kg conversion

# --- TOTAL WEIGHT CALCULATION ---
component_sum = sum(components.values())
contingency = component_sum * 0.05  # 5% contingency
total_weight = component_sum + pipe_mass + contingency

# --- BUOYANCY ANALYSIS ---
displaced_volume = total_pipe_volume
buoyant_force = displaced_volume * SALTWATER_DENSITY
safety_margin = 1.25  # 25% safety factor
required_buoyancy = total_weight * safety_margin
required_foam = required_buoyancy - buoyant_force
```

```
# --- FOAM MATERIAL OPTIONS (INCLUDING PINK EPS FOAM) ---
# Buoyancy is equal to F= Rho * V * g;
# Weight of item m = density*v
# effective bouyant force Fb = F - g*m

foams = {
    'Polyethylene': 0.90,    # Marine foam
    'Polyurethane': 0.85,    # Marine foam
    'PVC Foam': 0.52,        # Structural
    'Syntactic Foam': 0.88,  # Deep water
    'Pink EPS Foam': 0.98    #  lb/ft³ density (~32 kg/m³)2
}

print("[BUOYANCY ANALYSIS]")
print(f"Polycarbonate Pipe Mass: {pipe_mass:.2f} kg")
print(f"Total Vessel Weight: {total_weight:.2f} kg")
print(f"Pipe Buoyancy Contribution: {buoyant_force:.2f} kg")
print(f"Total Buoyancy Required: {required_buoyancy:.2f} kg")
print(f"Required Foam Buoyancy: {required_foam:.2f} kg\n")

print("[FOAM VOLUME REQUIREMENTS]")
print("Material         | Volume Needed (liters) | Example Thickness (cm)")
print("-----------------|------------------------|-----------------------")

for material, buoyancy in foams.items():
    volume = required_foam / buoyancy if required_foam > 0 else 0
    thickness = (volume * 1000) / (30 * 15)  # 30x15cm base area
    print(f"{material:16} | {volume:8.1f}              | {thickness:5.1f}")
\end{lstlisting}
```

7.2 Electromagnetic Coil Modeling and Magnetic Field Calculations

A critical component of the RMS Titanic 2 system is the electromagnetic coil, which generates a low-frequency magnetic field for underwater detection and tracking. To optimize the coil design and predict its performance, a Python-based simulation was developed. This code calculates the electrical properties of a rectangular coil and simulates the resulting magnetic field at a specified observation point, using both analytical and numerical methods.

7.2.1 Inductance and Electrical Properties Calculation

The script first defines the coil geometry and material parameters, such as the number of turns (N), loop dimensions (W, H), wire diameter (d), and frequency (f). The inductance of the rectangular loop is calculated with a standard formula that accounts for the loop's physical dimensions and number of turns. The resistance is determined from the total wire length and resistivity, while the impedance is computed at the operating frequency. The magnetic moment, which sets the strength of the magnetic field, is also calculated as $m = NIA$.

7.2.2 Magnetic Field Simulation

The code then estimates the magnetic field at a specified observation point (typically 1 meter above the loop center) using two methods:

```
    # Magpylib Simulation (most accurate)
    if 'magpy' in globals():
        loop = magpy.current.Loop(
            current=N*I,
            diameter=np.sqrt(W**2 + H**2),
            position=(W/2, H/2, 0)
        )
        results['Magpylib'] = loop.getB(obs_point)

    # Biot-Savart Numerical Integration
num_segments = 100  # Per side
dl = W/num_segments
B_bs = np.zeros(3)

for side in ['bottom', 'right', 'top', 'left']:
    for i in range(num_segments):
        if side == 'bottom':
            x = i*dl
            segment = np.array([x, 0, 0])
            dvec = np.array([dl, 0, 0])
        elif side == 'right':
            y = i*dl
            segment = np.array([W, y, 0])
            dvec = np.array([0, dl, 0])
        elif side == 'top':
            x = W - i*dl
            segment = np.array([x, H, 0])
```

```
            dvec = np.array([-dl, 0, 0])
        else:  # left
            y = H - i*dl
            segment = np.array([0, y, 0])
            dvec = np.array([0, -dl, 0])

        r = obs_point - (segment + dvec/2)
        r_mag = np.linalg.norm(r)
        B_bs += np.cross(dvec, r) / r_mag**3

B_bs *= (4*np.pi*1e-7) * N*I / (4*np.pi)
print("Biot-Savart B-field at observation point:", B_bs)
```

7.2.3 Output and Design Optimization

The script prints all key electrical parameters, including magnetic moment, resistance, inductance, impedance, and required voltage for the desired current. It then outputs the magnetic field at the observation point for both calculation methods, supporting direct comparison and validation. If the magnetic moment is below a target threshold, the code suggests how to scale up current, turns, or area to achieve the desired performance.

7.2.4 Engineering Value

This modeling workflow enables rapid and accurate iteration of coil designs, balancing detection range, power consumption, and manufacturability. By integrating both analytical and numerical field calculations, the system ensures robust magnetic field generation tailored to the operational requirements of the RMS Titanic 2 platform.

7.3 B-Field Coding

Created a function that performs a comprehensive evaluation of square electromagnetic coils by analyzing various wire gauges and turn counts to identify feasible coil configurations that meet specified magnetic moment targets. Given a coil side length and a target magnetic moment range, the function calculates key electrical parameters including resistance, inductance, current requirements, and voltage ranges for each configuration. It utilizes a database of American Wire Gauge (AWG) specifications, incorporating wire diameter, resistance per meter, and maximum allowable current to ensure operational safety and efficiency. By iterating over practical turn counts and verifying current constraints, the analysis provides a set of viable coil designs optimized for magnetic performance and manufacturability. This systematic approach facilitates informed decision-making in coil design, balancing physical dimensions and electrical characteristics to achieve desired magnetic moments within practical power and thermal limits. We ultimately did not use this- but we mention this here as something we had tried.

$$V = \oint \overrightarrow{E} \cdot d\,\overrightarrow{l} \tag{2}$$

You can use this link to find the full github repository : https://github.com/grgao/boat/tree/main/ECE

8 Operating Instructions

Follow these steps to safely operate the Autonomous Surface Vehicle (ASV):

1. **Power On:**
   - Ensure the batteries are charged. The solar panel provides slow passive charging and should not be relied on for full charge.
   - Inside the electronics enclosure, connect the battery wires. Each lead is clearly labeled for polarity—connect positive to positive and negative to negative.
   - Verify that LEDs on the flight controller (SpeedyBee F405 V4) illuminate, indicating power to the system.
2. **System Initialization:**
   - Wait a few seconds for the flight controller to initialize.
   - Confirm GPS lock. The GPS module's LED (typically solid or blinking depending on model) indicates satellite connection.
3. **Manual Control (Optional):**
   - Turn on the FlySky transmitter. Ensure the receiver on the ASV is powered and paired.
   - When connected, you can use the transmitter to manually control throttle and rudder. This is useful for testing or override.
   - Manual control is not required for autonomous operation but is available at any time.
4. **Autonomous Mission Launch:**
   - Use iNav Configurator to upload or verify the waypoint mission.
   - Use iNav Configurator to verify basic telemetry such as GPS status, battery voltage, and input channel readings.
   - Confirm that all connections are secure and components are functioning.

- Arm the vehicle using the transmitter or iNav interface. The motor should begin spinning, and the boat can now be manually operated or left to drift as designed.

5. **Magnetic Field Activation:**
    - The signal generator automatically powers on with the system and begins outputting a 40 Hz sine wave.
    - The output is amplified and fed to the coil. If needed, use a clamp meter to verify that current is flowing.
6. **Monitoring:**
    - Observe the ASV visually or via iNav telemetry if connected.
    - Monitor GPS LED status and waypoint progress to confirm correct operation.
7. **Return to Home and Shutdown:**
    - Use the transmitter or iNav to switch to "Return to Home" mode. The ASV will autonomously return to its starting location.
    - Once the vehicle has returned and stopped moving, disarm it using iNav or the transmitter.
    - Disconnect the battery by separating the labeled leads.
    - Verify that all indicator LEDs are off and reseal the electronics enclosure to maintain waterproofing.

Before each deployment, double-check polarity labels, confirm dry connections, and verify GPS and flight controller status.

9 Troubleshooting

If your device is not fully working, describe exactly what is not working and the steps you have taken to fix it. If you are still unsure of the problem, carefully describe your next steps you would take if you had time.

10 Testing and Experiments

Here you can talk about your experimental results and include plots of any relevant data. The plots should be of professional quality. Use Python, MATLAB, or OriginLab. Excel in the engineering world is not professional.

11 Future Work

There is a considerable amount of work that can be done to improve the ASV, as this was a prototype. During our design phase, we were limited by time and budget constraints, but future teams can build on our work to create a more robust and effective systems, especially if they can learn from our mistakes. The following sections will discuss some of the most important areas for improvement, including physical design, electronics, software, and testing.

11.1 Physical Design

Several improvements to our prototype's mechanical structure should be considered for future ASV iterations:

- **Optimized Part Geometry for Weight & Strength:** Our 3D-printed components were designed under tight time constraints and saw only a few iterations. If budget allows, future teams should perform wear tests on the 3D printed parts to see where they fail, and then redesign to optimize for weight and strength. There were a few prints where it was clear that the part was acceptable, but could use an easy redesign to improve the functionality. For example, the flange was one piece, but if it was split into two pieces, it would be easier to print and assemble.

- **Bracket Offset & Mounting Security:** The solar panel (27.5" wide) extended beyond our only one of four bolts could engage, leading to instability. This could be solved by redesigning the bracket geometry or increasing the offset distance to ensure all fasteners seat properly. Additionally, the panel support rods currently rely on friction and panel weight to stay in their mounts. Introduce captive set-screws or spring-loaded clips in each bracket to mechanically lock the rods in place, preventing slippage under harsh conditions

- **Platform Material Stiffness:** Our polycarbonate sheet platform flexed under load. A stiffer base, such as treated wood, aluminum, or even a thicker sheet of polycarbonate, would reduce deflection, improve stability, and better support mounted components.

- **Waterproofing at Fastener Joints:** To preserve disassembly ease, we avoided epoxy and ran bolts through PVC fixtures, which allowed water ingress. Future designs should apply marine epoxy or silicone sealant at critical joints, or employ O-ring-sealed fastener assemblies, to balance rigidity, waterproofing, and maintainability. The mounting holes may have to be redesigned to accommodate this, as the current design doesn't allow for easy disassembly after the epoxy is applied.

11.2 Electronics

Several lessons from our prototype's wiring and power distribution should guide future iterations:

- **Modular Motor Connections:** Our motors were hard-wired via fully soldered leads, making removal and replacement cumbersome. Future designs should employ waterproof, keyed connectors inside the electrical box to allow rapid motor swap-outs for maintenance or upgrades without desoldering.

- **Reverse-Polarity Protection:** During our demo, the battery pack was accidentally connected backwards, risking damage to electronics and breaking our ESC. Future designs should incorporate reverse-polarity protection—using an ideal-diode IC or MOSFET-based blocker in the main power feed—to automatically guard against destructive reverse connections and prevent user error.

- **Overcurrent & Short-Circuit Safeguards:** We lacked fusing or electronic breakers on our high-current rails. Future designs should include appropriately rated fuses or resettable circuit breakers on each major branch (motor, batteries, electronics) to isolate faults and protect wiring and components.

- **Power Distribution Board (PDB):** Our prototype relied on wiring into a terminal junction bock, which increased bulk cabling and complicated troubleshooting. Future designs should use a custom PDB with integrated connectors, breakers, and status LEDs, with silk-screened labels marking each output (e.g. "Motor," "MPPT," "Servo"). A dedicated PCB, designed from the ground up, could consolidate off-the-shelf power components (amplifiers, signal generators, buck converters) into a single compact board, significantly reducing wiring complexity and system footprint.

11.3 Software

11.4 Testing

References