Columbia SEA LION:

Surface Emergency Autonomous Location-Identifying Oceanic Navigator

Surface Autonomous Vehicle for Emergency Response (SAVER) Challenge

Columbia Space Initiative, Columbia University, 116th St & Broadway, New York, NY, 10027

Team Contacts

Minju O'Rourke* [m.orourke@columbia.edu, 510-990-5012]   Kathryn Lampo* [k.lampo@columbia.edu, 720-688-8583]

Concept Video Pitch: https://youtu.be/7EIyBsVx5uU

Team Members

Minju O'Rourke* (m.orourke@columbia.edu), Co-Lead
Class of '25, Mechanical Engineering

Kathryn Lampo* (k.lampo@columbia.edu), Co-Lead
Class of '25, Mechanical Engineering

Electrical Systems

Arnaud Lamy (aml2379@columbia.edu)
Class of '25, Electrical Engineering

Kevin Qiu (kzq2000@columbia.edu)
Class of '25, Computer Engineering

Daryl Choo (dcc2161@columbia.edu)
Class of '25, Electrical Engineering

Julio Ramirez (jar2358@columbia.edu)
Class of '25, Electrical Engineering

Claire Cizdziel (ctc2156@columbia.edu)
Class of '25, Electrical Engineering

Rebekah Cornish (rc3395@columbia.edu)
Class of '24, Applied Mathematics

Mechanical Systems

Jessica Bolar (jab2479@columbia.edu)
Class of '25, Mechanical Engineering

Manuella Kwawu (mek2255@columbia.edu)
Class of '26, Mechanical Engineering

Sandhya Sethuraman (ss5231@columbia.edu)
Class of '25, Chemical Engineering

Casandra Martinez (cm4149@columbia.edu)
Class of '25, Mechanical Engineering

Will Specht (wls2128@columbia.edu)
Class of '25, Biomedical Engineering

Kade Jimenez (kjj2125@columbia.edu)
Class of '25, Mechanical Engineering

Miles Huntley-Fenner (mnh2130@columbia.edu)
Class of '23, Mechanical Engineering

Ashley Gigon (aeg2245@columbia.edu)
Class of '23, Mechanical Engineering

Claudio Solano (cis2122@columbia.edu)
Class of '25, Mechanical Engineering

Autonomous Systems

Justin Beltran (jb4731@columbia.edu)
Class of '24, Computer Science

Jacob Boxerman (jib2137@columbia.edu)
Class of '26, Computer Science

Ethan Thomas (emt2188@columbia.edu)
Class of '25, Computer Science

Shimon Sarkar (sks2243@columbia.edu)
Class of '25, Computer Science

Annika Deshpande (aad2221@columbia.edu)
Class of '25, Computer Science

Faculty Advisor
Professor Michael Massimino
[mjm252@columbia.edu, 212-854-4275]

Michael J. Massimino
Professor of Professional Practice

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A. Abstract

As NASA returns its focus to the moon with the Artemis program, crew safety and emergency preparedness are of paramount importance. As with all manned space flights, it is crucial to prioritize astronauts during every phase of the mission, particularly by developing robust contingency plans for various unforeseen circumstances. In the specific case of an unexpected water landing after launch, crew members taking refuge in the Orion capsule may need additional supplies and information about localized hazards. However, sending rescue teams in immediately could prove hazardous for both the astronauts and the first responders. Instead, autonomous techniques can be utilized to provide reliable, rapid assistance without risking any parties involved.

The Surface Emergency Autonomous Location-Identifying Oceanic Navigator (SEA LION) is an unmanned aqueous vehicle that delivers critical supplies and toxicity sensors to astronauts after emergency water landings. The design is a molded fiberglass catamaran hull with two pontoons designed to maximize stability. The interiors of each pontoon contain batteries, electronics, and a Raspberry Pi microprocessor relevant to the location-homing systems of the design. An elevated platform on the deck above provides easy access to payloads, including a Platypus water bottle and two ToxiRae sensors. On top of the deck, a modified Adcock loop antenna array receives the 121.65 MHz swept-tone signal emitted by the capsule, allowing for accurate location-finding. Ultrasonic and LIDAR sensors attached to the front of the SEA LION further help the autonomous systems to detect obstacles, as well as to stop the vehicle as it comes into close proximity of the astronauts. The entire design is propelled by two fully reversible motors attached to the rear corner of the pontoons. Autonomous algorithms control motor output power using data from the antennas and other sensors, guiding the SEA LION through small, iterative directional changes towards the target. Extensive testing and system calibration will allow for a swift, reliable mission execution. The design prioritizes simplicity, reliability, and precision, enhancing crew safety for the Artemis missions and far beyond.

B. Design Description

<u>Overview</u>

The following pages discuss the relevant mechanical, electrical, and autonomous systems that comprise the SEA LION. A high-level CAD diagram is given below for context.

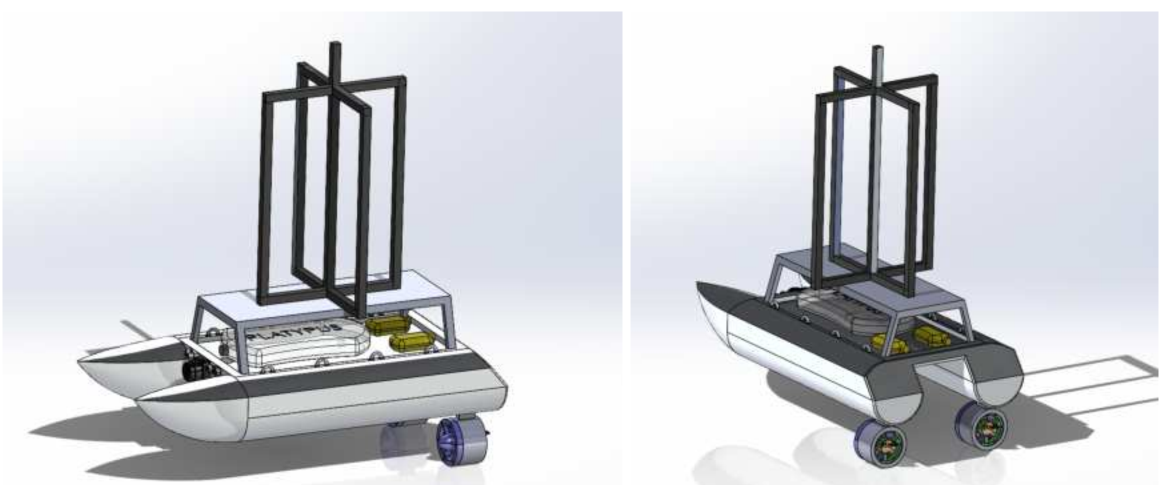

Figure 1: *Two views of the SEA LION, complete with proposed payloads.*

<u>Mechanical Systems</u>

Hull Design

In considering the mechanical design of the vehicle, one of the first major decisions was whether to utilize a multihull or monohull design. The team made CAD mockups of both designs, assuming a 2x safety factor and 26 lbs weight (assuming 20 lbs max device weight, 4.5 lbs of water, and 0.97 lbs of ToxiRae Sensors). The catamaran design, depicted in *Appendix Figure A*, was chosen for a few key reasons, including stability, speed, and volume. The first advantage of a multi-hulled design is stability. Stability is critical given the emergency utilization of the SEA LION, and thus impacted many decisions regarding hull design. Because the hulls will be used for storage, the weight can be distributed farther away from the center of mass, thus increasing the moment of inertia. This greater moment will allow for more stability and reduce the risk of capsizing. Additionally, a catamaran of similar volume to a monohull design can have a larger footprint and will therefore allow for more space between motors, increasing slow speed maneuverability and reducing turbulence due to overlapping wakes.

Furthermore, when performing the mission objective, speed was taken into consideration. Due to the overall purpose of the SAVER, a short arrival time is critical to ensure that the crew is adequately equipped to deal with the emergency situation at hand. The catamaran's reduced volume per unit surface area allows for a higher power to weight ratio, and consequently increases speed and acceleration. In addition to speed—a major factor to consider in the decision of any rescue vehicle—stability, reliability and maneuverability at low speeds were also primary concerns. Therefore, the hull does not attempt to hydroplane or use other techniques that increase speed at the expense of reliability and maneuverability. Additionally, while the team recognizes that the SEA LION's twin motors have the potential to act as a hydrofoil, disrupting stability, the SEA LION's relatively low speeds should minimize this potential risk. Increasing the depth of the hull's pontoons will be considered if hydrofoiling becomes a significant concern.

Volume was another key consideration when designing the SEA LION's hull. Each hull is 6" wide x 36" long x 6" tall, with a 6" bridgedeck connecting the hulls. The hulls are 36" long to reduce drag by minimizing the slenderness ratio. These dimensions were initially determined based on buoyancy calculations, which assume that the hull is cylindrical, and employ a 2x safety factor to account for the weight of an astronaut's hand and other random disturbances that might occur. The design will support the maximum allowed weight, which includes the mass of the PLA, fiberglass, batteries, sensors, and payload. The payload and batteries will be distributed evenly in the horizontal direction, and low enough in the catamaran relative to the center of mass so that capsizing, even when accounting for an unevenly distributed payload, is low risk. Finally, the large, shallow footprint of the catamaran will also allow for better support of the antenna system required to locate the RF signal. *Appendix Figure B* highlights these dimensions, particularly the size and height of the antenna in relation to the catamaran itself. This ratio is further discussed in the next section.

Payload and Antenna Support Mechanism

In compliance with the challenge constraints, the payload (ToxiRae sensors and Platypus water bottle) will sit in a depressed bed on the bridgedeck, below a raised platform designed to hold the antenna. The payload will be attached to the device using bungee cords, which will be laced through eyelets attached to the main hull (*Appendix Figure C*). The ToxiRae sensors will be loaded onto the back of the bridge deck's depression, again attached with bungee cords to reduce motion; the water bottles will be placed immediately in front of them. A 1.5" diameter hole at the back of the bridgedeck serves two purposes: providing a spot for an astronaut to hook a carabiner onto once the vehicle has arrived, and facilitating the opportunity to further secure any part of the payload to the SEA LION. Additionally, a bright beacon will be affixed to the SEA LION to allow easy sight from a distance. This addition further integrates human factors concerns into the design, ensuring astronauts can see the SEA LION coming, especially in the dark.

The payload will be protected by the cover provided by the antenna base, but should still be easily accessible for loading and unloading. To support the large footprint of the antenna system and provide it with the necessary line of sight to the capsule, the antennas will be mounted on an elevated platform above the payload and short range sensors (*Appendix Figure B*). While the antenna and associated platform amass a relatively large size, they will be constructed of wire and PLA, respectively, and thus will be quite light, minimizing potential torque and mass issues.

Given the environmental considerations of the mission, waterproofing was a major mechanical necessity. To facilitate the transmission of communication and power signals, the bridgedeck will contain a thin horizontal hole for large, waterproof wires between hulls (*Appendix Figure D*). Most of the remaining wiring will occur within the hulls with small waterproofed holes to lead out to the necessary sensors and motors. Waterproofing precautions are discussed in detail in the *Safety* section.

Propulsion System

The selected propulsion system is a fully waterproof bi-directional automatic underwater thruster system. This mechanism will consist of two 1.2 kg thrust, 12 V propellers attached to each pontoon at the stern of the SEA LION (*Appendix Figure E*).

Bi-directional thrusters were chosen to give the SEA LION full multi-directional movement, crucially allowing it to slow to a stop within two feet of the target. This design is optimal because of the low voltage draw and high rotation to thrust conversion efficiency, and will be capable of transporting the 20 lb payload. To avoid corrosion, the underwater thrusters will be made of nylon fiber glass composites, which makes them ideal for search and rescue missions.

Two 14.8 volt batteries with 6000 maH were chosen to power the motor. When selecting a battery, the main constraint was the motor's voltage requirements. The motor runs at an input range of 12 V-14.8 V, so to ensure continuous functioning, the chosen battery operates at the maximum of the motor voltage range. This voltage also falls within the 30 V regulatory constraint set by the fourth operational requirement of the challenge. Given the voltage, 6000maH ensures the SEA LION can run for roughly 30 minutes without recharging, not accounting for other circuitry. The other main constraint on the choice of battery is its weight. Since it is assumed that the USV will have a maximum capacity of 20 lbs, the aim was to find the lightest available option to both stay under the weight limit and reduce the need for corrective weight distribution. The lightest 14.8 V battery was 1.358lb, giving a battery weight total of 2.716 lbs.

With a forward thrust of 1200g to 2500 g (11.77 N to 24.52 N), the SEA LION can expect to experience an acceleration of about 1.23 $\frac{m}{s^2}$ to 2.57 $\frac{m}{s^2}$ without taking the resistance into account.

Materials and Manufacturing

When preparing to manufacture the SEA LION's hull, numerous factors were considered, including waterproofing and ease of manufacturing. The optimal method for manufacturing was determined to be the use of composites, as they posed fewer potential issues than common materials such as plastic, wood, aluminum, and steel.

While manufacturing the hull and exterior structures would be particularly easy using 3D printers, it would be difficult to find a printer large enough to print the everything in one piece, and a segmented hull would inevitably lead to severe waterproofing liabilities. Wood was deemed undesirable because of the multihull design: manufacturing and joining so many faces is time intensive and technically challenging. Aluminum was dismissed as a potential option after considering saltwater degradation; while anodization is possible, the equipment and knowledge required made it unnecessarily complicated. Finally, while stainless steel would have circumvented any issues with saltwater degradation, its weight and notorious difficulty of manufacturing made it undesirable.

Given the design constraints, wet layup of fiberglass over a hollow male 3D printed mold was found to be the least complicated method of fabrication that also allowed for mass minimization. Being able to control thickness and infill of the mold allows for a greater control over the strength-to-weight ratio of various components, as different components have different design requirements. One example of this is the need to minimize pontoon mass for buoyancy, and the simultaneous need to maximize structural strength of the bridge deck to prevent plastic deformation caused by the weight of the payload. While using a foam mold was considered due to it having a lower density than PLA plastic, reducing the overall weight of the hull, manufacturing of mold itself would have introduced significant challenges and possible liabilities. Examples of challenges include the removal of the foam mold from the pontoons after layup and contending with the high technical ability required to manufacture a hollow foam mold. The minor weight reduction gained by using a foam mold would have introduced significant manufacturing challenges and high possibility of error, thus it was deemed unnecessary. Additionally, the use of composites allows for the 3D printing of the mold in sections, as any seams from the mold will be covered in the final fiberglass hull.

Due to the aqueous nature of the SEA LION, waterproofing is critical, and an important consideration in the manufacturing process. The SEA LION's exterior is essentially one continuous piece of fiberglass with all of the water sensitive components stored within the pontoons; this minimizes the potential of leaks. The only perforations put into the design are those required for wiring and maintenance of electronics. As referenced previously, the specific waterproofing plan, including measures taken to prevent leaking at perforation sites, can be found in the *Safety* section.

Electrical Systems

Direction Finding Systems

The SEA LION's core technical challenge is to locate the ANGEL beacon, and promptly autonomously navigate to it. Thus, the device requires a direction finding system able to detect the ANGEL beacon's 121.65 MHz homing signal. The team considered a multitude of antenna designs, weighing the respective benefits and pitfalls of each system. Of the many direction finding systems, the rotating dish antenna was the most simple in regards to signal detection. However, this system introduces severe mechanical complications by relying on a motor for the antenna's rotation, and other concerns arise regarding the radiation pattern, where high directionality could lead to difficulty in finding the angle of arrival and low directionality could lead to inaccurate measurements. The Pseudo-Doppler system was another compelling option that mimics an antenna's motion in a circular pattern by multiplexing between elements in a circular antenna array. This system is mathematically intensive with regard to compiling the multi-element array data and requires a non-trivial amount of circuitry, and—more significantly—requires ample space for antenna spacing, which would infringe on the Micro-g challenge constraints. Another option was the interferometer, but due to the nature of the system, the antennas would need to be spaced far apart, similarly violating challenge volume constraints. This size constraint issue was consistent in a significant number of direction finding methods; the antennas usually need to be placed $\frac{\lambda}{4}$ to $\frac{\lambda}{2}$ apart, or about 60-120 cm for the particular wavelength emitted by the beacon. Not only do large antenna systems exceed the Micro-g challenge volume constraints, but they often additionally add mass and increase the SEA LION's moment of inertia beyond what the vehicle can sustain.

Due to the strict mechanical constraints of the SEA LION, it is essential that the device's antenna system is light, compact, and portable. The Watson-Watt direction finding system was chosen as the antenna system best suited to fit the SEA LION's needs, maximizing reliability whilst minimizing mass and volume. The system implements a modified Adcock antenna array using rectangular loop antennas to calculate the angle of arrival of the ANGEL beacon's signal. As illustrated below, an Adcock antenna array is typically composed of five monopoles: two orthogonal antenna pairs, which cover each of the four cardinal directions when combined, and one omnidirectional antenna in the middle. Then, by replacing the axial monopole antenna pairs with single loops, the footprint of the antennas is decreased while behaving equivalently to the typical antenna pairs. A comparison of these arrays can be seen below:

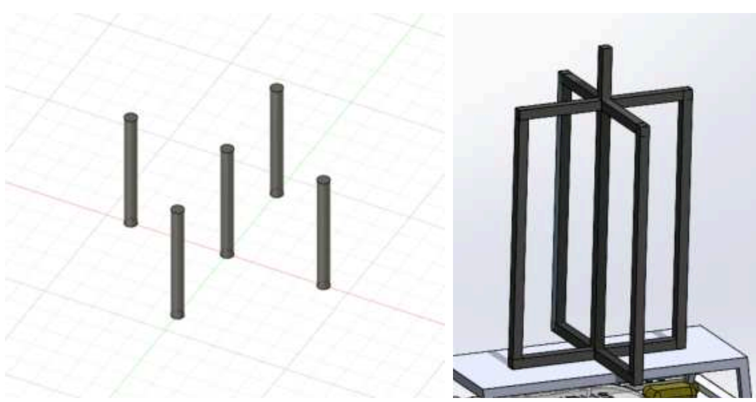

Figure 2: *Left - Typical Adcock antenna array; Right - SEA LION's modified Adcock antenna array*

As previously mentioned, the Adcock antenna array consists of two orthogonal antenna pairs, which break down the incoming signal into two orthogonal components, r_{NS} and r_{EW}. Note that r_{NS} and r_{EW} are signals produced by the induced voltages in the antennas with respect to time. A trigonometric comparison of the phases of r_{NS} and r_{EW} finds the incoming signal's angle of arrival. However, r_{NS} and r_{EW} can only determine when r_{NS} and r_{EW} are in phase or in opposition. Consequently, a third omnidirectional antenna producing a third output signal, r_0 which is used to resolve the 180° ambiguity. The final expression yields:

$$\phi = atan2(sign_{NS}\|r_{NS}\|, sign_{EW}\|r_{EW}\|),$$

with ϕ denoting the signal's angle of arrival, and

$$sign_{NS} = sign\,of(phase\,diff_{NS\,and\,0} = sign\,of(phase\,diff_{EW\,and\,0}).$$

It is relevant to note that the high directionality of the antenna pairs is essential, because r_{NS} and r_{EW} need to measure only the component of the incoming signal normal to their antenna pair. While this is usually achieved using a pair of monopoles, the SEA LION implements a rectangular loop antenna instead, to minimize the system's volume. The specifics of the Watson-Watt system calculation and implementation can be found in *Appendix C*, as well as in the *Autonomous Systems: Direction Finding* section.

With an incoming frequency of 121.65MHz from the ANGEL beacon, the signal will have a wavelength of approximately 2.46m. The antenna spacing in a typical antenna pair for an Adcock antenna system is half of a wavelength, which would be about 1.2m or 47" in this case, which is far larger than the 18" x 18" x 36" vehicle. While the challenge constraints allow for antennas outside of the vehicle, it would impose unnecessary mechanical challenges, particularly by disrupting weight distribution, exposing the antennas to damages, and ultimately rendering the vehicle inadequately large. Instead, a loop antenna typically strives for a circumference equal to the wavelength, λ, where the directivity is high and the input impedance is still rather low. It should be noted that many receivers, particularly, are designed with smaller circumferences—up to $\lambda/10$. However, to minimize noise and output an accurate angle-of-arrival, it is essential the NS and EW signals are reactive to changing direction; they must be highly directional. As such, the loop antennas should approach a circumference of $\lambda = 2.46m$. The SEA LION's rectangular loop antenna will be constructed with sides $s_1 = 14in \cong 35cm$, and $s_2 = 20in \cong 51cm$, with a resulting circumference $C = 68in = 1.72m = 0.70\lambda$. The omnidirectional antenna will be a whip antenna with length $\lambda/6 = 16in \cong 41cm$. Outsourcing the manufacturing of the antenna to a private firm will offer the ability to tailor the design to these specific constraints, allowing the SEA LION to utilize a custom antenna as described above.

Distance Finding Systems

It is essential that the vehicle does not collide with the target buoy to avoid harming any personnel and to avoid damaging both the buoy and the SEA LION itself, in addition to the crew members of Artemis missions. Following the challenge constraints, the SEA LION is designed to stop within 2 feet of the target buoy. The Watson-Watt system accurately determines the direction of the signal source, but a reliable distance-calculation system is needed to ensure that the SEA LION detects the location of the target buoy, and comes to a stop. A system of three sensors—a combination of ultrasonic and LiDAR sensors—will be used to determine when to halt the device. Mounted on the front of the vehicle, these sensors will allow for the consistent, accurate detection of hazards. A singular LiDAR sensor centered at the front of the device points directly forward, with a narrow detection beam. LiDAR provides high accuracy at a range of up to 10 meters, hence its central placement. Two auxiliary ultrasonic sensors are placed on either side of the LiDAR sensor, pointing ±15° from the center angle. The two ultrasonic sensors serve to cover the main sensor's blindspots, angled to have a view different to that of the LiDAR, with a conical detection beam covering a larger region. Utilizing multiple sensors has significant value: not only is a larger area covered, allowing for improved distance monitoring, but in the case where any single sensor fails to detect the target buoy, the SEA LION can still rely on its two other sensors to avoid collision. Furthermore, if a nearby obstacle is detected only on one of the auxiliary sensors, autonomous systems will turn the SEA LION to avoid the hazard, allowing for advanced maneuvers. With both ultrasonic and LiDAR distance finding systems, the team is confident that the SEA LION will not only consistently detect the target buoy and halt the device at the final target, but also perform additional hazard avoidance maneuvers to ensure crew safety.

Power and Controls

The SEA LION is controlled by a central Raspberry Pi 4 Model B microprocessor and powered using two 14.8V, 6000mAh batteries. Batteries are used to power the motors, the microprocessor, the ultrasonic and LIDAR distance sensors, and an emergency LED. A simple input/output diagram for the Pi is included in *Appendix Figure G*. Each motor will require between 12-16V depending on the speed at which the SEA LION moves. The device has the power and capacity to exceed speeds of 2 m/s, but it seems unlikely that the SEA LION will utilize this speed (and draw) for normal usage. The Raspberry Pi will require an input of 5V, which will consequently be used to power the connected ultrasonic and LIDAR sensors. The device's beacon LED (not to be confused with Beacon location), which serves to indicate that the vehicle is active and to make the vehicle noticeable from a distance, will draw around 1500 mA at around 15 V. As a result, the SEA LION operates at voltages under 30 V, as specified in the challenge description.

The SEA LION includes a manual on/off switch, as well as a remote control switch for an emergency all-stop. The manual switch will connect or disconnect the power supply to the larger circuitry system and the microprocessor. The remote switch for an emergency stop will be controlled by a wireless remote control, which will send a radio signal to a receiver on the vehicle. Upon the signal's reception, all operations of the system will cease as after a short shutoff sequence that protects sensitive integrated circuit components before disconnecting the power supply. The remote switch is a 5 V remote switch relay transmitter and a corresponding receiver which have been selected to be compatible with the Raspberry Pi.

Autonomous Systems

Software Implementation

SEA LION's systems will be controlled by custom software running on the Raspberry Pi Model B. The software will be written in Python, which was chosen for its readability, ease of use, and availability of libraries to make implementation efficient and robust. The autonomous system connects all aspects of the device. This includes the direction finding component, the distance finding component, and the motion control system. The methodology behind each process is described below.

Direction Finding

As previously mentioned, the SEA LION utilizes the Watson-Watt technique to determine the direction of the target beacon. The implementation and motivation for the Watson-Watt direction-finding method are clearly outlined in *Appendix C*. To reiterate, the computer will receive three voltage signals from the Watson-Watt system: r_O, r_{NS}, r_{EW}. These signals will be interpreted by the operating system of the Raspberry Pi using the Adafruit CircuitPython ADS1x15 Python library, where the voltage channels are easily read from arbitrary pins on the board. For example:

```
r_o_chan = AnalogIn(ads, ADS.P0) # r_o uses pin 0
r_ns_chan = AnalogIn(ads, ADS.P1) # r_ns uses pin 1
r_ew_chan = AnalogIn(ads, ADS.P2) # r_ew uses pin 2
```

The following code defines a function `update_angle()` that takes the voltage from each channel established, and calls a function `find_angle()` to calculate the transmission angle based on the parameters r_{NS}, r_{EW}, and r_O, then updates the global variable `angle` with this newly calculated value:

```
def update_angle():
        r_o = r_o_chan.voltage
        r_ns = r_ns_chan.voltage
        r_ew = r_ew_chan.voltage

        global angle
        angle = find_angle(r_ns, r_ew, r_o)
```

Because the angle of direction of the radio transmitter is constantly updated as the SEA LION moves and turns, the `update_angle()` function will be placed in an infinite loop within the main block of code that executes every Δt seconds. This can be done with a simple while loop and a sleep statement:

```
DELTA_T = 0.01
while(True):
       update_angle()
       # ...
       # Other infinitely-executed functions go here
       # ...
```

```
            time.sleep(DELTA_T) # Here, the code sleeps for 0.01 seconds
```

However, the `find_angle()` function itself has yet to be defined. The `find_angle()` function takes three arguments, `r_ns`, `r_ew`, and `r_o`. Since `r_o` is only used to solve the ambiguity problem and not in the angle computation itself, `find_angle()` makes use of a helper function `compute_angle()`.`compute_angle()` takes two arguments, `r_ns` and `r_ew` and relies on the result $\phi = \arctan(r_{NS}/ r_{EW})$ derived from the *Electrical Systems: Direction Finding Systems* section:

```
def compute_angle(r_ns, r_ew):
        if r_ew == 0:
                return (math.pi / 2)

        quotient = r_ns/r_ew
        angle = math.atan(quotient)

        if(angle < 0):
                angle = angle + math.pi

        return angle
```

The `compute_angle()` function returns the result $\phi = \arctan(r_{NS}/ r_{EW})$ in radians. However, it is key that certain conditional checks are made. If the `r_ew` parameter is passed an argument of `0`, `quotient = r_ns/r_ew` would result in a `ZeroDivisionError`. Instead, the code assumes that `r_ns` is non-zero, and therefore `r_ns/r_ew` approaches infinity. Since $\tan(\pi/2)$ approaches infinity, the method returns `math.pi/2`.

Since the function $f(x) = \arctan(x)$ has a range of $-\pi/2$ to $\pi/2$, the method must also check whether the result is less than 0. If so, adding π is necessary to obtain an equivalent positive result, making the range 0 to π.

Using the `compute_angle()` function in the parent `find_angle()` function, the method converts the radian angle obtained from `compute_angle()` to degrees. Then, it checks whether `r_o` is less than `0`. If so, the radio transmitter is in the back-left (III) or back-right (IV) quadrants (about the SEA LION), so the method returns the `angle + 180` degrees. If `r_o` is non-negative, the radio transmitter is in the front-right (I) or front-left (II) quadrants, so the method just returns the `angle`. Then, a final adjustment is made so that the angle returned is with respect to the front of the SEA LION, clockwise:

```
def find_angle(r_ns, r_ew, r_o):
        angle_rads = compute_angle(r_ns, r_ew)
        angle = math.degrees(angle_rads)

        if (r_o < 0):
                return angle + 180

         # Orient angle with respect to the front of the SEA LION
         angle = angle - 90
         if (angle < 0):
                  angle = angle + 360

         # Compass-style angle convention
         angle = (angle - 360) * -1

        return angle
```

In short, this structure updates a global angle variable every Δt seconds with the direction of the radio transmitter concerning the SEA LION at that time t. This global variable can be used in other functions throughout the program for changing the SEA LION's direction.

Movement

The movement of SEA LION is determined by throttle control. Therefore, the direction of the SEA LION can be changed by adjusting the power of individual engines relative to one another and propelling the SEA LION forward using equal power in the engines. To decide which engine to throttle, the angle of the signal is used, calculated by the `find_angle()` function. There are two possible cases to account for, which are indicated visually in the figure below.

1. Case 1 Front: Signal is in front of SEA LION (angle is between 315° and 45°)

In this case, power will reduce on one motor such that SEA LION reaches a complementary angle to the angle of the signal. Then, as it moves forward and slowly turns toward the signal, it will continue reading the angle of the signal and adjust power accordingly. As the catamaran becomes parallel to the signal (signal angle approaches 0 degrees from the North, which is from the front of the device), the power setting of each motor will become equal, thus allowing the device to move straight forward. SEA LION will call `left_turn()` and `right_turn()` as appropriate.

2. Case 2 Behind: Signal is behind SEA LION (angle is between 45° and 315°)
   In this case, the device will call `pivot()` and reverse power of one motor while going to a calibrated power forward setting pivoting the catamaran until the angle reverts to Case 1.

Figure 3: *A visualization of the directional compass used by the SEA LION.*

The functions used to execute this process will be the following:
Note: The -1, 0, and 1 in `set_power()` are arbitrary and determined by the PID loop defined later.

```
def left_turn():
       while(angle > 315)
              left_motor.set_power(0)
              right_motor.set_power(1)

def right_turn():
       while(angle < 45)
              left_motor.set_power(1)
              right_motor.set_power(0)

def pivot():
       while(angle < 315 and angle > 180)
              left_motor.set_power(1)
              right_motor.set_power(-1)

       while(angle < 180 and angle > 45)
              left_motor.set_power(-1)
              right_motor.set_power(1)
```

Stopping
Using a LiDAR sensor, the SEA LION will measure its distance to the target. Once the SEA LION is within range, a stop function will reverse the thrust of the engines to stop the device. The engines will run in reverse until velocity is reduced to zero. A function `current_speed()` will be called to measure the speed of the catamaran when it is near the target.

*Note: In calibration, a distance **d** will be measured to find the optimal distance at which to stop the catamaran, so that it stops within 2 feet of the target.*

```
def current_speed():
       previous_distance = measure_distance()
       time.sleep DELTA_T
       new_distance = measure_distance()
       return (previous_distance - new_distance)/0.1

def dual_set_power(left, right):
    left_motor.set_power(left)
    right_motor.set_power(right)

def stop():
       while current_speed() > 0.1 or current_speed() < -0.1:
              if (current_speed() > 0) :
                     dual_set_power(-1, -1)
              else
                     dual_set_power(1, 1)
```

```
dual_set_power(0)
```

As described in the *Electrical Systems: Distance Finding System* section, ultrasonic sensors will be mounted on either side of the SEA LION in addition to a central LiDAR sensor, as a collision avoidance redundancy. The sensors will continuously read in a distance variable and if they detect an object at 2 feet or less will run the stop method. In the event the device is not at the target buoy, it will then turn away from the side the sensor detected on and resume its course to target. Given the conditions of the NBL and the Micro-g challenge, this procedure is likely to be performed if SEA LION is near the side of the pool. However, this instance could also occur for other obstacles, including the diver. It is imperative that the SEA LION is able to avoid collision to successfully carry out the rescue mission, and maintain the safety of all parties involved.

In addition to maneuvering the SEA LION in response to obstacles, the system must also be prepared to halt operations if the emergency all-stop is actuated. As mentioned in *Electrical Systems: Power and Controls*, the SEA LION is outfitted with a remote control switch that enables an emergency all-stop. In the event the RaspberryPi receives the remote switch's emergency stop signal, the shut off sequence will initiate. It will shut off power to the motors then begin shutting down sensitive integrated circuit components. After sensitive components have shut down the RaspberryPi will disconnect power from itself and the rest of the device.

PID

A Proportional, Integral, Derivative (PID) control loop allows for a high level use of current error as well as past error from the target to inform output power. This ensures that the SEA LION accelerates and decelerates gracefully, as opposed to changing speeds at a jarring rate.

Simple PID loops are common and fairly straightforward to implement. The PID loop will require some tuning (covered in the *Autonomous Systems: Calibration* section).

$$\Delta m = K_p(\frac{\tau_d}{\tau_i} + 1)\Delta e(t)$$

Proportional action

$$\Delta m = \frac{K_p}{\tau_i}\int e(t)\,dt$$

Integral action

$$\Delta m = K_p \tau_d \frac{de}{dt}$$

Derivative action

Where: K_p = proportional gain, $e(t)$ = error value, τ_i = integral time constant, τ_d = rate time constant

Calibration

Significant testing will be needed to calibrate all of the Autonomous Systems, from throttle control to braking to distance detection.

One crucial element is the calibration of pathfinding systems. First, the process of calibration is used to determine the proper distance *d1* to begin running the `stop()` method. It is critical to identify at what distance from the target the system should begin to stop as to halt the device without collision. The team must understand the speed at which the SEA LION can slow down after LiDAR and ultrasonic sensors detect an upcoming hazard. Additional tests are necessary to understand how long SEA LION will take to physically stop—the team will run the SEA LION at full speed then run the `stop()` method. From the time to slow to a stop, the team can determine the distance *d* at which the SEA LION should begin to break as to halt before contacting the target buoy, as well as quantify the speeds that the SEA LION can reach at different levels of power output. One foot is added to this distance to create the distance *d1*—the SEA LION will aim to halt one foot before the target buoy to ensure that the device stops in the center of the 2 foot region.

Additionally, calibration is necessary to determine at what point navigation should be generally guided by distance sensor rather than the direction finding antenna. While both direction and distance systems will run for the entire duration of the rescue, it's important to have a sense of which systems will be more accurate in which places. For example, the accuracy of the Watson-Watt antenna fails at short distances, whereas the LiDAR and ultrasonic distance sensors are highly accurate at short ranges. At a certain point, the navigation system should pivot to relying on distance sensor data (and traveling straight), rather than guiding navigation based on the Watson-Watt antenna data. Calibrating that distance *d2* in which Watson-Watt systems become unreliable should be fairly straightforward: the team can test the limits of the sensor. The radar beacon will be placed in an open area and a program will be written to take data from the Watson-Watt antennas, LiDAR, and ultrasonic sensors. SEA LION will be manually moved (by hand) slowly towards the target, all while writing data to a file for further analysis. After the test is complete, the data can be analyzed and the point where Watson-Watt becomes ineffective will be apparent. As with the prior distance calculation, one foot of buffer is added to this distance *d2* to avoid potential collisions. The team will halt the consideration of direction data in navigation at this distance d2, and rely solely on distance sensors (LiDAR and ultrasonic sensors) to navigate the device.

The other testing required is calibrating engine throttle amounts. This testing will be done in Columbia's pool. Most importantly, the turning of the catamaran will need to be calibrated, as will power outputs generally. SEA LION's sensors will provide all of the necessary data, which can be transmitted wirelessly to a poolside laptop and graphed. With the data the PID controllers can be tuned and power levels can be adjusted to ensure that SEA LION performs as expected. The PID system for braking (detailed above) will need to be calibrated, which can be done by again reading position and desired position data and tuning the PID controller accordingly. The PID controller will be tuned by slowly adjusting the K_p,K_i , and K_d values (the strength of each factor) until the desired behavior is achieved. This calibration will allow SEA LION to accurately maneuver and stop in the NBL.

C. Operations Plan

Phase I: Preparation (to be done pre-testing)

1. Communicate with NBL divers about the components of the SEA LION, taking considerable time to note each safety hazard to ensure safe practice for all parties involved. Familiarize the diver with the "on" switch located on the SEA LION, as well as the handheld Emergency All-Stop Remote Control Switch, which they can use to remotely cut the SEA LION's power.
2. Prepare payload (ToxiRAE sensors and Platypus water bottle), and place payload into the designated emergency supply compartment on the top of the hull. Secure using bungee cords.
3. Transport the SEA LION into the NBL, being sure to avoid the areas indicated as potential hazards in the *Safety* section below.

Phase II: Usage of the device

Once submerged in the pool, the NBL diver must power on the device using the on-off switch. The device is designed to be fully autonomous, so the NBL diver's main task will consist of turning the device on. After the switch is turned on, the NBL diver should move slowly away from the SEA LION as it locates and navigates towards the beacon. The NBL diver should keep eyes on the SEA LION at all times, as well as team members on deck. One team member must always keep a hand on the Emergency All-Stop Remote Control Switch, ready to shut off the SEA LION's power if necessary at any point.

Phase III: Data Collection

The main objective of the SEA LION is to navigate to within 2 feet of the target buoy. However, this is not the only metric of interest—valuable data can be gathered through observation and surveying the diver's experience. Over the course of the testing session, data will be collected by members of the team through the following metrics:

1. Ease of use: device initialization (ask diver: "on a scale from 1 to 5, with 1 being the most easy and 5 being the most difficult, how easy was it to turn on the device?")
2. Time from PowerOn to initial movement of the device's motor
3. Time from initial movement of the device's motors to steady motion towards the direction of the beacon
4. Ability of the SEA LION to maintain a straight course once it has corrected to the direction of the buoy
5. Accuracy of incremental angle adjustments (does the SEA LION over or undershoot as it turns?)
6. Final distance of the SEA LION to the target buoy, after the motors halt to a stop.
7. Whether the SEA LION comes in contact with the buoy at any point
8. Amount of water present on the payload when it reaches the buoy
9. Ease of use: payload rescue (ask diver: "on a scale from 1 to 5, with 1 being the most easy and 5 being the most difficult, how easy was it to remove the payload from the SEA LION?")

10. Ease of use: power off using remote control switch (ask diver: "on a scale from 1 to 5, with 1 being the most easy and 5 being the most difficult, how easy was it to shut off the device?")

Phase IV: Analysis

From the data collected in accordance with the parameters listed above, the team can quantify the device's deficiencies and locate points of improvement. Moreover, it's likely there are complications and problem areas previously unconsidered that only become apparent through testing. Potential changes to design and operations methods will be considered based on the collected data.

Phase V: Results

The CSI team expects that the device will safely and efficiently deliver the emergency rescue payload to the beacon. Given the emergency nature of this device, the team will work to ensure consistency and reliability through considerable testing and calibration, outlined in the section entitled "*Autonomous Systems: Calibration*". Thus, the device should be reliable by the NBL testing date. However, numerous complications may arise, and there are always more ways to improve! Based on the invaluable data and feedback that gained from testing in the NBL, the team will seek changes that will address problems that may be encountered, and will work to improve the diver's ease of use. Both the quantitative data and qualitative comments on the use of the device will be addressed and considered to improve the design.

D. Safety

Overview

The SEA LION is a complex device, with mechanical and electric components as well as an autonomous control system. Therefore, it is worthwhile to address some concerns related to the design. The team will work to minimize these safety concerns through extensive calibration and testing in Columbia's Uris Pool, as well as a dialogue with Micro-g organizational staff throughout the year to ensure that the SEA LION is fit for safe, effective use in the NBL.

Safety Requirements and Compliance

1. **Requirement #1:** The USV control system shall power on and begin operations via single switch throw/actuation.
   Compliance: The SEA LION will be initiated via a manual switch. This will be placed before the Raspberry Pi microprocessor connects to the rest of the circuitry, and will trigger the initiation of all operations by closing the circuit and initiating power.
2. **Requirement #2:** The USV control system shall not require external calibration or warmup time greater than 60 seconds from control system power-on.
   Compliance: The team intends to spend significant time calibrating the device to ensure that when the SEA LION is placed in the NBL, it is able to accurately navigate to the beacon. SEA LION will undergo extensive calibration in Columbia's Uris pool prior to usage in the NBL. The details of the calibration plan can be found in the *Autonomous Systems: Calibration* section. Additionally, no other systems will require significant warm up times greater than 60 seconds. The antenna system shouldn't require any calibration prior to use, and the propellers should work right away after being connected to the power supply, given their relatively small size as compared to industrial motors. Lidar and Ultrasonic sensors will be ready for immediate use.
3. **Requirement #3:** The vehicle control system shall have an Emergency All-Stop configuration that is remotely activated by human interaction for the purposes of NBL testing
   Compliance: The SEA LION will utilize a wireless remote control switch as a secondary option to power off the system. The remote control switch replicates a garage door keyfob, and will cut the power of the entire system when initialized. A 5V switch has been selected, as it is compatible with the 5V raspberry pi.
4. **Requirement #4:** The USV control system and USV hardware shall be waterproof.
   Compliance: Due to the majority of the water-sensitive components (electronics, batteries, etc.) being stored within the pontoons, the choice of hull materials solves most of the potential issues with waterproofing. The 3D printed hull should provide a moderate degree of protection from leakage, but the bulk of waterproofing will be done by the fiberglass exterior. The combination of the two materials should prevent water from penetrating–even in extreme cases of inclement weather. One weakness of this design is a difficulty in accessing the components within the pontoons. This was addressed with the

addition of circular holes placed into the pontoons. These holes will be lined with bottomless Polypropylene cylinders with waterproof covers. These cylinders will be epoxied into place, with caulk lining the exterior edges to prevent leaks. The covers are easily removable and replaceable, ensuring ease of access for maintenance–and easy replacement in unlikely event that a cover does not seal adequately. Additionally, this allows easy creation of multiple perforated covers that allow wiring to run from the pontoon chambers to the exterior of the craft. The ease of production allows the creation of several covers that can then be tested to ensure that any that are used are completely waterproof.

Safety Concerns and Mitigation

1. **Sharp Front Edges of Catamaran Hull**

   Description of Concern: The SEA LION is designed to stop within 2 feet of the target buoy without making contact with the buoy. However, the nature of aqueous motion makes stopping and holding position difficult, and in the off chance that the vehicle comes in contact with the target, the pointy tips of the catamaran hull pose safety concerns to the target buoy and to any associated astronauts.

   Mitigation Plan: While the aforementioned tips should not be sharp enough to pierce the buoy, the team will also complete extensive calibration (as specified under the "*Autonomous Systems: Calibration*" section) to make it very unlikely that the vehicle will contact the buoy at all. This testing will ensure that the device is consistent and reliable before running in the NBL. Additionally, the team intends to add bright colored indicators (orange duct tape or a similar solution) to ensure that the danger of sharp edges is clear for all parties involved. It is also of the team's intention to investigate attaching an inflatable bumper to the exterior of the hull, to ensure that even if contact is made, the hull will pose no injury to any party involved.

2. **Antenna - Contact with Astronaut**

   Description of Concern: The size and angular nature of the Watson Watt antenna establishes the antenna system as a safety hazard for astronauts utilizing the device. When an astronaut / NBL diver is seeking to access the payload, they must reach below the Adcock antenna, as the payload is located below the platform to which the antenna is mounted on the hull.

   Mitigation Plan: The team will communicate this risk with NBL divers in the operations plan prior to testing, and practice the payload removal process on dry land before entering the pool, so that astronauts are comfortable with the process. There is also a loop built into the hull itself to which astronauts / NBL divers can attach a carabiner on a rope to ensure the SEA LION does not float away from them while they access the payload. While not represented in the current CAD design, the team plans to add a handle on the side of the hull, which will allow the astronaut to stabilize the SEA LION, reducing their chance of contact with the antenna.

3. **Motors - Contact with Astronaut**

   Description of Concern: Two motors, placed on the rear of the hull, are a hazard to divers interacting with the device.

   Mitigation Plan: Propellers were specifically chosen to minimize safety risks. The propellers include small openings with plastic guards designed to guide the water to the propeller effectively and to keep any blades separated from contact with the astronauts. Motors are placed under the hull - no part of the motor extends behind the hull, only extending straight downward. Thus, the probability of contact between a diver and the motor is unlikely, and the team intends to attach brightly-colored signage to the rear of the hull to indicate divers of the motors hidden below. The team will communicate with NBL divers in the operations plan prior to testing, so divers are familiar with the location of the motors, and aware of the potential risks.

4. **Autonomous Systems Failure**

   Description of Concern: While unlikely, there is a possibility of the autonomous system failure. If, in any case, the autonomous system operates in an unexpected manner and the vehicle moves in a direction that puts anyone at risk, the SEA LION could cause serious harm to any party involved.

   Mitigation Plan: The CSI team will work to minimize the chance of Autonomous Systems failures through extensive calibration. However, in the off chance that an Autonomous System fails, multiple processes are in place to ensure that no one is harmed. The team will converse with the Astronaut prior to testing to ensure that they are aware of the risks involved in the system, are familiar with the emergency all-stop, and will keep their eyes on the device at all times during testing. The emergency all-stop remote control switch intends to provide a fast deactivation of the device in the case of any system failure—the remote cuts power to the device, immediately halting all operations. The team intends to implement multiple remote control switches, and grant multiple people the ability to power off the device, to ensure that multiple crew members will have the ability to power off the device in case of an unforeseen system failure.

E. Technical References

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F. Appendix

Appendix A: Figures

Figure A: *An image of the hull design. The two pontoons, central depression, and loop for carabiner to hook onto are clearly visible. For scale, the hull will measure 18" wide by 36" long, and is 6" deep.*

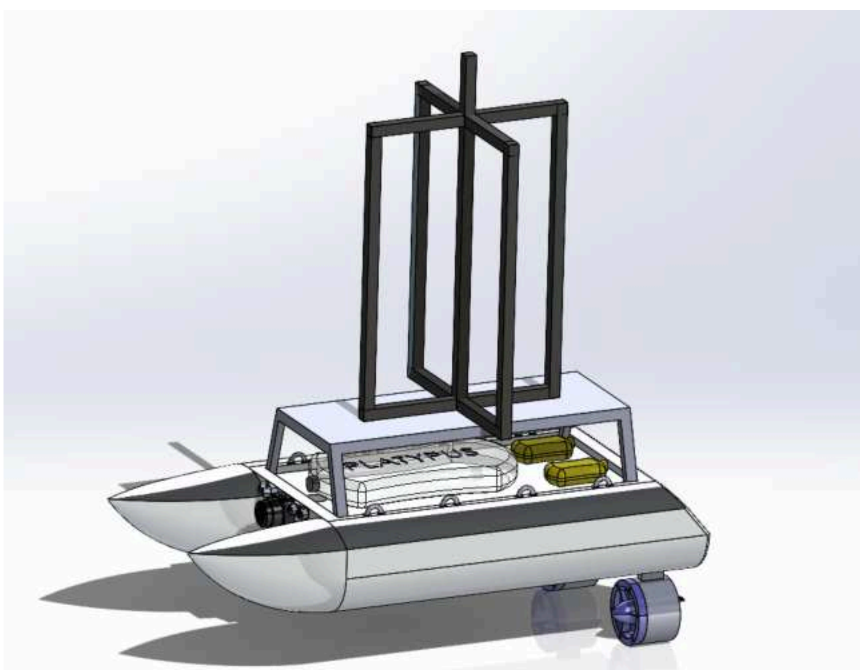


Figure B: *An image of the entire assembly, including payload.*

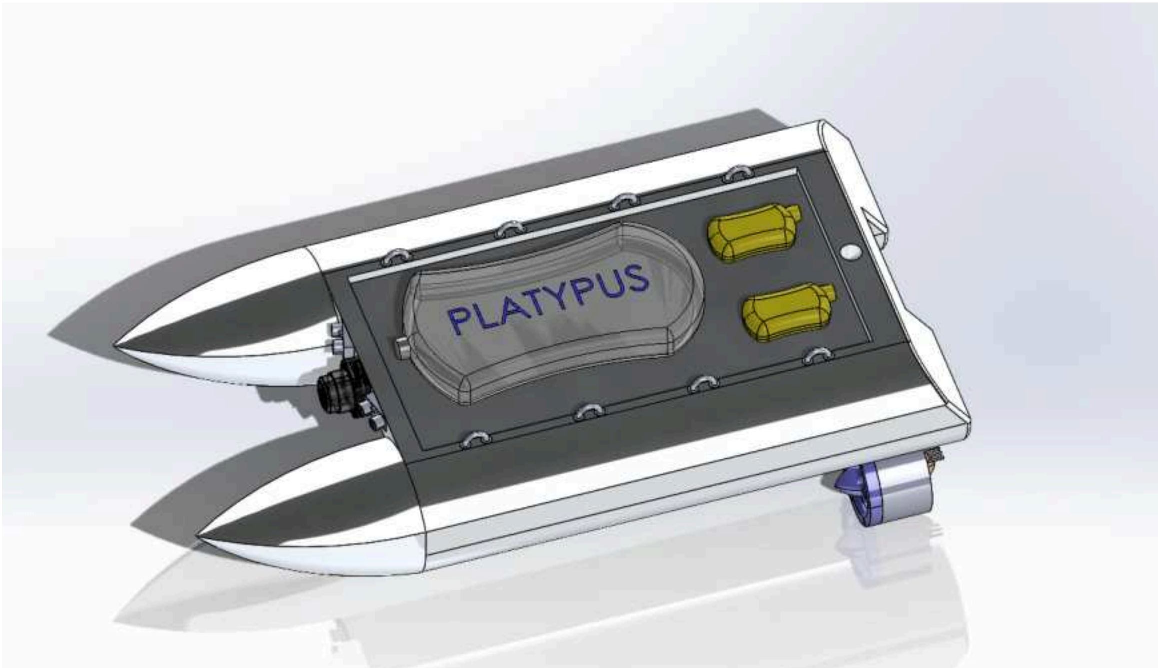


Figure C: *The payload depression on the top of the catamaran, with simple geometric mock ups of the Platypus water bottle and ToxiRae sensors for scale. Both the bottle and sensors will be secured using bungee cords that feed through the eyelets that line each side of the depression. The raised platform and antenna will sit above the payload, but are removed in this shot.*

Figure D: *A cross-sectional cut of the hull from the top that reveals the "tunnel" in the bridgedeck between hulls that allows for wiring to connect the two sides without chance of contacting water.*

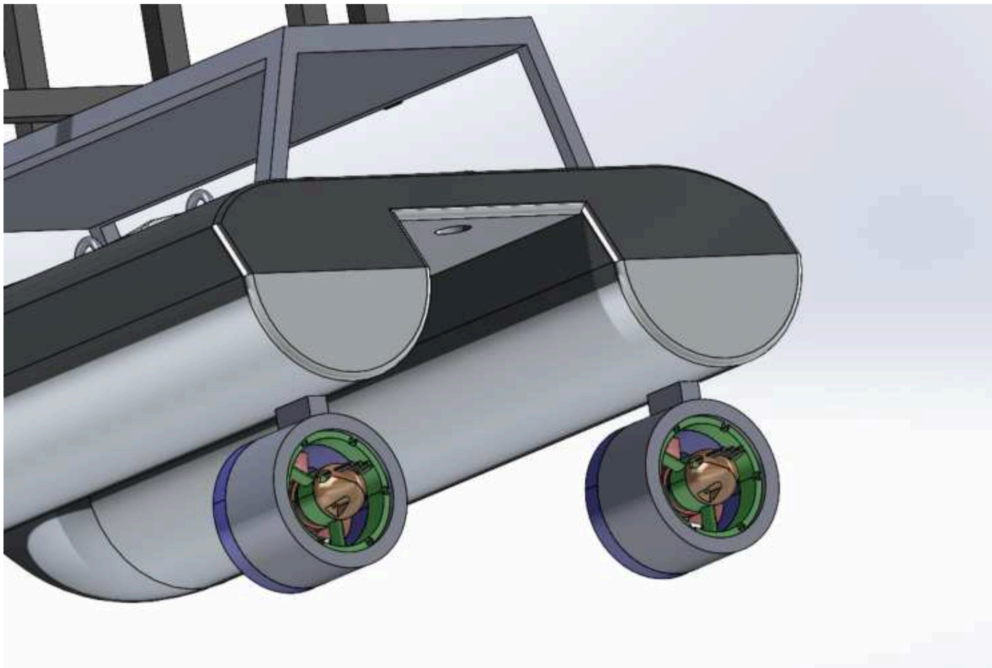


Figure E: *SEA LION's propeller system. Two 1.2 kg thrust, 12 V propellers are attached to each of the rear corners, controlled by the autonomous systems to guide the design towards the buoy.*

Figure F: *A photo of a scaled-down mockup of the 3D printed hull in the team's pool. Note the relatively high position of the SEA LION in the water—while not explicitly weighed down like the final design will be, the PLA infill is high to simulate added mass and provide proof of concept for adequate buoyancy.*

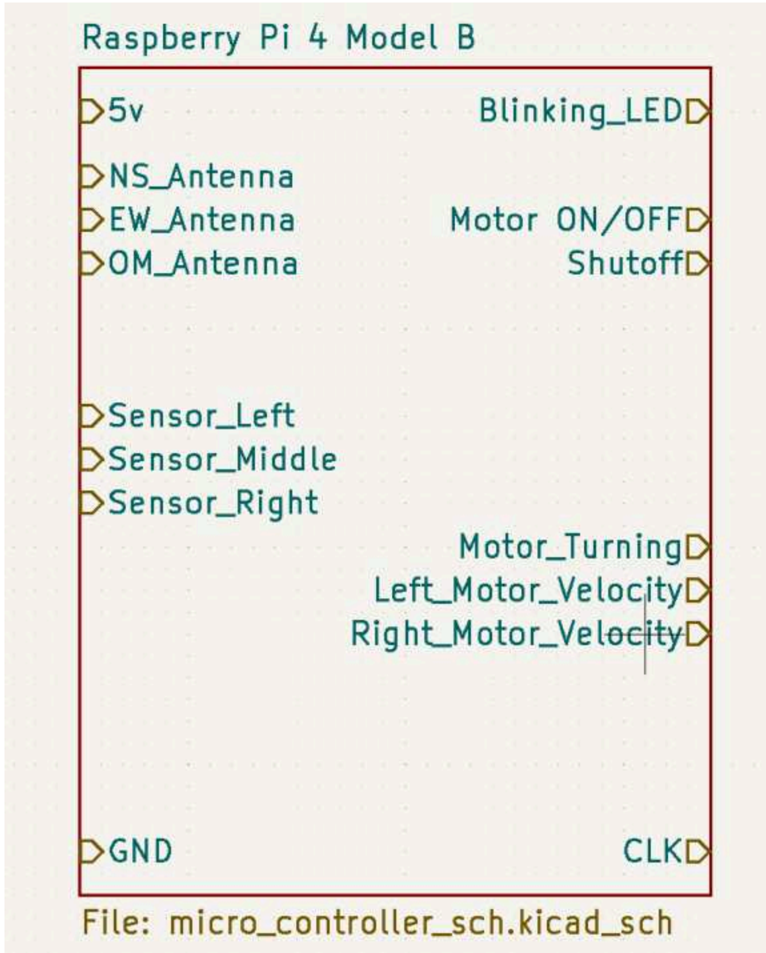
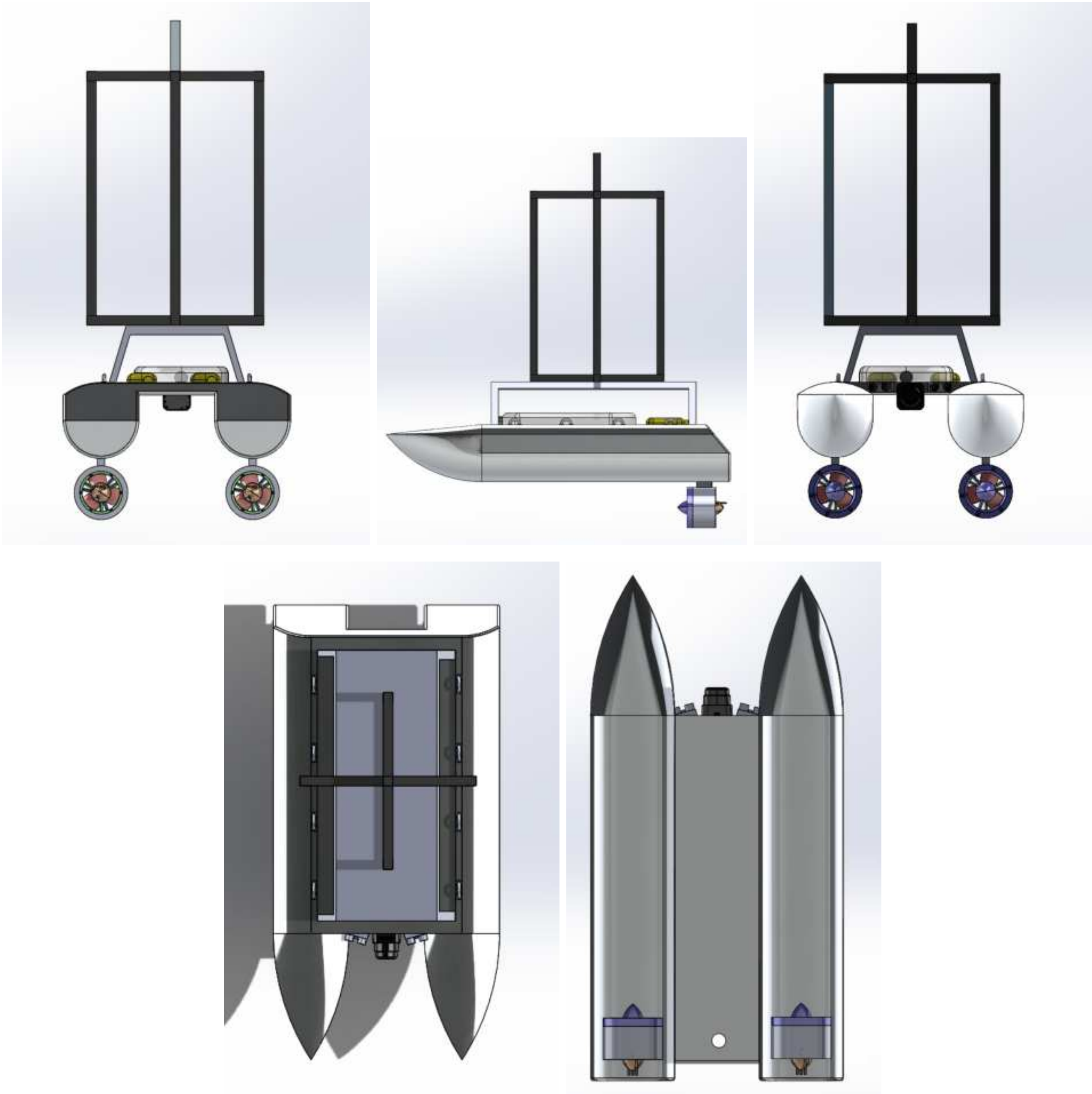
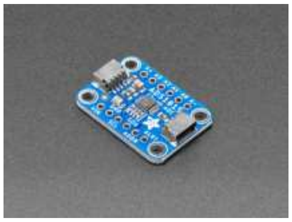


Figure G: *Anticipated inputs/outputs of the Raspberry Pi microcontroller. Inputs are indicated on the left and outputs are indicated on the right.*



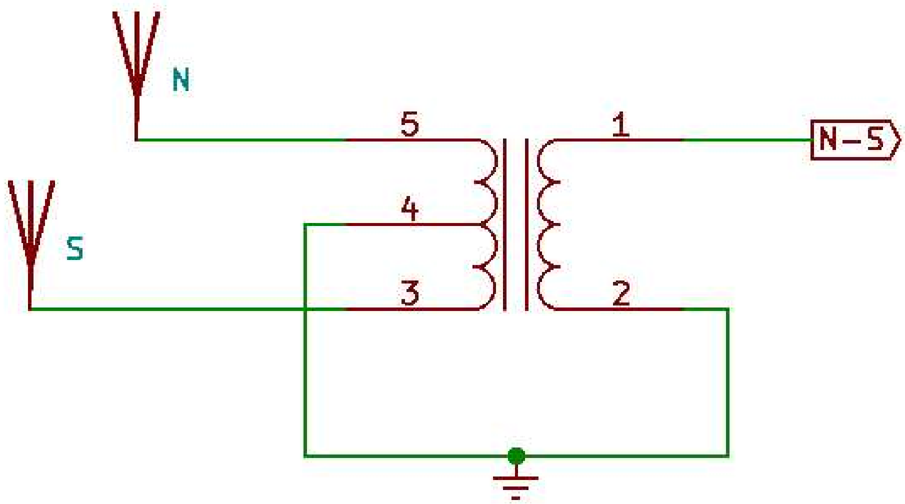
Additional Figures: *Isometric views of the design from all key angles.*

Appendix B: Component Specifications

Component Name	Image	Purchase Link	Technical Specifications
A. ADS 1015 12-Bit ADC		ADS1015 12-Bit ADC - 4 Channel with Programmable Gain Amplifier	Dimensions: 25.4mm x 17.8mm x 4.6mm Power: 2 - 5V
B. 2 x 12V Brushless Motor		DIAMONDDYNAMICS 1.2kg Thrust 12V Brushless Motor with bi-Directional ESC	Dimensions : 28mm x 38mm Thrust Forward: 1200 - 2500g Current: 13A Input Voltage: 12 - 14.8V Power: 60 - 312W
C. 14.8V Battery		YOWOO Graphene Battery 4S Lipo Battery	Battery Cell Composition: Lithium Polymer Capacity: 6000 mAh Voltage: 14.8 V Dimensions: 155 x 50 x 37 mm Weight: 1.35 lbs
D. Ultrasonic Sensors		Maxbotix Ultrasonic Rangefinder	Range: 0 - 254 in Dimensions: 15.5mm x 22.4mm x 20mm
E. LiDAR		Garmin LIDAR-Lite Optical Distance LED Sensor	Range: 5cm - 10m Current (during acquisition): 85mA Uses lensed LED with wavelength of 940nm
F. Raspberry Pi		Raspberry Pi Model B	2 GB RAM

Appendix C: Watson-Watt Direction-Finding Calculation

A basic array of the Adcock antenna consists of four equidistant vertical elements labeled accordingly as “North (N)”, “South (S)”, “East (E)”, and “West (W)” to receive directional radio waves, as well as an additional vertical element labeled “Omnidirectional (O)” to resolve any 180° ambiguity. The N and E elements are respectively combined with the S and W elements as outputs of transformers as shown in the circuit diagram below,



Figure*α *: Circuit diagram combining N and S elements to produce a difference as the output of a transformer (Fuentetaja).

while the O element is left central to the array, equidistant from the other antennas. This setup produces three antenna outputs: North minus South (NS), East minus West (EW), and Omni (O). Consequently, the SEA LION only requires three phase-coherent channels at its radio frontend, to provide an accurate 360° coverage of a signal’s angle of arrival.

Referencing the O element, when the signal arrives at the SEA LION’s Adcock antenna array from an angle, ϕ, as shown in the floor plan below, the O element receives a signal, $r_O = m(t)e^{j2\pi f_c t}$

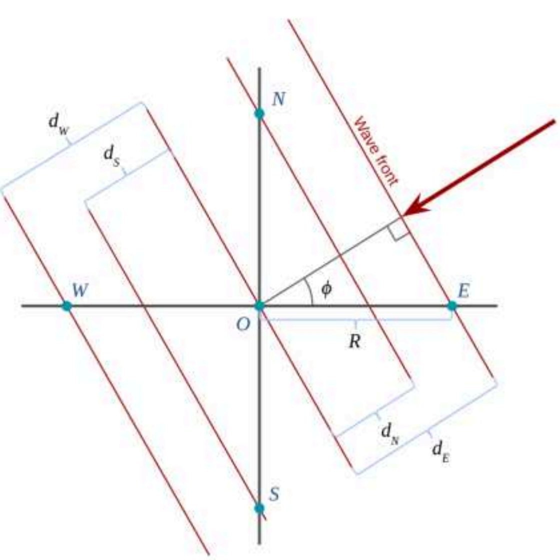


Figure* β*: Floor plan showing the transmitted signal’s angle of arrival with reference to element O (Fuentetaja).

where *m(t)* is a band-limited component carried at a frequency f_c. Ignoring noise and utilizing the "far-field assumption" (that the receiving antenna is far from the Tri-Band Beacon, so that the wave front of the transmitted signal wave can be considered a plane perpendicular to its direction of propagation), the signal arrives earlier at the "E" and "N" elements before reaching the O, S, and W elements. The additional distance, d_E, that the signal travels between the time it reaches E to the time it reaches O will then be:

$$d_E = R\cos\phi$$

which is of the same magnitude as d_W, while

$$d_N = R\sin\phi$$

which is of the same magnitude as d_S,. The signal then reaches element E a time

$$\frac{d_E}{v} = \frac{R\cos\phi}{v}$$

earlier than it reaches O, where v is the signal's propagation speed. Therefore, the element E receives a signal:

$$r_E = m(t + \frac{R\cos\phi}{v})e^{j2\pi f_c(t+\frac{R\cos\phi}{v})}$$

Given the "narrow-band assumption" that the base signal *m(t)* changes slowly relative to the rate of change of the carrier frequency, f_c,, the signal received by element E, and by extension the other elements, can be simplified to:

$$r_E = m(t)e^{j2\pi f_c(t+\frac{R\cos\phi}{v})}$$

$$r_W = m(t)e^{j2\pi f_c(t-\frac{R\cos\phi}{v})}$$

$$r_N = m(t)e^{j2\pi f_c(t+\frac{R\sin\phi}{v})}$$

$$r_S = m(t)e^{j2\pi f_c(t-\frac{R\sin\phi}{v})}$$

$$r_{EW} = r_E - r_W = m(t)e^{j2\pi f_c(t+\frac{R\cos\phi}{v})} - m(t)e^{j2\pi f_c(t-\frac{R\cos\phi}{v})} = m(t)e^{j2\pi f_c t}(e^{j2\pi f_c\frac{R\cos\phi}{v}} - e^{-j2\pi f_c\frac{R\cos\phi}{v}})$$

$$r_{NS} = r_N - r_S = m(t)e^{j2\pi f_c(t+\frac{R\sin\phi}{v})} - m(t)e^{j2\pi f_c(t-\frac{R\sin\phi}{v})} = m(t)e^{j2\pi f_c t}(e^{j2\pi f_c\frac{R\sin\phi}{v}} - e^{-j2\pi f_c\frac{R\sin\phi}{v}})$$

Since, according to Euler's Formula,

$$e^{jx} - e^{-jx} = \cos(x) + j\sin(x) - (\cos(x) - j\sin(x)) = 2j\sin(x)$$

then

$$r_{EW} = r_O 2j\sin(\frac{2\pi f_c R\cos\phi}{v})$$

As v/f_c is the wavelength of the carrier frequency, λ_c, then:

$$r_{EW} = r_O 2jsin(\frac{2\pi Rcos\phi}{\lambda_c})$$

$$r_{NS} = r_O 2jsin(\frac{2\pi Rsin\phi}{\lambda_c})$$

If R is significantly smaller than λ_c, then $2\pi R/\lambda_c$ is small, so much so that $sin(x) \approx x$ for small values of x, and

$$r_{EW} \approx \frac{r_O j4\pi Rcos\phi}{\lambda_c}$$

$$r_{NS} \approx \frac{r_O j4\pi Rsin\phi}{\lambda_c}$$

By dividing r_{NS} by r_{EW}, the angle of arrival can be recovered: $\phi = arctan\ (r_{NS}/r_{EW})$

To know which quadrant the signal of arrival, ϕ, is in, the signs of both r_{NS} and r_{EW} must also be known. However, r_{NS} and r_{EW} can only be distinguished when they are in phase or in opposition, while their signs cannot be determined with only r_{NS} and r_{EW}.

To resolve which quadrant the signal of arrival is in, the phases of both r_{NS} and r_{EW} can be compared with the last input signal, r_O. By considering the phasor from the input signal r_O as the strongest frequency component, the phasors of all the signals received by the elements of the antenna array can be represented in the phasor diagram below:

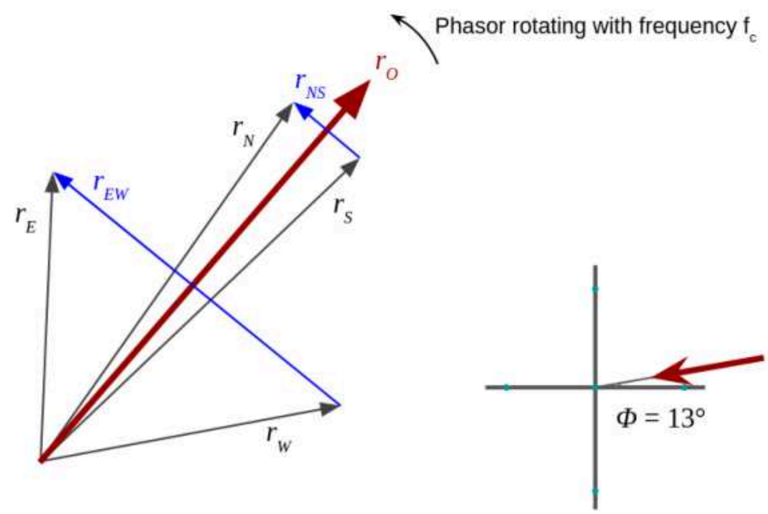


Figure* ɣ*: *Phasor diagram showing signals received by each element (Fuentetaja).*

When the signal's angle of arrival is in the first quadrant with the phasors rotating counter clockwise, r_N would be ahead of r_O, while r_S would be behind r_O by the same phase difference. The difference between phasors r_N and r_S, r_{NS}, would be 90° with respect to r_O, with a magnitude of $2sin\phi$. Similarly, r_W would be ahead of r_O, while r_E would be behind r_O by the same phase difference, though significantly greater than the phase difference between r_N and r_O or r_S and r_O. Hence, the phase difference between phasors r_E and r_W would also be 90° with respect to r_O, with a magnitude of $2cos\phi$, so that both r_{NS} and r_{EW} are in phase, as expected in the first quadrant.

For an angle of arrival in the second quadrant, r_E would be ahead of r_O, while r_W would be behind r_O, so that the phase difference of r_{EW} would be -90° with respect to r_O. Comparing both r_{NS} and r_{EW} with respect to r_O, the phase difference between r_{NS} and r_{EW} with respect to r_O would either be +90° or -90°, so that the signs of the phase difference would determine the quadrant the signal's angle of arrival is in. Applying the signs of both r_{NS} and r_{EW}, the signal's angle of arrival can be obtained:

$$sign_{NS} = \text{sign of (phase difference of } r_{NS} \text{ and } r_O)$$

$$sign_{EW} = \text{sign of (phase difference of } r_{EW} \text{ and } r_O)$$

$$\phi = atan2(sign_{NS}||r_{NS}||, sign_{EW}||r_{EW}||)$$

II. STEM Engagement Section

A. Introduction & Background

Columbia's Micro-g NExT team operates as a part of the Columbia Space Initiative (CSI), a larger student-run organization on campus dedicated to space science and engineering. Each year, CSI facilitates robust educational outreach efforts in underserved schools in the greater New York community by volunteering directly in local middle and high schools. This year, one of the project's Co-Leads, Kathryn Lampo, is also serving as the Director of Outreach for the larger Columbia Space Initiative, and as a result, the team has been hard at work to continue CSI's legacy of highly successful outreach programming. Micro-g specifically provides a unique opportunity for CSI to educate and engage students on topics such as human spaceflight, engineering for low-gravity environments, and the upcoming Artemis programs. Many of the students that CSI serves are a part of the "Artemis generation," making the team's efforts of particular relevance to the future of spaceflight and humanity's return to the moon.

The team has developed several plans related to outreach throughout NYC, the largest of which involves a partnership with Sophie Gerson Healthy Youth (SGHY), a local non-profit dedicated to supporting underserved middle schoolers in the city. Through this partnership, CSI has visited five middle schools in the area several times over the past few years, with a number of visits already planned for this year. Each visit consists of a space-focused STEM lesson, complete with an interactive activity to allow students to directly engage with the topic. Throughout each educational lesson and activity, CSI emphasizes the hands-on nature of STEM, and works to convey every club member's deep passion for space exploration. Outside of these recurring visits, the team is also creating digital curriculum focused on model rocketry, which includes volunteer-created video lessons and interactive activities. These lessons provide instruction on aerodynamics, propulsion, and the impetus behind space exploration (including information about the Artemis program). It will be facilitated by the outreach team throughout the semester, and will culminate with a model rocket launch attended by the middle school students. Designs created by students in the program will be modeled and manufactured by Columbia volunteers, allowing them to make their rockets flight-ready and launchable. Thanks to an additional partnership and further funding from the Columbia Center for Science and Society, these same programs will also be implemented at Eagle Academy, a high school in the Bronx.

Below, you will find further information on a number of formally planned outreach events with SGHY and Eagle Academy in the next year, as well as smaller, one-time supplemental events that CSI will also be hosting. Additionally, correspondences with relevant parties are included, many with Kristian Breton, the Columbia Engineering Outreach Director. Taken together, the following two sections provide an outline of the steps being taken to meet the team's STEM Engagement goals for this year, and to continue CSI's record of enthusiastic space-centered outreach.

B. Planned Events with SGHY & Eagle Academy

<u>Auditorium Programs</u>

The cornerstone of CSI's outreach in local middle and high schools are so-called auditorium programs: large group activities, often with an entire grade level of students, dedicated to a specific space topic. The team has planned 1-2 auditorium programs at each of five middle schools in New York for the fall of 2022, and the same number at the Eagle Academy. 2-3 programs at each school are tentatively planned for the spring semester.

Objective: To engage students with STEM topics, promoting an enthusiasm for space exploration through hands-on activities; to leverage the experience of Micro-g volunteers to push students to consider all facets of spaceflight (e.g.: rescue and recovery); to broaden participants' understanding of what goes into space exploration.

Audience Type: Middle and high school students across six schools in Manhattan and the South Bronx. All schools served consist primarily of students living at or below the poverty line, who would not otherwise have access to STEM programming or exposure to the topics discussed.

Number of Participants: 100-130 students per event; ~1000 for the fall semester depending on recurring enrollment

Dates: Programming is due to start in the last week of October, and to continue once to twice a week throughout the school year. Different schools host programs on different days of the week, but they will often be facilitated on Fridays.

Specific Activity Plans: Some of the proposed lectures and their accompanying activities are described below. The second is a legacy program that has had great success in prior years, while the others have been newly developed by this year's team.

1) Gravity Lecture & Egg-Drop Activity: This program will focus on near-Earth gravity, and how it differs from gravity in space. Microgravity environments like the moon will be discussed, as will gravity conditions on the International Space Station. Following this discussion, students will participate in an egg-drop activity to demonstrate the effects of gravity and challenge them to apply STEM principles to safely return their eggs to the ground. This also ties closely to the Micro-g team's SAVER challenge, allowing CSI to incorporate a discussion of what happens during splash-down, and how NASA ensures the safety of their astronauts in many ways. This lecture aligns with New York curriculum standards MS-PS2-4 and MS-PS2-4, which discuss gravitational interactions and the existence of fields between objects that allow contactless interference. Applying these standards to space is an engaging way for students to consider the effects of gravity (or the lack thereof).
2) Aerodynamics/Flight Lecture & Paper Airplane Activity: In this lecture, students will learn about flight (both here on Earth and in space), including information surrounding drag, spacecraft design, and propulsion. Ties will be made to how the atmosphere affects flight, as well as how the same principles apply to fluids, like in the case of the SAVER vehicle. The lecture will be followed by CSI's returning (and very popular) paper airplane activity, where students will have a chance to build paper airplanes, and put their designs to the test as they attempt to strike a drone with the paper airplanes. The activity will provide students with a chance to engage with New York standard MS-ETS1-3, which concerns the analysis of data from tests to improve an engineering solution. Students will be able to iteratively create paper airplanes and test them as they go, bettering their design each time.
3) Structures and Stresses Lecture & Moon Habitat Building Activity: This lecture will focus on engineering stress and strain, particularly as it pertains to space structures like rovers or the International Space Station. Structural integrity will be emphasized, and volunteers will discuss the effect of different shapes (e.g.: triangular vs rectangular vs cylindrical supports) on stability, giving examples from rovers and landers to emphasize the relevant applications of the lesson. In the subsequent activity, students will be given simple materials (notecards & tape) to construct "moon habitats" that will then be weighted using textbooks to see how much stress they can withstand. Students will be able to observe how different folds and constructions affect project success, helping them connect back to the importance of lander construction, including for the Artemis missions.
4) Astronomy Lecture & Pipe-Cleaner Constellation Activity: This lecture will have more of a space-science focus, and will teach students about the stars that are visible from Earth, and what they're actually like out in space. While not directly connected to the work of Micro-g, the lecture will push forward CSI's greater mission of spreading the club's passion and curiosity of space. Visible constellations will be discussed, as well as different types of stars and the star life cycle. An emphasis will be placed on space exploration, and what motivates scientists and engineers to further pursue such distant entities. Following the lecture, students will have an opportunity to construct different constellations from pipe cleaners. Each star in the given constellations will be discussed and described, tying back to the lesson. This activity ties to standard MS-ESS1-3, helping students to develop a concept of the scale of the solar system by discussing the scale of visible objects in the night sky.
5) Solar System Lecture & Orbit Demonstration: In this lecture, students will learn about the planets and other celestial bodies that make up the solar system. An emphasis will be placed on the orbits of planets and moons, and how gravity affects these bodies at scale. Human spaceflight to the moon and Mars will also be discussed, contextualizing what such journeys entail. The activity associated with this lecture will be a solar viewing event using a telescope and solar lens recently purchased with funding from the Columbia Center for Science and Society. Volunteers will emphasize the role of the sun as the center of the solar system. Importantly, appropriate safety precautions will be taken, and the dangers of direct viewing of the sun will be heavily emphasized. This activity relates to standards MS-ESS1-1 and MS-ESS1-2, which concern the motion and interaction of bodies within the solar system.

Last year's CSI volunteers hosting Auditorium programs at SGHY partner schools.

<u>Model Rocketry Program</u>

Outside of the in-person auditorium programs described above, the team is also currently developing online rocketry curriculum for implementation in the aforementioned partner schools. This program will include a launch event, as well as a poster session on Columbia's campus where students will have a chance to present their designs and what they learned. This entire project is closely aligned with all standards under the "Engineering Design" category of NY state science standards, as it guides students through a true iterative design process from inception to completion.

Objective: To allow students to engage in a longer-term engineering project through the iterative design process; to encourage enthusiasm for human spaceflight and the Artemis missions; to instruct on the value and challenges of spaceflight.

Audience Type: Middle and high school students in the same schools mentioned in the previous section.

Number of Participants: Depends on the school and the method of implementation. Some schools have indicated a desire to use the curriculum with students in a club, while others are more inclined to use it in a classroom setting. An estimated cohort of 300 students across all six schools.

Dates: The first lessons will be delivered in Mid-October, with a proposed launch during the spring semester once it is warm enough and the curriculum has been completed (ideally early April). The poster session will take place during Spaceposium (see "Additional Outreach Events" below) in late April.

Specific Activity Plans: As mentioned above, the rocketry curriculum will consist of both written instruction and volunteer-created video lessons and activities. It will be built to be flexible, allowing for delivery in both classroom and afterschool settings. The hybrid nature of the curriculum allows CSI to increase the amount of lessons that students will experience, and removes limitations on physical presence of volunteers.The current lessons include a kickoff (attended in person by CSI volunteers), a lesson on the history and impetus for spaceflight, an ideation session, a construction session, and an in-person launch event.

For the actual construction, design, and launch part of the program, the team plans a close partnership between CSI volunteers and the students that are a part of the program. The model rockets themselves will be propelled by A8-3 Engines, which are designed for flights in vehicles weighing less than 3 ounces, including the engine. Students will be given a central casing that is pre-designed to hold the engine by CSI volunteers. Using craft materials (cardboard, cardstock, quick dry clay, glue, etc), they will design and build nosecones and fins to fit their rockets during Lesson 2. Following that, they will make technical drawings of their ideas, including detailed measurements, scale, and shape of their designs.

Following that lesson, CSI volunteers will take the students' drawings and models and use them to mock up each team's design in CAD. Using the resources of the Columbia Makerspace, the nosecones will be 3D printed and the fins will be laser-cut. Following the in-house manufacturing, teams will be given their parts and allowed to assemble their design during Lesson 3. During that session, they will also have a chance to create posters describing their design for their final presentation at the end of the project.

The final two sessions of the project will represent the culmination of the students' work, and will take place in late spring. The first will be the rocket launch itself, for which Professor Mike Massimino—the team's Micro-g advisor and a former NASA astronaut—will be in attendance. At the event, each team will have a chance to safely test their design and watch their peers do the same. Finally, the program will conclude with a poster session on Columbia's campus which will be open to the public, and which most CSI members will attend. Each student team will have the opportunity to showcase their poster and design, as well as to tour the Columbia Makerspace to see where their designs were manufactured.

Students from MS302 during Spaceposium on Columbia's campus. Right: Two students present the antibiotic resistance project they completed with CSI in AY 2021-2022 to Professor Mike Massimino.

Former Outreach Director and Micro-g Co-Lead Matthew Werneken presents Columbia's AY 2021-2022 Micro-g project to middle school students during Spaceposium.

C. Additional Outreach Events

SGHY Summer Camp Astronomy Counseling

Objective: To send CSI volunteers to a Summer camp hosted by SGHY to further engage CSI outreach program participants in a non-academic setting; to inspire an interest in space science and exploration.

Audience Type: Middle school students in the same schools mentioned in the previous section.

Number of Participants: About 200 campers.

Dates: Mid-to-late July for a week.

Specific Activity Plans: At SHGY Summer Camp, CSI volunteers serve as astronomy counselors, guiding students through astronomy activities, as well as a model rocket launch and talks about space exploration. The Outreach team recently purchased a telescope to enhance this program, and plans to send students back this coming Summer. A link to a video of last year's rocket launch can be found here.

Visits to Intrepid & The American Museum of Natural History, ISS Downlink

Objective: To further engage students in CSI's outreach programs by bringing science and space to life; to promote practical applications of STEM concepts taught during auditorium programs and in class.

Audience Type: Middle school students in the same schools mentioned in the previous section.

Number of Participants: About 500 students.

Dates: Several times during the year with different cohorts of students.

Specific Activity Plans: As part of CSI's partnership with SGHY, volunteers will attend other outreach events with participants, including museum trips and an ISS downlink. These events bring space to life in a particularly tangible way, enhancing outreach programming.

Spaceposium

Objective: To send CSI volunteers to a Summer camp hosted by SGHY to further CSI's outreach participants in a non-academic setting; to inspire an interest in space science and exploration.

Audience Type: Undergraduate and graduate science and engineering students; Columbia engineering faculty.

Number of Participants: About 100

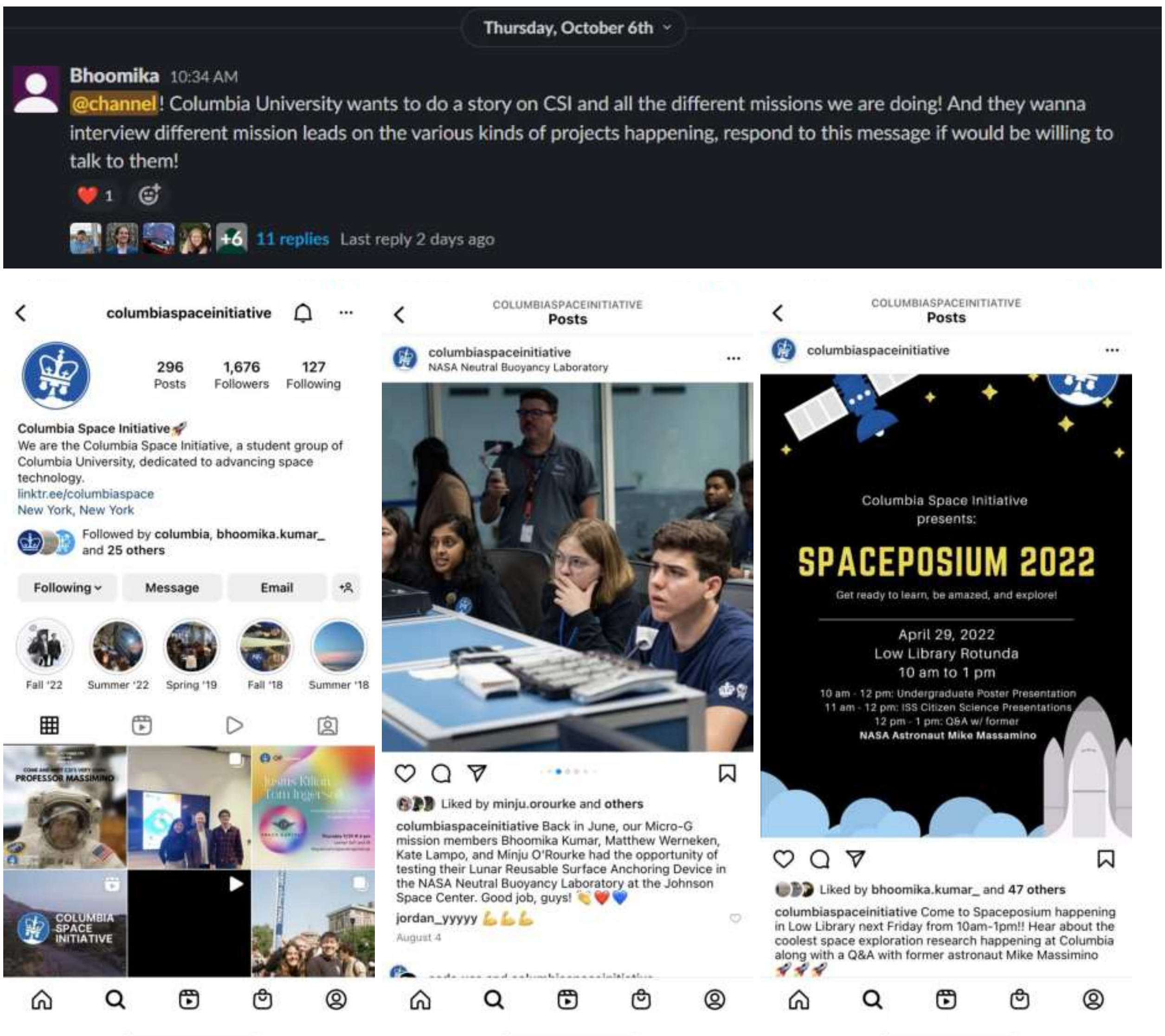
Dates: Mid-to-late April

Specific Activity Plans: Spaceposium is an annual science symposium hosted by CSI which attracts students and faculty from Columbia University interested in aerospace engineering. At the event, CSI will present the results of the Micro-g project with a poster presentation alongside the work of other teams in the club, and will also host the poster presentations of participants in the model rocketry program.

D. Press & Social Media

CSI is very active in the broader Columbia community, and has a significant social media presence across several platforms. The team often participates in media efforts spearheaded by Columbia Engineering, including sharing posts, collaborating on press, and creating other media relevant to CSI's accomplishments. Additionally, CSI has an active website and Instagram account, as well as a Slack channel (which is home to over 1,800 members, alumni, and advisors) that is used to share news and updates on a regular basis. The team plans to continue these media efforts this year, sharing accomplishments regarding both Outreach and Micro-g to both the CSI community and the larger Columbia community. Finally, Columbia plans to do an in-depth profile of CSI this fall (see Slack screenshot below) with each project getting its own dedicated section, including Micro-g. The team's members will have a chance to share their work with the wider Columbia audience. Some other examples of CSI's media presence are linked below:

- CSI Website (Micro-g Specific Page)
- CSI Introduction Video (including last year's Micro-g team)
- Columbia profile on a CSI experiment on the International Space Station
- CSI Linkedin Page, which is home to a budding alumni network



Screenshots from CSI's Slack workspace and Instagram page.

E. Contacts, Letters, & Agreements

Email screenshots from several of the team's partners detailing plans for this year's programs are included below. While much communication takes place during meetings and face-to-face, these correspondences offer a glimpse into CSI's outreach plans for the year. The relevant persons are:

- Kristian Breton, Columbia Engineering Outreach Director
- Alan Gerson, Director of Sophie Gerson Healthy Youth
- Melinda Miller and Caroline Surman, contacts from the Columbia Center for Science and Society who facilitate the grant that funds programming at the Eagle Academy
- Anne Degnan and Andrew Peterson, contacts at Eagle Academy who are helping to implement CSI's outreach there

Threads 1 & 2: *Email threads concerning the award of a Columbia Center for Science and Society grant to CSI that marks the beginning of the team's work with Eagle Academy. The purchase of outreach materials (like the drone, projector, and telescope) are also included.*

CSS Public Outreach Grant Application External Inbox × Clubs/CSI/Outreach ×

Theodore Maximilian Nelson <tmn2126@columbia.edu> Sun, May 1, 11:12 PM
to scienceandsociety, Matthew, Gabrielle, Bhoomika, Tycho, Ben, Jordany, me

Dear Columbia Center for Science and Society,

Please find attached a grant application on behalf of Columbia Space Initiative.

Sincerely,
Theodore Nelson

Co-Director of Outreach and Operations 2021-2022, Columbia Space Initiative

2022 Center for S...

Melinda Miller <mmm2370@columbia.edu> Fri, Jun 24, 4:27 PM
to Caroline, Theodore, Matthew, Gabrielle, Bhoomika, Tycho, Ben, Jordany, me, Columbia

Dear Theo,

Apologies for the delay in getting back to you. I am reaching out to let you know that the Center for Science and Society will be able to partially support your request for funds (in the amount of $2,320) to expand the Columbia Space Initiative to additional schools, such as the Eagle Academy. The reviewers were strongly in favor of supporting these important outreach activities; however, they were hesitant to fund one item in your budget: the outreach/video drone. However, I am happy to discuss any alternative ideas you may have for collecting video or documenting these projects. Additionally, if you have received any other support related to this school outreach program since your email from May 17, or if you want to revise the budget in any way, please let me know.

I am attaching two items:

- CSS Grant Guidelines that will provide you with additional details about award payment, recipient financial responsibilities, and final reports.
- CSS Event and Activity Worksheet. Although not all questions may be applicable to your proposal, we ask that you complete and submit the worksheet to the best of your ability before starting your project. Most important is the final question regarding your DEI efforts. Feel free to cut and paste information from your original proposal.

Note that Public Outreach funds are generally managed by the Center for Science and Society, and most purchases will need to be made directly by our Center or by another department using our chart string. If you have a timeline for when you need items purchased, please share that as soon as possible with me and my colleague Caroline Surman (copied above) so we can ensure that we can make these purchases in time for the start of your programs.

We look forward to working with you on this important project. Congratulations!

Best,
Melinda

Kathryn Lampo <kel2169@columbia.edu>
to Caroline, Melinda, Columbia

Sep 8, 2022, 10:35 PM

Hi again!

Our Outreach team just wrapped up our meeting, and as promised, I have updates on everything Melinda mentioned! Thank you again for your patience on this.

First, I've attached Amazon links to both the drone and the projector we're looking to buy—let me know if these don't work for any reason.

- Projector ($479): https://www.amazon.com/gp/product/B08V857HSC/ref=ewc_pr_img_1?smid=ATVPDKIKX0DER&psc=1
- Drone ($60): https://www.amazon.com/SYMA-Foldable-Quadcopter-Adjustment-Beginners/dp/B09B4RXX4H/ref=sr_1_5?keywords=drone%2Bwithout%2Bcamera&qid=1662688288&sr=8-5&th=1

For the smaller supplies, access to the Amazon account is perfect! You can go ahead and set me up as the requestor—let me know what you need from me to make that happen.

In terms of the background checks, our funding plans for that line item have actually changed. We also partner closely with the Columbia Engineering Outreach office on our programs, and they have graciously agreed to fund those checks and cover all the involved logistics. This is a recent update on our end, but we think that letting the Outreach office handle those will be the best course of action for us this year.

That said, I wanted to ask if it'd be possible to put those funds towards a different part of our program. I completely understand if that's not an option because it wasn't included in our original proposal, but we've found a new need during our recent program planning that we think would add significant value to our outreach.

Specifically, we're trying to have a stronger focus on astronomy during our programs this year, and are looking to purchase a telescope to help with those lessons. For context, we send a few volunteers to a summer camp in upstate New York each year to serve as space science counselors, and the lessons that they deliver during that program involve astronomy activities and the use of telescopes. However, we've found that the telescopes currently made available by Sophie Gerson Healthy Youth (the host organization, who also helps with our school year outreach) are finicky and difficult to use in a classroom environment. With the money originally allotted to background checks, we'd love to invest in a higher-quality telescope (and potentially a solar lens for daytime viewing) to supplement our programs this year.

If the reallocation of funds like that is possible, I'd be happy to draft up a more official description of what we're looking for, or to provide any additional details if needed.

Let me know what else you need from me in the meantime!

Thanks,
Kate

...

Melinda Miller
to me, Caroline, Columbia

Sep 15, 2022, 2:45 PM

Hi Kate,

We are going to go ahead and make the projector and drone purchases now. Amazon deliveries still haven't been the most consistent to our office - they don't go through Columbia's mailroom and sometimes they get lost or returned as undeliverable. Would it work to send these items directly to your mailing address or someone else's in the group? If so, please share the address.

Additionally, I have invited you to our Amazon Business account. I will also need your mailing address for those purchases.

Finally, in terms of the telescope: Yes, please send me a more detailed (does not have to be more than a couple of paragraphs) proposal for the reallocation of funds with the type of telescope and lens you are looking for, the cost and a link to where we can purchase it, how it will be used and for which specific programs and dates, and a brief plan for who will be responsible for it and how it will remain with the Columbia Space Initiative from year to year. Please include something along the lines of "We understand that this equipment will remain property of Columbia University, and the executive members of the club will retain and maintain this equipment from year-to-year specifically for activities of the Columbia Space Initiative. If the equipment is no longer needed by the Columbia Space Initiative, or if the club is disbanded or put on hiatus, the executive members of the club will return the equipment to the Center for Science and Society."

Let me know if you have any questions.

Kathryn Lampo <kel2169@columbia.edu>
to Melinda, Caroline, Columbia

Sep 16, 2022, 12:48 AM

Hi Melinda,

Great! You can go ahead and send the projector and drone to my mailing address, as well as link it with the Amazon account. The address format that Columbia Mail uses is below; including my UNI is the most important part.

Kathryn Lampo
[redacted]

I've also attached a PDF with further information about the telescope, as well as links to the items we'd hope to purchase. While there are no set dates for our events yet, I described many of the specific uses we'd have for the telescope this academic year and the following summer. Let me know if you need any more information from me regarding that.

Thanks,
Kate


CSS Reallocation ...

Melinda Miller
to me, Caroline, Columbia

Sep 23, 2022, 11:58 AM

Hi Kate,

We have reviewed your request to reallocate funds to purchase the telescope for the Columbia Space Initiative. Your outreach plans and the retention and maintenance plan for the telescope look good, and we will approve your request.

Please just make sure that there is some information packaged with the telescope (in the box, or a sticker somewhere) that indicates that it is property of Columbia University with some contact information (columbia space initiative email address, perhaps?). Please do the same for the projector and drone.

Would it be ok if I order these items to be shipped to your address? Do you plan to make any other purchases before October 1, through Amazon or elsewhere?

Best,
Melinda

Columbia Space Initiative Outreach Grant + New Team Members

External | Clubs/CSI/Outreach

Theodore Maximilian Nelson <tmn2126@columbia.edu>
to Kristian, Columbia, Bhoomika, Matthew, Tycho, Ben, Gabrielle, Jordany, me

Sat, Jun 25, 6:56 PM

Dear Kristian,

I hope that you're summer is going well. As you probably saw from the SGHY email, I am writing to introduce some new members of our team. They are all cc'd above.

Outreach Director - **Kate Lampo**
Operations Director - **Benjamin Stettin**
Press Director - **Jordany Capellan**

Kate will be taking the lead organizing our outreach events next semester.

We have very exciting news regarding the potential of our outreach program: we have received a grant from the Center for Science and Society in the amount of $2,320 to expand the Columbia Space Initiative to additional schools, such as the Eagle Academy (as mentioned in the proposal that we shared with you). I will be attaching the proposal to this email, along with the grant guidelines. We have a significant number of obligations with regard to advertisement of our programs and media documentation, so we'd like to get a fall schedule prepared as soon as possible to share with the grant coordinators.

We are primarily interested in outreach at the either the elementary or high school level, but we could conceivably also plan a panel for educators to present our curriculum.

Kate will be reaching out soon to schedule a meeting at your convenience to discuss next semesters outreach programs.

Talk soon!

Sincerely,
Theo

Kristian Breton <kb3265@columbia.edu>
to Theodore, Columbia, Bhoomika, Matthew, Tycho, Ben, Gabrielle, Jordany, me

Jul 6, 2022, 9:24 PM

A belated congratulations! This is great news. I've let my contacts at Eagle Academy know and they are excited.

I'm in the middle of summer programs for high school students, but we should setup a time in August to meet and strategize for the fall.

Again, congrats!

> On Jun 25, 2022, at 6:56 PM, Theodore Maximilian Nelson <tmn2126@columbia.edu> wrote:
>
> Dear Kristian,
>
> ...

2 Attachments • Scanned by Gmail

CSS Outreach Gr...

2022 Center for S...

Threads 3 & 4: *Email threads concerning CSI's plans for outreach with SGHY this year.*

Updates & Follow Up Questions External Inbox ×

alan jay gerson
to me, Matthew, Theodore, James, bole.pan, Hunter, James, Kristian, Swati

Tue, Sep 20, 1:10 AM

Hi Kathryn & CSI Team,

I hope everyone's off to a super-great start on the new school year!

First, a note about the past summer: Your Astronomy/Space Science program at camp was a big hit! Swati, Matthew, James, James & Hunter: you were big hits! We are still in the process of culling both photos and the questionnaires the kids filled out. I will send a compendium to you in the near future. But as a sneak preview, the responses were overwhelmingly positive. The adjectives used to describe the program and the five of you were "awesome," "cool," "fantastic" and the like. The comments included "I never thought I'd see the Moon so close-up," "this was my first time seeing a planet" or a falling star," "the rockets...laser tag...drones were a lot of fun." And repeatedly by many: "It got me interested in astronomy." Clearly you inspired our campers, expanded their horizons, and fostered new thoughts and dreams about the cosmos and their futures. Thanks so much. Kathryn, I hope CSI will continue this summer tradition!

Looking ahead, September is always hectic for us as we gear up to start programming come mid-October (after the Columbus Day Holiday). To that end, some updates....

~ We have met with all of our Principals. They all like the Rocketry theme, Kathryn, which you proposed. So we are good to go with that. We figure one CSI auditorium program as we've done in the past, one Mike Massimino program (hopefully), two (or three) class sessions on the rockets and rocket building, based on material or remote instruction you provide in advance (so no need for you to be present for this), and the grand finale rocket launching (for which it would be great if you could be present - could be next semester). Let me know what you think.

~ The above would be for each of our schools. We now serve five schools, but we recognize that not all schools will be able to get all programs. So let me know how many schools you can undertake with the above program if we split you up in teams of two or three CSI members per school. For each school we really only need one team to go to the school twice, for the intro auditorium program and for the rocket launching. It could be one visit each semester. So, it's really a question of how many teams, and can each team cover one or two schools. Please advise.

~ We are still waiting to hear from NASA on the date for the ISS hook up. We will keep you apprised. It would be great if you could participate.

~ We have added a grade-wide trip to the Intrepid to our program repertoire, in addition to the Museum of Natural History. We will apprise you of dates and you are more than welcome to accompany the schools, which would certainly make for more meaningful experiences with your involvement.

~ Looking ahead, we would love to plan a reprise of the campus visit in the spring, as it went so well. We could help with Low Library and other expenses.

~ Kristen, or anyone, do you know if the Astronomy Department has yet engaged an outreach coordinator to replace Jana? If so,could you make an introduction?

Let me know what you think of the above. Then we can start the scheduling. We remain cognizant of your crazy busy schedules and appreciate any time you can offer to our kids. It really makes an impact on them!

One other thing, we plan to hold our first Sophie Gerson Healthy Youth gala since the pandemic, in the early spring. We will invite all of you as our guests. I think we tend to throw good parties!

All the best, with great appreciation,

Alan
917-836-3272

Kathryn Lampo <kel2169@columbia.edu>
to alan, Matthew, Theodore, Kristian, Columbia

Sep 22, 2022, 11:55 PM

Hi Alan,

We successfully hosted our first outreach meeting tonight, so I have some updates on our plans for the year! We liked your proposal for one auditorium program and one launch event, and we have the capacity to cover all five schools in that regard. Our volunteers are also enthusiastic about creating the remote instruction materials for the rocket project, and we'll focus on that in the next couple weeks--people threw out ideas tonight about videos and interactive lessons that we think could be particularly engaging for our students. I'll send a further update once we have a better idea of what those lessons will look like, and how CSI volunteers might be able to help in the manufacturing process too.

We'd also love to send volunteers to the ISS downlink event and the trips to Intrepid and the Museum of Natural History. Let me know when you nail down dates for those, and I'll pass the information along to the team! The same goes for an on-campus event in the spring; it'd be great to have the students back again.

Excited to get going on this--let me know if you need anything else from me in the meantime.

Kate

...

First Auditorium Program

External Inbox ×

alan jay gerson
to me, Columbia, Leonard

Mon, Oct 24, 6:07 PM (9 hours ago)

We have our first date!!!!

The Bronx school would like to host their first auditorium program on earth Friday, November 18 or Wednesday, November 16th. Either day, it would be in the afternoon from around 1:45 - 2:40. But the school will confirm the specific time based on your recommendation.

They are excited about the Rocketry program! This will involve two or three class sessions plus a spring launch.

I have copied Mr. Rosny Louis, Assistant Principal, who will make all arrangements as your point of contact. His cell is 516-430-0339. We request that you be in direct touch to work out all details on the above.

Also, Mr. Louis, please get back to us on dates for the Planetarium and Intrepid trips, per our discussion. And, please schedul class visits (one at a time) to the Aerospace center with Zohar at (212) 608-6164. CSI, if any of you can join the school for any of these expeditions, I'm sure it will enhance the experience for the middle school students and you will find it meaningful and fun. We will keep you apprised.

CSI, I ran into Professor Massimino at homecoming. We left it that we would follow up on possibly scheduling days for his auditorium program.

I will get back to CSI as the week progresses and I hear from the other schools.

Time to blast off!!

Alan

Thread 5: *Correspondence with contacts from Eagle Academy concerning plans for outreach for the year.*

Introductions External Clubs/CSI/Outreach ×

Kristian Breton <kb3265@columbia.edu> Tue, Aug 23, 12:58 PM
to Nancy, Anne, Andrew, me

Hello Andrew, Nancy, and Kate,

It is my pleasure to introduce the three of you! Nancy works for Columbia and is a PI on a NSF grant in collaboration with Eagle Academy. Andrew is an all-star teacher at the Eagle Academy-Harlem school and has welcomed other Columbia Engineering people into his classroom.

Earlier this year one of the best student clubs on campus, the Columbia Space Initiative, won a modest grant to expand their outreach efforts. Last year they worked with a school in Chinatown and one in the Bronx to deliver a series of fun workshops about space and rockets. With this additional funding they can serve Eagle Academy.

To get the ball rolling can the four of us meet next week? We could review the calendar and hear from Andrew about what makes the most sense for Eagle Academy.

Progress!

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Kristian Breton | he/him/his
Outreach Director
The Fu Foundation School of Engineering and Applied Sciences
Columbia University
475 Riverside Drive, Suite 850
New York, NY, 10027
(646) 745-8420

Kathryn Lampo <kel2169@columbia.edu> Tue, Aug 23, 3:52 PM
to Kristian, Nancy, Anne, Andrew

Hi Andrew and Nancy!

It's a pleasure to virtually meet you! I'll be serving as the Chair of Outreach for the Columbia Space Initiative this year, and I'm excited to extend our efforts to Eagle Academy. Like Kristian mentioned, we've begun planning our programming for this academic year, and are now looking to solidify some ideas based on what works best for our new students.

I'm flying back to campus and moving in next Friday, but I'm completely free Monday through Thursday, so whenever works best for you then is fine by me. Looking forward to it!

Kate

...

Anne Lee Degnan <ald1@columbia.edu> Aug 23, 2022, 5:28 PM
to me, Kristian, Nancy, Andrew

Hello Kate:

I will speak with Andrew on Tuesday about our NSF work together and double check when he has room in his schedule.

Then, we can all connect and talk about your exciting Space Initiative.

Thank you for leading on this amazing educational support to the Eagle Academy students.

And, Kris, thank you for getting us all connected.

Kate, have safe and smooth travels if you, Andrew and I don't connect before your move back to campus.

All my best,
Nancy

Nancy Degnan, Ph.D.
Associate Research Scientist
The Department of Earth and Environmental Engineering
The Fu School of Engineering and Applied Sciences
Columbia University

c: 917-923-3474

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Columbia Space Initiative Outreach Updates External Inbox ×

Kathryn Lampo <kel2169@columbia.edu>
to Anne, Andrew, Kristian

Fri, Sep 23, 12:19 AM

Hi All!

As promised, the CSI Outreach team has hosted our first meeting, so I have some updates for you all regarding our plans for the year and our capacity for programming at Eagle Academy. We have more volunteers than we did last year, but we're still a modestly-sized team, and many of our students have several other commitments. With that in mind, here's what we brainstormed regarding programming:

For the fall semester, we can do one or two auditorium-style programs like I mentioned before. This could be with larger groups of students (a full grade level, for example), and would consist of a space science or engineering lesson followed by an interactive activity like building paper airplanes. We'll also hopefully have the capacity to host 2-3 of these in the Spring.

We'd also be happy to go forward with the rocket program, but we can't commit to weekly visits. Instead, the Outreach team is currently working on designing lessons and activities related to building and launching model rockets that we'd be happy to share with you. These lessons would include videos made by the team alongside instruction that could be implemented either in-school or during an after-school club, but that would not be taught directly by our students. We could do a school visit to kick off the program, as well as manufacture students' designs here at Columbia so that they're flight-ready. We'd also be able to do an in-person launch event at the end of that program, which we'll try to have Professor Mike Massimino (a former NASA astronaut) present for.

So, in brief, we can do the following this Fall:
- 1-2 auditorium-style visits
- A rocket project kickoff
- A rocket launch event
- Delivery of rocket project curriculum to guide students through the process of creating their model rockets
- Manufacturing (think 3D printing, laser cutting) of students' designs here at Columbia

Let me know your thoughts! Of course, if you'd prefer we put more time into the auditorium programs as opposed to the rocketry project (or vice versa) we'd be happy to move things around.

Additionally, I don't think I have Ms. Davis' email, so if someone could pass this along to her, that'd be great.

Excited to get going on this!

Best,
Kate

Anne Lee Degnan
to me, Andrew, Kristian

Oct 7, 2022, 3:32 PM (2 days ago)

Hello Kathryn:

This is terrific news and I thank you and your team for the great work/gift you are bringing to the students.

I am sure that Mr. Peterson (Andrew) will get back to you as soon as possible.

And, I think that another conversation, by phone or zoom could be beneficial.

Have a wonderful weekend.

Best,
Nancy

...

--

Andrew Peterson
to Assistant, Anne, me, Kristian

Oct 7, 2022, 9:17 PM (2 days ago)

Dear Kate,

Please forgive me for the delay in responding and thank you for the follow up. I CC'd AP Davis on this so that you have her email and she can join the conversation. I think with the school calendar filling quickly, another meeting to schedule dates would be a great idea.

AP Davis are there two dates that would be ideal to have the whole middle school together in the auditorium or gym in October or November that we can set now?

Is there a time next week that works to meet and discuss dates and further detail the rocket building and launch event?

Thank you for the opportunity!

Sincerely,
Andrew Peterson

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III. Administrative Section

A. Mentor Request

The team is not currently working with a point of contact at NASA, and would benefit from additional support in the next phases of the Micro-g NEXT challenge, if selected to continue.

B. Institutional Letter of Endorsement

COLUMBIA | ENGINEERING
The Fu Foundation School of Engineering and Applied Science

October 24, 2022

Proposal Review Committee
Micro-g NExT 2023 Design Challenges
Microgravity University
Johnson Space Flight Center
Houston, TX 77058

Re: NASA Micro-g NExT 2023 Design Challenges

Dear Members of the Review Committee,

The Columbia Space Initiative is a student-led organization within Columbia University in the City of New York. Its faculty sponsor is Michael Massimino, a Professor in the Department of Mechanical Engineering.

The Fu Foundation School of Engineering and Applied Science endorses the team's participation and commits to support the participation of the Columbia Space Initiative in their challenge.

Please do not hesitate to contact Professor Massimino or I should you have any questions or concerns.

Sincerely,

James Hone
Wang Fong-Jen Professor of Mechanical Engineering
Chair, Department of Mechanical Engineering

The Fu Foundation School of Engineering and Applied Science

C. Statement of Supervising Faculty

COLUMBIA | ENGINEERING
The Fu Foundation School of Engineering and Applied Science

October 10, 2022

Dear Microgravity University Committee,

As the faculty advisor for an experiment entitled "SEA LION: Surface Emergency Autonomous Location-Identifying Ocean Navigator" proposed by a team of undergraduate students from Columbia University, I concur with the concepts and methods by which this project will be conducted. I will ensure that all reports and deadlines are completed by the student team members in a timely manner. I understand that any default by this team concerning any Program requirements (including submission of final report materials) could adversely affect selection opportunities of future teams from Columbia University.

Sincerely,

Michael J. Massimino
Professor of Professional Practice

D. Statement of Rights of Use

COLUMBIA | ENGINEERING
The Fu Foundation School of Engineering and Applied Science

October 10, 2022

As a team member for a proposal entitled "SEA LION: Surface Emergency Autonomous Location-Identifying Ocean Navigator" proposed by a team of undergraduate students from Columbia University, I will and hereby do grant the U.S. Government a royalty-free, nonexclusive and irrevocable license to use, reproduce, distribute (including distribution by transmission) to the public, perform publicly, prepare derivative works, and display publicly, any data contained in this proposal in whole or in part and in any manner for Federal purposes and to have or permit others to do so for Federal purposes only.

As a team member for a proposal entitled "SEA LION: Surface Emergency Autonomous Location-Identifying Ocean Navigator" proposed by a team of undergraduate students from Columbia University, I will and hereby do grant the U.S. Government a nonexclusive, nontransferable, irrevocable, paid-up license to practice or have practiced for or on behalf of the United States an invention described or made part of this proposal throughout the world.

Sincerely,

Michael J. Massimino
Professor of Professional Practice

Kathryn Lampo
Minju O'Rourke
Manuella Kwawu
Miks Huntley-Fenner
Kade Jimenez
Annika Deshpande
Shimon Sarkar

Ethan Thomas	Ethan Thomas
JACOB BOXERMAN	[illegible]
Justin Beltran	[illegible]
Rebekah Cornish	[illegible]
Claudio Solano	Claudio Solano
Daryl Chon	[illegible]
Claire Cizdziel	[illegible]
Kevin Z. Qiu	[illegible]
Jessica Bolar	Jessica Bolar
William Specht	[illegible]
Sandhya Sethuraman	[illegible]
Arnaud Lamy	Arnaud Lamy
Julio Ramirez	[illegible]
Casandra Martinez	[illegible]
Ashley Gigon	Ashley Gigon

E. Funding and Budget Statement

Funding for Columbia's previous Micro-G NExT teams has come from the Activities Board at Columbia, the Columbia Mechanical Engineering Department, and the School of Engineering and Applied Science (SEAS) Dean Travel Fund. The team plans to use the same sources for expenditures this year. While some of the costs below are estimates, many specific items are also listed and linked in *Appendix B: Component Specifications*.

Item	**Projected Cost**
Materials and Supplies	
PLA (for fiberglass layup, platform, antenna, miscellaneous components) *Provided free of cost by Columbia Engineering*	$0.00
Fiberglass (3 yds)	$50.00
Polyester Resin (1 qt)	$20.00
Caulk	$10.00
Polypropylene Cylinders	$15.00
Propellers (qty. 2)	$150.00
Eyelets & Bungee Cords	$40.00
Antenna (outsourced manufacturing)	$600.00
Raspberry Pi Model B	$40.00
Batteries (qty. 2)	$150.00
Ultrasonic Sensors (qty. 2)	$60.00
Lidar Sensor	$60.00
ADC	$10.00
Beacon Light	$35.00
Miscellaneous Electronic Components (coax cable, PCBs, wires, etc)	$150.00
Platypus Water Bottles (qty. 2)	$40.00
Materials and Supplies Total	$1430.00
Travel	
Airfare for Six Students	$3,000.00
Hotel Stay (2 rooms, 3 nights)	$1,500.00
Car Rental (4 days)	$500.00
Food	$800.00
Miscellaneous	$400.00
Travel Total	$6,200.00
GRAND TOTAL	$7,630.00

F. Parental Consent Forms

All team members are 18 or older, so there are no parental consent forms required.