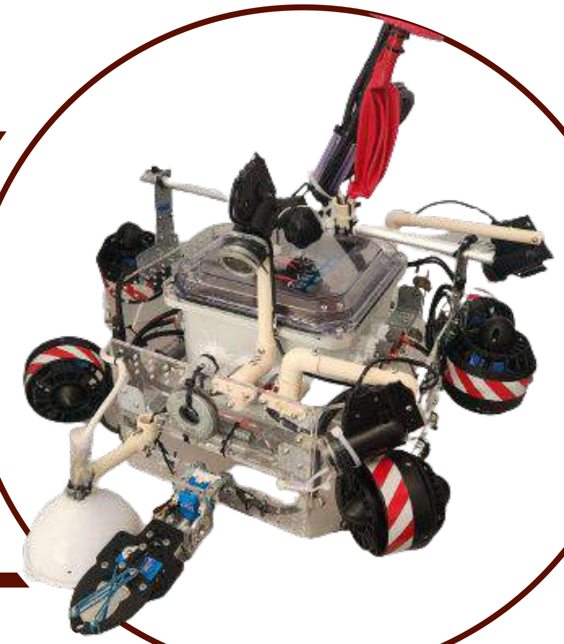
HORIZON

MTL

Mount Laurel Library | Mount Laurel, New Jersey, USA

Redfin ROV



MTL Horizon

100 Walt Whitman Ave,
Mount Laurel, New Jersey, USA

EMPLOYEES

Adithya Selvakumar '23
Founder, CEO, JSO

Shreeya Soma '25
CFO, Mechanical Engineer

Matthew Pugh '25
CMO, Electrical Engineer

John Shenouda '25
Mechanical Engineer

Kristin You '26
Electrical Engineer

Vivaan Talreja '27
Mechanical Engineer

Adam Freedman '25
Senior Mechanical Engineer

Akshya Amarnath '25
Senior Electrical Engineer

Alex Tornese '25
Senior Software Engineer

Noah Hyun '25
Software Engineer

Shubh Kapadia '27
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Anirud Sriram '27
Software Engineer

COACH

Ms. Maureen Barrett

HORIZON

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1: ABSTRACT

MTL Horizon is a marine robotics company based on the East Coast of the United States. Collectively, our team has several years of experience developing innovative subsea systems, and we care deeply about addressing the most imminent threats to the global ecosystem. Redfin is our latest enterprise, a state-of-the-art Remotely Operated Vehicle (ROV) fully equipped to compete in the 2023 MATE World Championship.

Redfin is the result of months of prototyping, troubleshooting, and testing, and it meets the highest quality and safety standards. Vectored thrusters and variable speed control give it six degrees of freedom and the ability to perform precise operations, for example, collecting a water sample. It features a specialized 'vertical boost' that helps increase the vertical thrust while retrieving heavy payload, including the sunken container in Dillon Reservoir. The manipulators were designed specifically with the tasks in mind: a dual-action rotating gripper flawlessly removes the biofouling from the wind turbines, and the UV light system is capable of irradiating the diseased coral. Equipped with four cameras, Redfin is ready to fly a transect line in Lake Titicaca, pilot into a "resident ROV" docking station, and handle complex maneuvers.

Redfin reflects our company's commitment to service and sustainability. MTL Horizon is proud to release Redfin in conjunction with the United Nations' proclamation of a Decade of Ocean Science for Sustainable Development. We are excited to join the greater global effort to beat ocean pollution, restore ecosystems and biodiversity, and unlock ocean-based solutions to climate change.

Company Employees
Front Row (left to right): Vivaan, Kristin, Akshya, Adithya, Shubh, Anirud
Back Row (left to right): Shreeya, John, Alex, Matthew, Adam, Noah
Photo Credit: M. Barrett

2: PROJECT MANAGEMENT

Company Profile

MTL Horizon is a first-year robotics startup based out of Mount Laurel, New Jersey. Many employees worked for the now-disbanded LHS Horizon last year. Lenape High School made the tough decision to dissolve LHS Horizon for financial reasons. The company's former employees searched for a new home and are pleased to finally announce an affiliation with the Mount Laurel Library, which will serve as the company's dedicated space moving forward.

At MTL Horizon, employees deliver innovative, high-quality products tailored to meet and exceed our clients' needs. The company has twelve employees, ranging from eighth through twelfth grade. Each employee specializes in one or more engineering disciplines: mechanical, electrical, and/or software. Alongside technical responsibilities, some employees volunteered for leadership roles. These positions oversee various aspects of the company:

★ Chief Executive Officer (CEO) – Strategic leadership and decision-making
★ Chief Financial Officer (CFO) – Financial oversight
★ Chief Marketing Officer – Brand management and social media expertise
★ Job Safety Officer – Occupational safety and compliance management
★ Senior Mechanical, Electrical, & Software Engineers – Departmental oversight and coordination

Scheduling & Planning

MTL Horizon conducts weekly virtual meetings to facilitate company-wide project scheduling and provide updates on departmental progress. These meetings serve as a platform for departments to present their accomplishments from the previous week and outline plans for the upcoming week.

To streamline the scheduling process, MTL Horizon utilizes Google Sheets to create project schedules, which are accessible to employees via a shared Google Drive. The CEO is responsible for creating schedules for every company department, including software (see example below), electrical, and mechanical. The senior engineers from each department collaborate with the CEO in developing these schedules, leveraging their department-specific expertise to establish realistic goals and deadlines.

Mission Task	Point Value	Job Summary	Member(s) Responsible	Priority	Difficulty	Status
3.1 ~ Design and construct an operational vertical profiling float	up to 60 points	Write a computer program for the vertical profiling float's control system that enables the float to both complete profiles and communicate wirelessly.	Adithya	1	4	In Progress
2.3 ~ Administer Rx to diseased corals	up to 30 points	Add a dial to the topside control unit that allows the pilot to more finely adjust the motors' speed and perform precision operations.	Alex Anirud	2	2	Done
2.6 ~ Recover a heavy container from the bottom of Dillon Reservoir	up to 20 points	Add a "vertical boost" switch to the topside control unit that diverts all propulsion amperage to the vertical motors	Adithya	3	3	Done
2.1 ~ Create a 3D model of a coral head	up to 30 points (manually using CAD)	Use photogrammetry to create an automatic 3D model of a coral head using visual input from the camera feed.	Alex Noah	4	5	Not Started

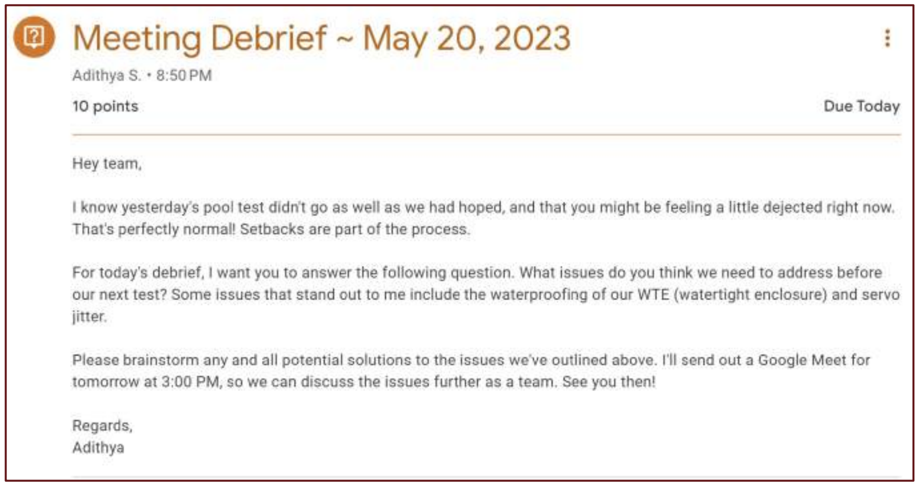
Project Schedule (Software)
Credit: A. Selvakumar

2: PROJECT MANAGEMENT

Collaborative Workspaces

MTL Horizon utilizes various collaborative workspaces to meet the mission objectives outlined in the company's project schedules and proactively address day-to-day operational problems.

- ★ Google Classroom
  - Track attendance
  - Post meeting agendas
  - Conduct debriefs
- ★ Google Drive
  - Facilitate easy, cloud-based file sharing
- ★ Discord
  - Instant messaging
- ★ Google Meet
  - Video collaboration for virtual meetings
- ★ Shared GrabCAD project
  - Collaborate on CAD designs and assemblies
- ★ GitHub
  - Maintain code repository
  - Collaborate on software projects

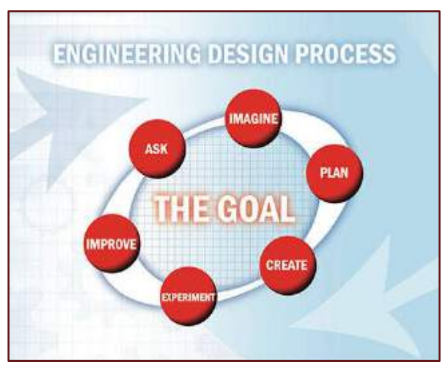


Meeting Debrief (Google Classroom)
Credit: A. Selvakumar

3: DESIGN RATIONALE

Engineering Design Rationale

MTL Horizon's employees refer to NASA's Engineering Design Model as a step-by-step planning and design process to guide the company's research and development (R&D) efforts. Each step contributes to mission success and may be described as follows: *Ask* – identify the problem and project requirements & constraints, *Imagine* – research and brainstorm, *Plan* – sketch possible designs, ultimately choose a single design to prototype, *Create* – construct a prototype, *Experiment* – evaluate the solution through testing, and *Improve* – refine design using testing data. For an example of how MTL Horizon uses the model to facilitate thoughtful and balanced trade-offs, please refer to the Vehicle Structure section (page 8) and the Manipulator Subsystem section (page 11).



Engineering Design Process
Photo Credit: nasa.gov

3: DESIGN RATIONALE

Innovation

MTL Horizon places a strong emphasis on innovation. The team defines innovation as a relentless pursuit of incremental modifications that enhance functionality while driving down costs. Every employee is dedicated to exploring creative solutions that deliver value to company clients. For the 2022-23 competition season, MTL Horizon introduced several innovations in vehicle design:

- ★ Omni-directional motor configuration
- ★ Four custom manipulators
    - Dual-action servo gripper
    - Stationery gripper
    - Tent pin hook
    - UV light funnel
- ★ Variable ballast system
- ★ Vertical boost switch
- ★ Custom watertight enclosure
- ★ ...and many more!

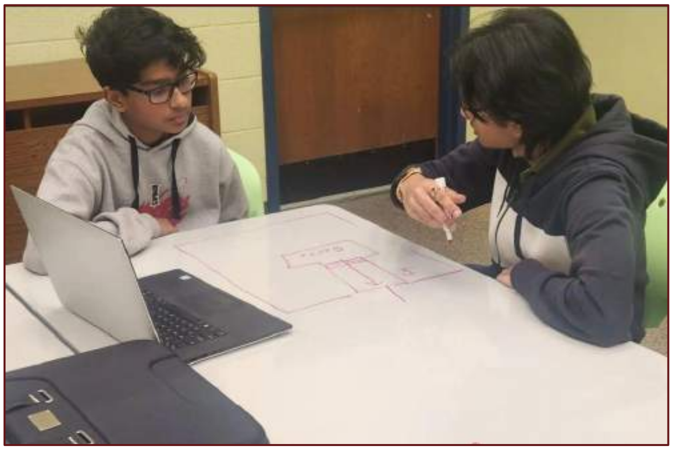
Alex builds the watertight enclosure.
Photo Credit: M. Pugh

Of the innovations listed above, the team believes that Redfin's custom watertight enclosure best represents MTL Horizon's approach to innovation. Please refer to the Watertight Enclosure Subsystem section (page 13) for a more detailed explanation.

Problem Solving

MTL Horizon recognizes that brainstorming is a valuable problem-solving tool. It promotes creative thinking, encourages collaboration, and allows for the exploration of a wide range of ideas, ultimately fostering innovative solutions to complex problems. The company established the following norms for group brainstorming sessions:

1. Embrace a culture where all ideas are welcomed and valued.
2. Attentively listen to all contributions.
3. Build upon and expand existing ideas.
4. Don't be concerned about similar ideas.



Adithya and Anirud brainstorm ideas.
Photo Credit: M. Pugh

Following brainstorming sessions, the team employs rational process, which involves. a clear data-driven framework to evaluate alternatives. For example, the mechanical department used data-driven problem solving techniques to choose a chassis material. Please refer to the Vehicle Structure section (page 8) for a more detailed explanation.

3: DESIGN RATIONALE

Systems Approach

Redfin is a complex robotic system consisting of many components. While designing Redfin, MTL Horizon made sure to consider the interrelationships and interactions between the robot's various mechanical, electrical, and software components. A well-functioning and optimized robotic system requires various independent subsystems to collaborate and integrate seamlessly to achieve the desired performance

With this in mind, all employees met to answer the following question immediately following the release of the MATE Center's request for proposals (RFP): "Based on the requirements outlined in the RFP, what independent subsystems does our robot need?" A finalized list is presented below:

★ A propulsion system
★ A vision system that offers the pilot a view of the ROV manipulators, the seafloor (for the flyover of the Lake Titicaca transect), and its surroundings
★ A chassis upon which to mount motors, cameras, and all other onboard ROV components
★ A manipulator system capable of transporting mission items (including a floating solar panel array, Eco-Mooring system, endangered native Northern Redbelly Dace fry, etc.)
★ A topside control unit (TCU) to house all topside electronics
★ A watertight enclosure (WTE) to house all onboard electronics
★ A tether to connect the TCU to onboard electronics
★ A computer program that takes pilot input, parses it, and outputs to all ROV components

Using a holistic systems approach, MTL Horizon's CEO assigned each independent subsystem to the mechanical, electrical, or software department.

Subsystem Name	Responsibilities
MECH-1: Propulsion	Choosing motors; deciding on thruster orientation/configuration
MECH-2: Vision	Choosing cameras; deciding on camera orientation/configuration
MECH-3: Chassis	Designing a chassis to house all onboard components
MECH-4: Manipulator	Building ROV manipulators capable of completing all mission tasks
ELEC-1: Topside Control Unit (TCU)	Building an easy-to-troubleshoot TCU to house above-water electronics
ELEC-2: Watertight Enclosure (WTE)	Building a custom watertight enclosure to house underwater electronics
ELEC-3: Tether	Design a tether to minimize voltage drop & maximize ROV performance
SOFT-1: Computer Programming	Programming Redfin's microcontrollers.

ROV Subsystems by Department
Credit: A. Selvakumar

3: DESIGN RATIONALE

Vehicle Structure

The mechanical department used NASA's Engineering Design Model to design and build Redfin's chassis.

1. *Ask* – To ensure the robot chassis is both durable and easy to machine, what material should we use? What structure should we select?
    a. Constraints: We have access to the following machine tools: 3D printer and laser cutter.
2. *Imagine* – Brainstormed ideas for chassis materials. Conducted online research & interviewed industry professionals. Please refer to the chart below.

Trade-off! **Chassis Material**
Chose Plexiglass because it is easy to machine, lightweight, and relatively durable, despite its moderate cost.

Meeting Notes
Date: January 6, 2023
Subject: Chassis Materials
Attendees: Mr. James Scott & MTL Horizon

- Acrylic and polycarbonate sheets
    - Laser cutting (low turnaround time):
        - Polycarbonate releases toxic fumes.
- ABS and PLA filament
    - 3D printing (medium turnaround time):
        - ABS releases toxic fumes.
- Aluminum extrusion
    - Requires industrial metal-cutting saw

Notes from Interview
Credit: S. Soma

3. *Plan* – Sketched two chassis designs (using laser-cut Plexiglass):
    a. H-shaped structure
        i. Advantages: less material, fewer joints (i.e. fewer points of weakness, which increases the chassis' structural integrity)
    b. Octagonal structure
        i. Advantages: compatible with a vectored thruster configuration, more modular (any side can be considered the robot's "front"), more room to mount manipulators, cameras, and wires

	Ultimate Tensile Strength (MPa)	Density (g/cm^3)	Turnaround Time	Can we machine?	Cost Ranking*	Safety Concerns
Plexiglass	83	1.18	Low	Yes (using laser cutter)	3	None
Aluminum Extrusion	310	2.70	High	No	5	None
Polycarbonate Sheets	70	1.20	Low	Yes (using laser cutter)	4	Releases toxic fumes
ABS Filament	22	1.04	Moderate	Yes (using 3D printer)	1	Releases toxic fumes
PLA Filament	37	1.24	Moderate	Yes (using 3D printer)	2	None
*1 = lowest cost, 5 = highest cost						

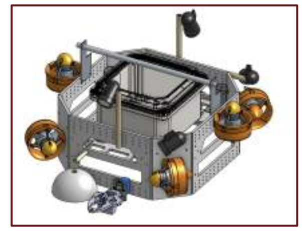
Chassis Materials Research Chart
Credit: A. Selvakumar & A. Freedman

3: DESIGN RATIONALE

Trade-off! **Vehicle Structure**
Chose to prototype the more modular octagonal structure, despite its larger size.

H-shaped Structure
Design Credit: S. Soma

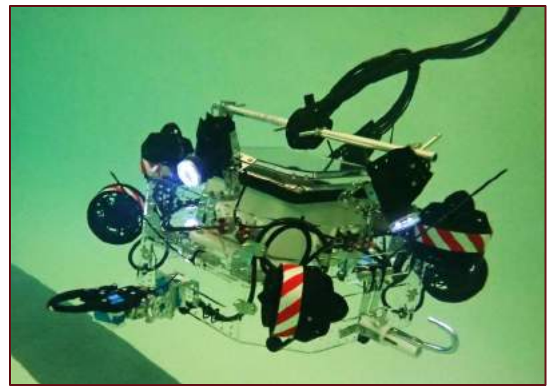
vs.



Octagonal Structure
Design Credit: A. Freedman

4. *Create* – The mechanical department constructed the octagonal chassis design using custom laser-cut Plexiglass sheets.

Redfin measures 77 cm in length, 57 cm in width, and 31 cm in height. The robot weighs 4.5 kg, thus earning maximum points for weight. Unlike in previous years, the MATE Center has not issued a specific size restriction. They do however advise that robots fit within the 85 centimeter cube docking station in task 1.3.

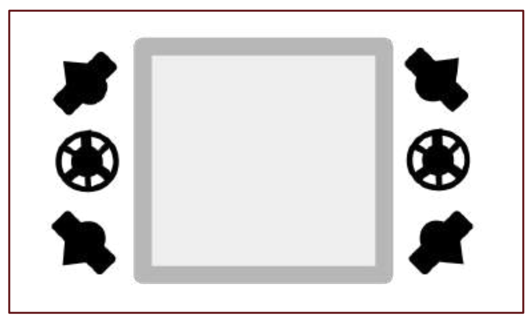


Redfin ROV
Photo Credit: M. Barrett

Employees continued to *experiment* and *improve* upon Redfin's design. For more details about vehicle testing, please refer to the Vehicle Testing Methodology section (page 20).

Vehicle Systems

★ Propulsion Subsystem



Thruster Configuration Diagram (Top View)
Design Credit: A. Selvakumar

Redfin is equipped with six Blue Robotics T200 thrusters. MTL Horizon reused these thrusters from a previous ROV build. The T200 thrusters are waterproof, lightweight, and reliable. The mechanical department chose to vector the robot's four horizontal thrusters at 45° angles to the horizontal. When placed in this configuration, all four thrusters contribute to the vehicle's overall motion in the cardinal directions. This configuration minimizes any flow interference with the vehicle's center.

Innovation in Software! **Vertical Boost Switch**
Redfin's TCU allows users to enable "vertical boost" mode. In "vertical boost" mode, a computer program diverts all the amperage away from Redfin's horizontal motors and sends it to the robot's vertical motors. This *doubles* Redfin's total vertical thrust and provides the ability to lift a heavy container in task 2.6.

3: DESIGN RATIONALE

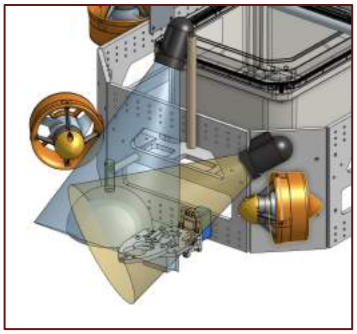
Trade-off! **T200s or T500s?**
MTL Horizon considered replacing Redfin's six T200s with T500s, the latest in Blue Robotics' line of thrusters, but they decided against it. Given the 12-volt, 25-amp power budget outlined in the MATE Center's RFP, the thrusters would only generate 14.4% more thrust force, but would be 232.6% more expensive!

★ Vision Subsystem

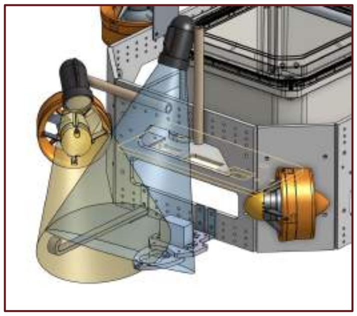
Redfin's vision subsystem features four cameras. The first camera is mounted in the front of the ROV and faces downward, enabling the ROV to see our dual action gripper system. The second camera offers the pilot a side view of the same gripper while also providing a view of the UV lighting manipulator used to irradiate the diseased coral in task 2. The third camera is mounted in the back of the ROV and points downward on the second gripper. A fourth camera gives our pilot a side view of that gripper and a view of the hook needed to lift the heavy container in task 2.

All four camera signals are multiplexed and output as HDMI to an external display.

All four cameras are reused and repurposed fishing cameras; they were donated to the company by a local STEM program. MTL Horizon's electrical department disconnected the cameras from their monitors' native power supplies, removed their ballast, and cut them to size. These used cameras are in good working order and still transmit a clear signal without interference.



Camera Views (Front)
Design Credit: A. Freedman



Camera Views (Back)
Design Credit: A. Freedman

Innovation in Software! **Video Capture Software**
Redfin's pilot uses video capture software to record and save video footage from its four cameras. This feature allows MTL Horizon to more reliably compare images to determine the recovery of a seagrass bed in task 2.4.

★ Manipulator Subsystem

The mechanical department considered building the robot's grippers using linear actuators instead of servo motors. Employees used NASA's Engineering Design Model to design Redfin's manipulators.

1. *Ask* – What component should power the robot's manipulators?
2. *Imagine* – Brainstormed two ideas: linear actuators and servos. Conducted online research.

3: DESIGN RATIONALE

	Cost	Durability	Relevance to Mission Objectives	Ease of Fabrication	Total Score
Linear Actuator Model	Linear actuator costs $170. Entire assembly costs around $200. *Score: 1*	Prone to breaking because of its large range of motion. *Score: 2*	Greater grip strength, but lacks precision. May struggle with tasks 1.2, 2.3, and 2.5. *Score: 2*	Relatively easy to build. *Score: 3*	8
Servo Motor Model	Servo motor costs about $50. *Score: 3*	Assembly is smaller and has less moving parts; less likely to break. *Score: 3*	Greater precision, but lacks grip strength. Struggles with Task 2.6. *Score: 3*	Easy to build. *Score: 4*	13
Scores range from 1 to 4, with 4 being the highest.					

Gripper Model Design Matrix
Credit: A. Selvakumar & A. Freedman

3. *Plan* – Sketched two gripper designs. Created a design matrix to evaluate alternatives.
    a. Made a balanced trade-off; chose to forgo the linear actuator model's better grip strength for the servo model's lower cost and increased durability.
4. *Create* – Constructed a servo-powered gripper prototype.

Employees continued to *experiment* and *improve* upon the gripper prototype.

Design Evolution! **Rubber Bands**
During pool testing, mechanical engineers noticed Redfin's servo-powered grippers lacked the grip strength to reliably hold onto the long-term camera in task 2.7. They added rubber bands to the gripper claws to increase friction.

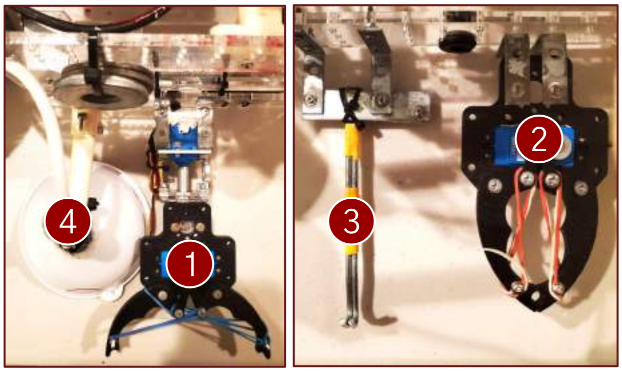
Redfin's four manipulators are built for the tasks specified in the MATE Center's RFP.

1) **A dual-action servo gripper**: Gripper can rotate 90˚; helps the pilot release the redbelly fish fry in task 2.5.

2) **A stationary gripper**: Mounted on the back of Redfin; helps the pilot *pull* the solar panel array behind the robot in task 1.1, and thus ensure none of the array cables get caught in the robot's thrusters.

3) **Tent pin hook**: Lifts the heavy container in task 2.6.

4) **UV light funnel**: Incorporates both a UV light and a plunging mechanism for task 2.3; a light irradiates the diseased coral; a plunging mechanism dispenses the coral's medication.



Redfin's Manipulators
Photo Credit: A. Selvakumar

3: DESIGN RATIONALE

Control/Electrical System

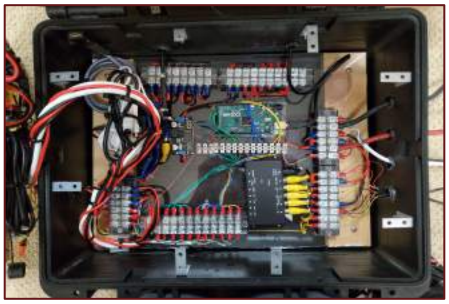
★ Topside Control Unit (TCU) Subsystem

The topside control unit is built from a repurposed and reused Pelican case. It houses several forms of pilot input (knobs, joysticks, switches), a watt meter, Arduino microcontroller, RCA multiplexer, voltage regulators, and a video capture card. Electrical engineers connected a 25-amp fuse in series with the power supply and routed power through a kill switch to shut off the ROV in case of an emergency. The watt meter reads input voltage and wattage, which can be used to troubleshoot the system as a whole.

Electrical engineers added strain relief in the form of rubber gaskets mounted to the side of the TCU to tug-proof Redfin's critical electrical connections. The TCU also features several power distribution blocks and terminal strips, which are cleaner and easier to troubleshoot than solder joints. All power is routed through two 12-gauge power cables in the tether. Both cables have two connectors—one for 12-volt power, and the other one for ground.

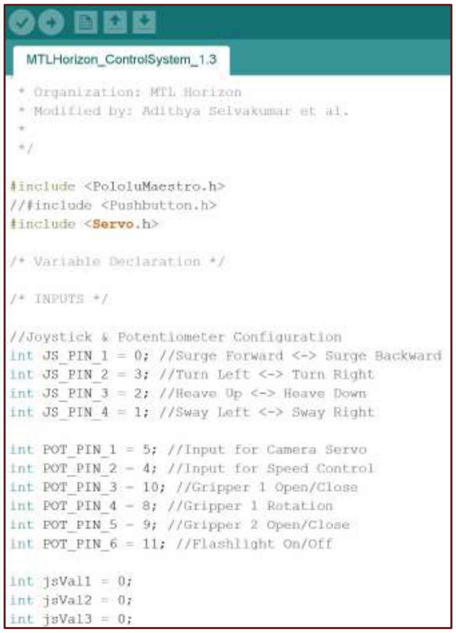
In brief, two parallel processes are happening in the TCU:

1. The Arduino microcontroller collects input from two joysticks, five potentiometers, and a push button. It parses this input and generates a set of ten outputs (six for T200 thrusters, three for servo-powered grippers, and one for the UV light funnel). The ten output values are encoded and sent down a two-wire pair to a serial receiver in the enclosure using serial communication, for distribution to onboard components.
2. Power is distributed to the four camera tethers. Four incoming signals are sent through a terminal strip to the RCA multiplexer. One of the incoming signals is also sent to the in-box monitor. The multiplexed signal is split; the first signal is converted to HDMI and sent to an external display, and the second is sent to a video capture card.



Redfin's TCU (Lower Tray)
Photo Credit: A. Selvakumar

Redfin's TCU (Upper Tray)
Photo Credit: A. Selvakumar



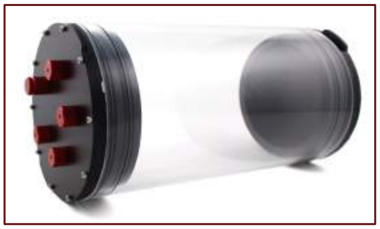
```
MTLHorizon_ControlSystem_1.3
 * Organization: MTL Horizon
 * Modified by: Adithya Selvakumar et al.
 *
 */

#include <PololuMaestro.h>
//#include <Pushbutton.h>
#include <Servo.h>

/* Variable Declaration */

/* INPUTS */

//Joystick & Potentiometer Configuration
int JS_PIN_1 = 0; //Surge Forward <-> Surge Backward
int JS_PIN_2 = 3; //Turn Left <-> Turn Right
int JS_PIN_3 = 2; //Heave Up <-> Heave Down
int JS_PIN_4 = 1; //Sway Left <-> Sway Right

int POT_PIN_1 = 5; //Input for Camera Servo
int POT_PIN_2 = 4; //Input for Speed Control
int POT_PIN_3 = 10; //Gripper 1 Open/Close
int POT_PIN_4 = 8; //Gripper 1 Rotation
int POT_PIN_5 = 9; //Gripper 2 Open/Close
int POT_PIN_6 = 11; //Flashlight On/Off

int jsVal1 = 0;
int jsVal2 = 0;
int jsVal3 = 0;
```

Arduino Control Algorithm
Photo Credit: A. Selvakumar

Innovation in Software! **Programmable Deadbands**

Redfin's TCU allows users to define a specific threshold around the joystick's center where small variations in input are not translated into actions by the system. This deadband helps eliminate unintended movements caused by joystick imprecision or natural hand tremors, providing a more stable control experience.

3: DESIGN RATIONALE



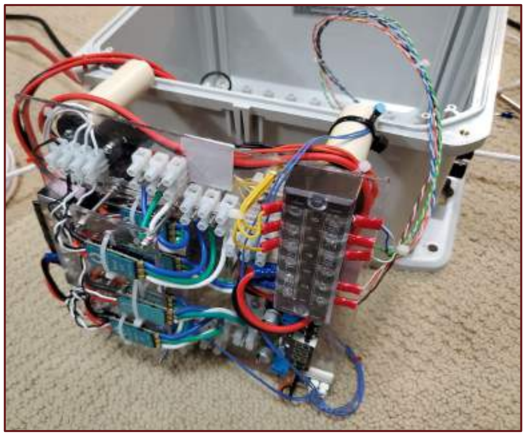
Cylindrical Enclosure
Photo Credit: Blue Robotics

Junction Box
Photo Credit: Polycase

★ Watertight Enclosure (WTE) Subsystem

According to our market research, nearly 77% of companies using watertight enclosures in the 2020-21 Ranger class chose the commercial Blue Robotics model. The electrical department, however, decided against a cylindrical enclosure. They claimed the shape made it more challenging to house the electronics without wasting valuable space. They also felt the volume of the watertight enclosure was too great. The ROV could become far too positively buoyant, requiring the team to add a significant amount of ballast, thereby slowing Redfin down. Given these concerns, and the commercial model's high cost, the CFO asked the company to consider building an in-house alternative to the cylindrical enclosure.

Redfin's watertight enclosure is built from a repurposed junction box (229.62 x 229.62 x 145.29 mm.). Tether wires enter the box through commercial cable penetrators. Rubber gaskets, marine epoxy, and liquid electrical tape serve as waterproofing. Since finalizing the design, the operations team at MTL Horizon is proud to announce it has had zero leaks. Redfin's custom enclosure is 400% less expensive than the commercial alternative. Its screw-top close is as effective, if not more, than the commercial model's friction-fit flanges. Its rectangular shape makes it simpler to mount to the ROV chassis and compactly house components. This is just one example of a modification that MTL Horizon made to enhance functionality while driving down costs.



WTE Electronics Tray
Photo Credit: A. Selvakumar

All electronics housed in the WTE are mounted to two acrylic electronics trays. The trays are elevated to protect the control system's integrity in case of a leak. It is also removable for easy access & troubleshooting.

Wires enter the WTE through cable penetrators and are immediately sent through terminal strips, which makes quick fixes simple (replacing a cable, checking conductivity, etc.).

The WTE houses a serial receiver. The receiver decodes the serial values sent from the topside Arduino microcontroller and outputs ten PWM signals to six electronic speed controllers (ESCs), three servo motors, and a UV light funnel. The enclosure houses an SOS Leak Sensor, a crucial safety feature that alerts the pilot if water penetrates the enclosure's seal.

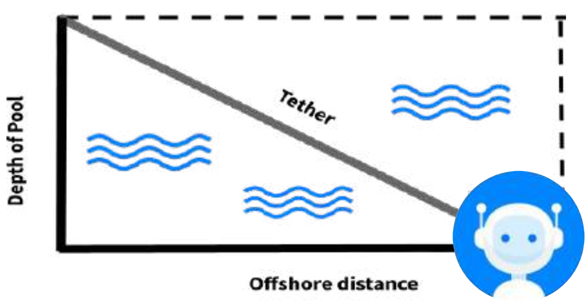
Innovation in Software! **Serial Communication**
Redfin's Arduino microcontroller encodes ten PWM signals into a single serial packet and sends it to an onboard serial receiver using *just two wires!*

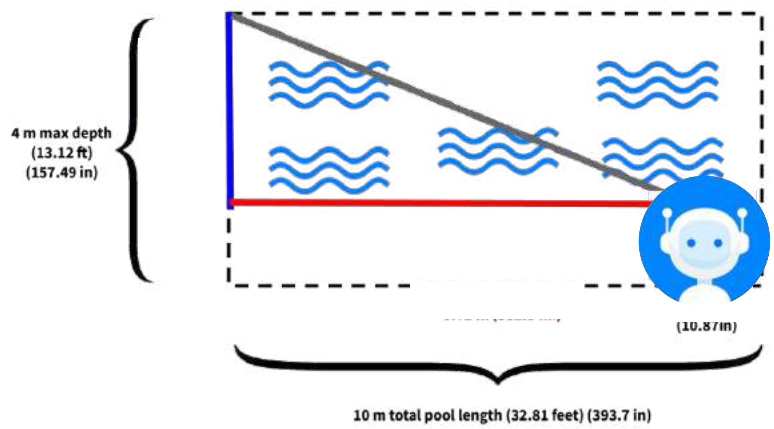
3: DESIGN RATIONALE

★ Tether Subsystem

Requirements: As per section 3.2.3 of the MATE Center's RFP, Redfin must be capable of operating at a maximum depth of 4 meters (13 feet) and a maximum offshore distance of 10 meters (32 feet). Upon the release of the RFP, the team used basic geometry to calculate a minimum tether length. Utilizing the Pythagorean theorem, Redfin needs 10.36 meters (approximately 34 feet) of tether from the poolside. After accounting for the distance from the pilot's seat to poolside and additional slack, company employees determined the tether length should be 13 meters (43 feet).

Design: The ROV tether consists of seven cables: two 12 gauge power cables, a four-conductor 24 gauge serial cable for signals routed through the WTE (serial communication to the Maestro, input from the SOS Leak Sensor), and four three-conductor, 30 gauge cables that carry power, ground, and signal to each camera.





Tether Length Diagrams
Design Credit: A. Selvakumar

Tether Management Protocol: Additionally, tether management is crucial to keep the ROV in perfect working condition. The company's JSO created a tether management checklist:

01	**During Deployment**	❑ Tether must be properly managed so it does not pose as a tripping hazard for poolside employees. ❑ Tether manager must be sure to properly control the tether while the pilot is maneuvering Redfin in the water. ❑ Strain reliefs are properly attached to keep the tether secure to the frame.
02	**Workplace Management**	❑ Tether must be kept away from sharp tools and objects to prevent nicks or cuts that may cause damage. ❑ Keep tether neatly coiled so it doesn't get tangled, twisted or knotted.

Tether Management Checklist
Credit: A. Selvakumar

3: DESIGN RATIONALE

Buoyancy and Ballast

ρ - density of fluid (g/cm^3)
V - volume of fluid (cm^3)
g - acceleration due to gravity (m/s^2)
m - mass of object (g)

$$\rho V g = mg$$
$$(1)(4860)(9.81) = m(9.81)$$
$$m = 4860 \text{ grams} = 4.86 \text{ kilograms}$$

Buoyancy Calculations
Credit: A. Freedman

Redfin is neutrally buoyant, meaning its average density is equal to the density of the fluid in which it is immersed. This makes it resistant to hydrostatic pressure and able to explore deeper depths for extended periods of time. More importantly, it ensures that the pilot doesn't need to correct for a tendency to ascend or descend.

Redfin has a maximum displacement of approximately 4860 cm^3. Using Archimedes' Principle, mechanical engineers calculated that the robot had to weigh 4.86 kilograms to achieve neutral buoyancy. Because the robot initially weighed 4.5 kg, employees mounted 360 grams of ballast to Redfin's chassis. Redfin's tether achieves a slight positive buoyancy using sections of pool noodles evenly distributed across its length.

Design Evolution! **Variable Ballast System (VBS)**
During pool testing, the pilot noticed that Redfin struggled to lift the heavy container in task 2.7. Mechanical engineers decided to implement a VBS. They attached a punching balloon to Redfin's chassis and used 19 mm. tubing to connect the balloon to a hand pump. When the balloon is inflated, it increases the robot's volume and its upward buoyant force.

Payload and Tools

★ Cameras

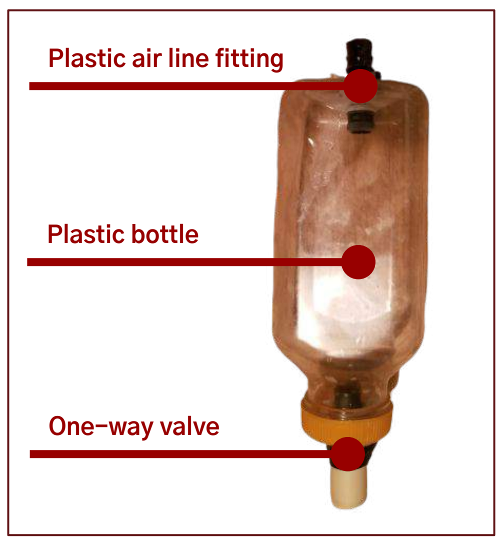
Redfin's vision subsystem features four Aqua-Vu fishing cameras. The cameras are integral for all subsea tasks; they offer the pilot a thorough view of Redfin's surroundings for general navigation. The fishing cameras come pre-waterproofed and are compatible with the RCA multiplexer in the robot's TCU. For more details regarding the placement of Redfin's cameras, please refer to the Vision Subsystem section (page 10).

★ Water Sample Collection Device (WSCD)

MTL Horizon has developed a water sample collection device (WSCD) to collect a water sample from above the coral head in task 2.2. The WSCD consists of a repurposed plastic bottle, a plastic air line fitting, a makeshift one-way valve (built from an O-ring and a metal marble), and CPVC pipe.

The WSCD connects to a hand pump on the pool deck using 19 mm aquarium tubing. When the hand pump sucks air, it creates an area of low pressure within the bottle, causing the one-way valve to open and let the water flow into the bottle.

Otherwise, the one-way valve remains closed. This ensures the sample is not contaminated by sea water, and it also prevents leaks.

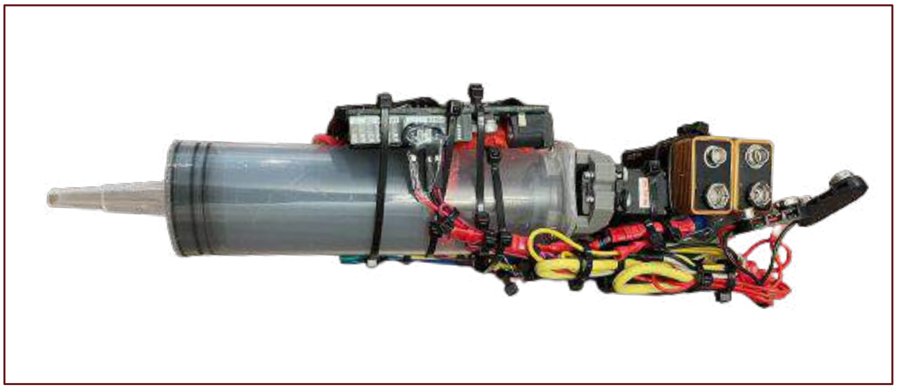


WSCD
Photo Credit: S. Kapadia

3: DESIGN RATIONALE

★ Vertical Profiling Float

MTL Horizon's vertical profiling float, Cousteau, is used in task 3 to complete two vertical profiles (i.e., travelling from the surface to the bottom and back to the surface) and communicating data to the mission station.



Cousteau's Buoyancy Engine
Photo Credit: V. Talreja

Cousteau
Photo Credit: V. Talreja

Cousteau is driven by a buoyancy engine. The buoyancy engine consists of a servo motor attached to a threaded rod, which actuates the plunger of a 100 mL syringe. The syringe tip is exposed to the surrounding environment, allowing it to intake or expel water and alter the float's mass.

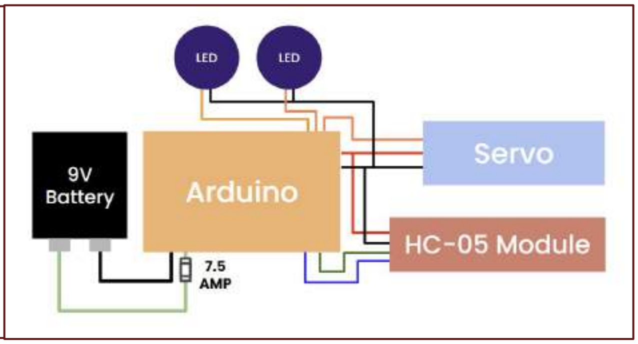
Innovation in Software! **Cousteau's Mobile App**
Cousteau uses an Arduino and a Bluetooth module to communicate with the mission station. To prevent wireless interference, the Arduino requires a password to pair with the mobile app.

Cousteau's Mobile App
Photo Credit: A. Selvakumar

Overcurrent Calculations
Arduino Uno: 0.05 A
Servo: 0.66 A
HC-05 Module: 0.04 A
LEDs (x2): 0.04 A

Total amperage draw: **0.79 A**
150% Margin: **1.185 Amps**

The profiler utilizes a 7.5 amp fuse



Non-ROV Device SID
Design Credit: S. Kapadia

3: DESIGN RATIONALE

★ Sensors

Redfin's watertight enclosure features an SOS Leak Sensor, which notifies the pilot in case of a leak. The sensor uses four re-usable sponge tipped probes with an adhesive backing. If water contacts a sponge, it will swell and connect two wires, completing a circuit. The sensor then transmits to Redfin's TCU. For more details, please refer to the WTE Subsystem section (page 13).

Build vs. Buy, New vs. Used

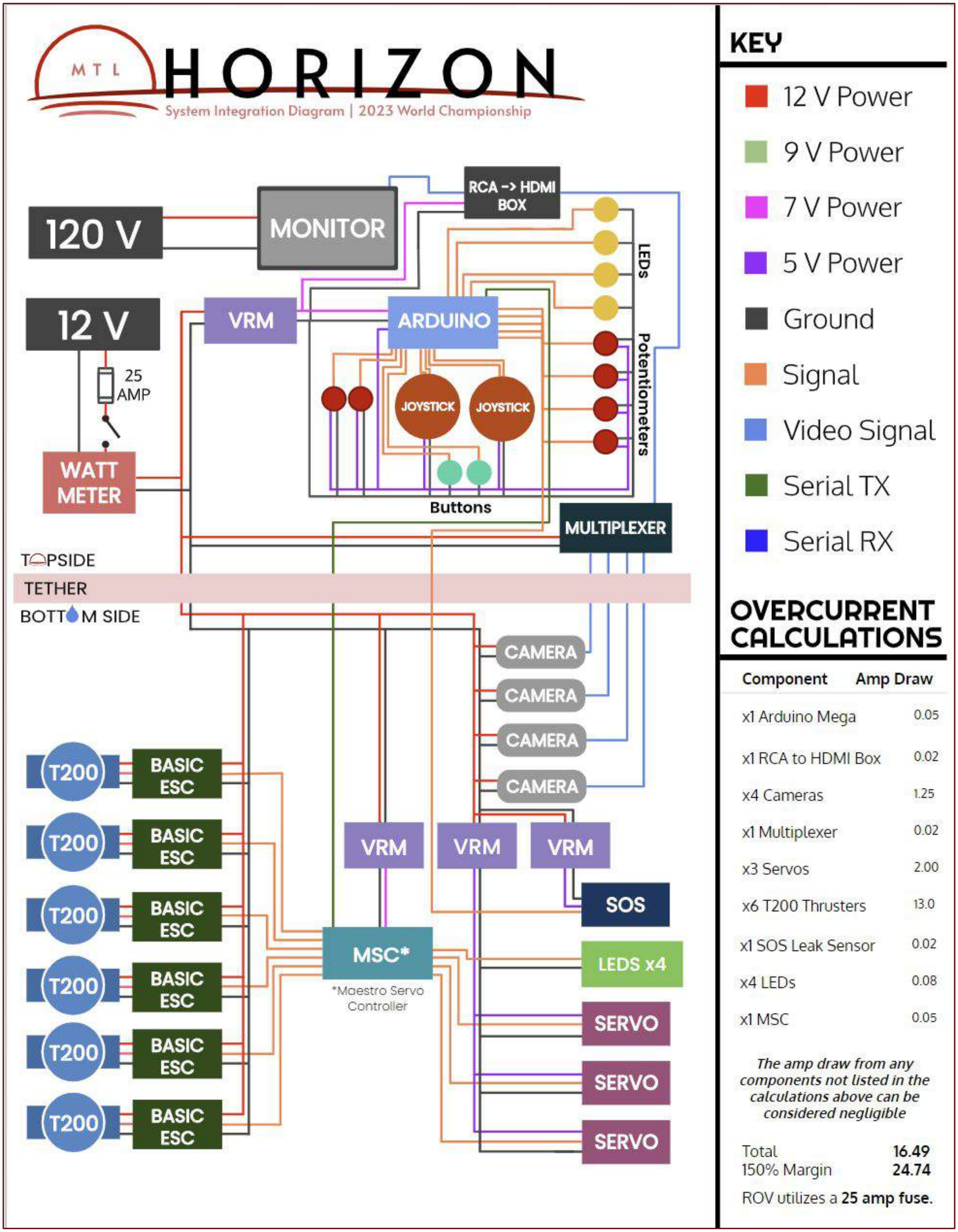
When deciding whether or not to buy commercial components, MTL Horizon's CFO asked employees from each department to answer the following questions:

- Do we have the expertise and knowledge in-house to develop the technology?
    - MTL Horizon decided to buy Arduino microcontroller because its employees do not have access to the tools needed to print their own PCBs.
- How does the cost of in-house development compare to the cost of outsourcing?
    - MTL Horizon chose to reuse gripper kits because they were readily available and suited for tasks 1.2, 2.3, and 2.5 (see page 11). Developing a new gripper attachment would cost the company time and money.
- How important is quality control and customization for the specific technology?
    - Rather than purchasing a commercial hook, MTL Horizon chose to construct a custom-made hook (see page 11) to more easily lift the heavy container in task 2.6.
- How will the decision affect our ability to meet customer needs and expectations?
    - Rather than purchasing Blue Robotics' cylindrical watertight enclosure, MTL Horizon chose to construct an enclosure from a junction box to minimize the robot's volume and save money.

Subsystem	Components built (in-house)	Components bought (outsource)
Propulsion	Thruster mounts	Blue Robotics T200 thrusters (reused)
Vision	Camera mounts	AquaVu fishing cameras (reused)
Chassis	Laser-cut Plexiglass sheets	Aluminum brackets (new)
		Conduit clamp for strain relief (new)
Manipulator	Tent pin hook	Gripper kits (reused)
	UV light funnel	Servo motors (new)
Topside Control Unit (TCU)	Electronics trays	Pelican case (reused)
		Terminal strips and jumper wires (reused)
	Co-pilot's box	Cable grips for strain relief (new)
		Electronics (Arduino, VRMs, etc.) (new)
Watertight Enclosure (WTE)	Electronics trays	Junction box (new)
		Electronics (ESCs, VRMs, etc.) (new)
		Cable penetrators (new)
Tether	Tether thimble	Power and serial cables (new)
		Camera cables (reused)
Computer Programming	Computer program	Computer w/ Arduino IDE (reused)

Build vs. Buy Analysis Chart
Credit: A. Selvakumar

4: SYSTEM INTEGRATION DIAGRAM



OVERCURRENT CALCULATIONS

Component	Amp Draw
x1 Arduino Mega	0.05
x1 RCA to HDMI Box	0.02
x4 Cameras	1.25
x1 Multiplexer	0.02
x3 Servos	2.00
x6 T200 Thrusters	13.0
x1 SOS Leak Sensor	0.02
x4 LEDs	0.08
x1 MSC	0.05

The amp draw from any components not listed in the calculations above can be considered negligible

Total	**16.49**
150% Margin	**24.74**

ROV utilizes a **25 amp fuse.**

System Integration Diagram
Design Credit: A. Selvakumar, S. Kapadia, A. Amarnath

5: SAFETY

Safety Rationale

MTL Horizon's first priority is the safety of our employees, our clients, and Redfin. Employees are committed to surpassing the safety guidelines set by MATE. The company's job safety officer (JSO) created and published a Job Site Safety Analysis (JSSA), a crucial document that outlines potential hazards and safety measures associated with specific job tasks or activities at a worksite.

Operations team on pool deck
Photo Credit: M. Barrett

At MTL Horizon, employees must adhere to basic safety practices. They must wear closed-toed shoes, secure long hair and use PPE while in the lab. The JSO also mandates the use of safety glasses, gloves, masks, and/or earplugs when operating specific tools.

All employees must undergo safety training before operating any equipment, such as standard machining tools and soldering equipment. MTL Horizon's operations team must undergo additional safety training to operate the robot. MTL Horizon completes a minimum of thirty hours of pool practice prior to competitions. This comprehensive training is aimed at training the pilot, co-pilot, and the rest of the operations team in routine safety protocols.

Safety Features

Listed below are some of Redfin's safety features.

Name	Function	Relation to Mission Tasks
Thruster Guards	- Protect employees from rotating blades - Prevent marine debris from entering the thruster assembly - Act as a barrier against collisions with obstacles, rocks, or other underwater structures - Rated IP20 (protects against solid objects larger than 12.5mm in size)	- In sensitive environments, such as coral reefs (task 2.1) or seagrass beds (task 2.4), thruster guards prevent damage to fragile marine habitats. - Thruster guards can also provide protection for external cables, like the ones on the floating solar panel array (task 1.1). By covering the thruster openings, they reduce the risk of entanglement
Strain Reliefs	- Prevent excessive strain on cables, reducing the risk of cable failure or disconnection - Provide mechanical support to cables, anchoring them firmly to specific mounting points	N/A
Fuses	- Act as protective devices against a sudden surge or excessive current flow - Redfin's TCU contains 25-amp inline fuse - Cousteau contains a 7.5-amp inline fuse	N/A
Kill Switch	- Allows for an instant shutdown of the ROV's operating systems in emergency scenarios	- In the event the robot gets tangled in the buoy ropes (task 2.6) or ferns in fish habitat sites (task 2.5), the pilot can use the kill switch to shut down the robot.
Watt Meter	- Allows for real-time monitoring of the electrical voltage, amperage, and/or power usage of the ROV	N/A
Waterproofing	- O-ring face seals, epoxy potting, solder seal wire connectors, etc.	- Prevents current leakage that could harm marine life, such as endangered fish fry (task 2.5)
SOS Leak Sensor	- Detects leaks in the robot's watertight enclosure	N/A

Safety Features Chart
Credit: A. Selvakumar

5: SAFETY

Safety Procedures

Please refer to MTL Horizon's operations and safety checklist below. While creating this checklist, the company's JSO referenced both Oceaneering's *HSE Employee Handbook* and safety documentation from Rovotics.

☐	Pre-Power Procedure (Operations team)
☐	Pool deck is clear (no tripping hazards)
☐	Verify kill switch is off
☐	Tether is wrapped neatly
☐	Tether is connected to TCU
☐	Tether strain relief secured to chassis
☐	Visually inspect ROV wiring for damaged wires and/or loose connections
☐	Electronics housing is sealed
☐	TCU is connected to a 12-volt power source
☐	Vacuum test electronics housing (refer to Vacuum Test Procedure below)
☐	Pressure relief valve (PRV) is properly fastened

☐	Vacuum Test Procedure (Tether manager)
☐	Verify WTE screws are tightened
☐	Detach PRV
☐	Connect vacuum hand pump to PRV plug
☐	Pump until the internal pressure of the WTE reaches about 20 kPa
☐	Verify the WTE holds about 20 kPa for at least five minutes.
☐	Remove vacuum pump and re-attach PRV
☐	Place vacuum hand pump back in toolbox

☐	Power-up Procedure (Pilot)
☐	Verify TCU is receiving 12 volts.
☐	Arduino is up and running
☐	Monitor is connected to TCU via an HDMI cable
☐	Ensure the entire operations team is attentive
☐	Call out "Powering on!"
☐	Power on TCU
☐	Call out "Dry test!"
☐	Test whether thrusters, cameras and manipulators are working properly.

☐	Launch Procedure (Tether manager)
☐	Place ROV in water
☐	Visually check for bubbles
☐	If bubbles are coming from the WTE, remove ROV from water immediately (refer to Leak Check Procedure)
☐	If no bubbles are present, call out "Ready to launch!"

☐	Retrieval Procedure (Operations team)
☐	Pilot calls out "Surfacing!"
☐	Tether manager calls out "ROV surfaced! Power off."
☐	Pilot powers off and calls out "Powered off!"

☐	Leak Check Procedure (Operations team)
☐	Power down system.
☐	Retrieve ROV by pulling to the surface using tether if required
☐	Visually inspect the O-ring face seal on the WTE
☐	Install pressure testing equipment and use soapy water to verify the source of the leak
☐	Create a plan to repair the leak
☐	Check all systems for damage
☐	Document the cause of the leak and all corrective actions taken

☐	Loss of Communication (Operations Team)
☐	Cycle power on TCU to reboot system
☐	If issue persists, retrieve ROV by pulling to the surface using tether if required
☐	If communication restored, check ROV for leaks before resuming operations
☐	Use troubleshooting techniques to identify the cause of the communications issue
☐	Check all systems for damage
☐	Document the cause of the issue and all corrective actions taken

☐	Pit Maintenance (All employees)
☐	Pit is well organized and free of tripping hazards
☐	All tools and equipment are stored in their designated locations
☐	Verify TCU and ROV are clean, dry, and safely stored

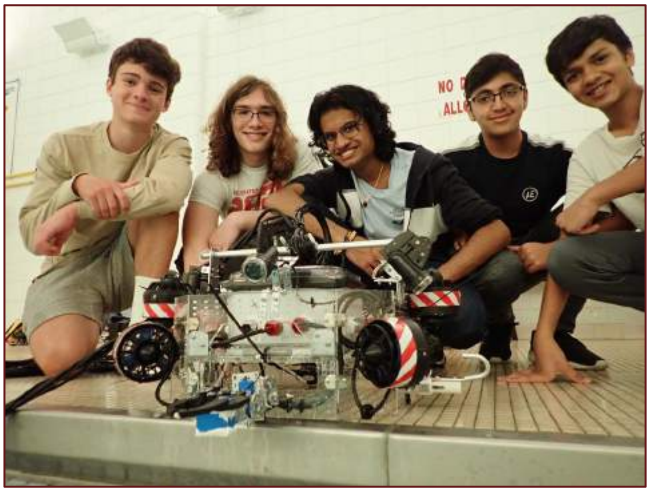
Operations and Safety Checklist
Credit: A. Selvakumar

6: CRITICAL ANALYSIS

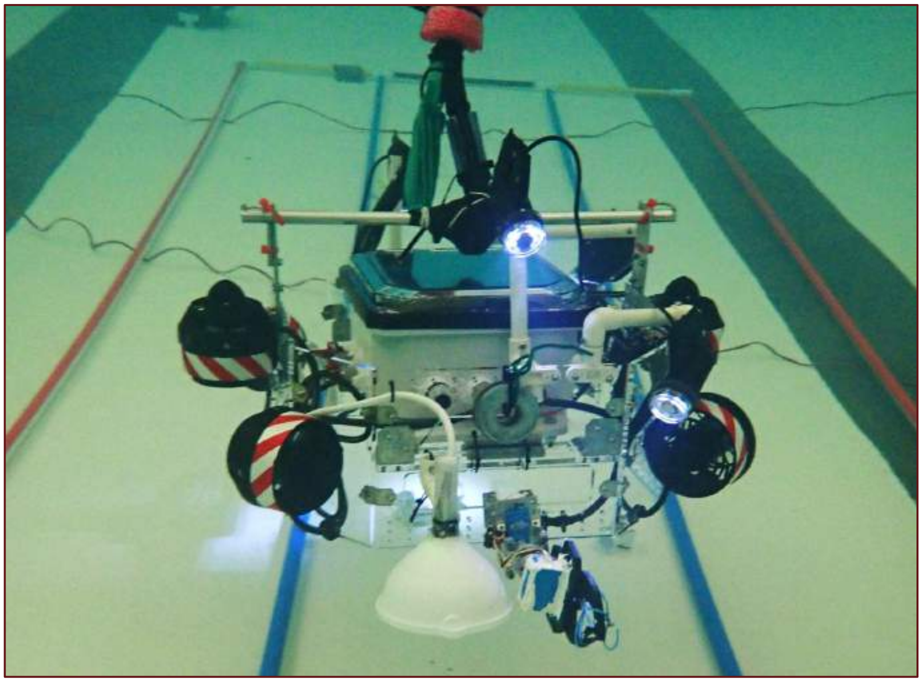
Vehicle Testing Methodology

MTL Horizon completes a minimum of thirty hours of pool practice prior to competitions. This comprehensive training is aimed at training the pilot, co-pilot, and the rest of the operations team in routine safety protocols. The team has a three-step vehicle testing process. MTL Horizon's pilot credits the process for the company's standout performance at the 2023 MATE PA Regional ROV Competition.

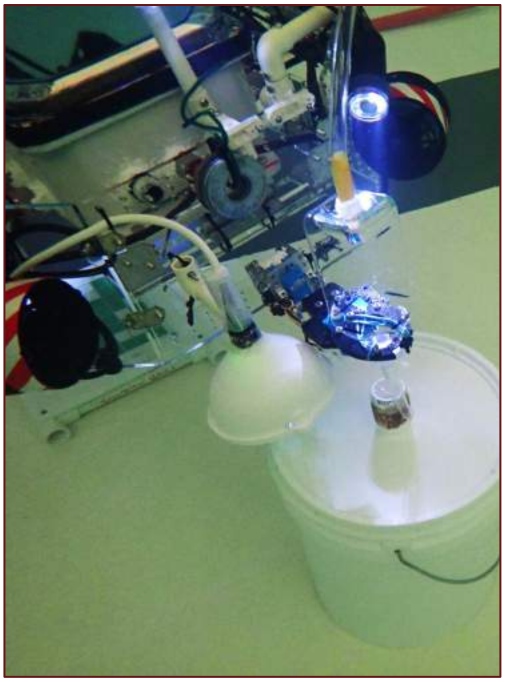
1. *Getting your feet wet!* – Redfin's pilot and the rest of the operations team become familiar with the system, its controls, and poolside safety procedures (see page 19).
2. *Sharpening the saw!* – The pilot creates a list of specific skills he needs to work on (such as precise lateral movement and using the tent pin hook). He ranks these skills in order of importance and practices each skill repeatedly.
3. *Going all in!* – The operations team completes full 15-minute product demonstration trials. The pilot optimizes his "flight plan," i.e., the order in which he intends to complete the tasks.



MTL Horizon's Operations Team
Photo Credit: M. Barrett



Redfin flies a transect
Photo Credit: M. Barrett



Redfin collects a water sample
Photo Credit: M. Barrett

6: CRITICAL ANALYSIS

HORIZON

Troubleshooting Strategies and Techniques

Vehicle testing does not always go as planned. Fuses blow, solder joints break, and leaks happen. MTL Horizon's employees possess strong analytical skills and excel in problem solving. They possess a solid foundation of technical knowledge and attention to detail. In other words, they are capable troubleshooters. Here are some of the company's tried and tested troubleshooting techniques:

1. *Systematic Approach*: Adopt a systematic approach to troubleshooting, starting with a thorough examination of the robot's components, sensors, and connections. Identify and isolate the specific subsystem or component where the issue resides.
2. *Observation and Analysis*: Observe the robot's behavior and gather relevant data to analyze the problem. Monitor sensor readings, error messages, or any abnormal behavior exhibited by the robot. This information aids in narrowing down the possible causes.
3. *Testing and Isolation*: Conduct tests to isolate the problem. This may involve running specific commands, performing component tests, or conducting experiments to reproduce the issue. Isolating the problem helps determine whether it is related to hardware, software, or environmental factors.
4. *Divide and Conquer*: Divide the problem into smaller parts and tackle each component individually. By breaking down the issue, it becomes more manageable, allowing for targeted investigation and resolution.

MTL Horizon's electrical and software engineers have created a troubleshooting checklist specific to Redfin. Please refer to the checklist below.

	Topside Control Unit (TCU)
☐	Ensure the fuse is intact.
☐	Check resistivity between system power and ground.
☐	Check that wires are not loose or broken.
☐	Check the microcontrollers' I/O pins.
☐	Check whether any screws in the terminal blocks are loose.
☐	Check whether voltage regulator modules are delivering the correct voltage.
	Watertight Enclosure (WTE)
☐	Check the LED indicator on the SOS Leak Sensor.
	Hardware Components (servos, cameras, etc.)
☐	Test component independently.
☐	Switch component out with a replacement known to work.
☐	Check for overheating.
	Uploading Complications
☐	Verify the program for errors; check the board and port are correct.
☐	Switch the microcontroller out with a replacement known to work.
☐	Restart the computer.

Troubleshooting Checklist
Credit: A. Selvakumar

6: CRITICAL ANALYSIS

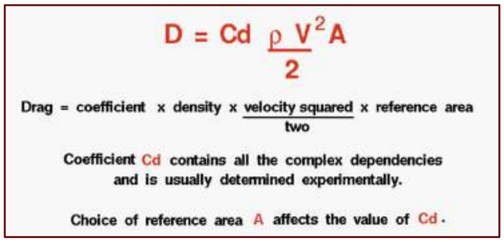
Prototyping and Testing

★ Mechanical

For an example of MTL Horizon's mechanical engineers using prototyping to evaluate designs, please refer to the Vehicle Structure section (page 9) or the Manipulator Subsystem (page 11).

★ Electrical

Only two of the ten cables in Redfin's tether are used for power. These two cables, however, are responsible for more than 90% of the tether's cross-sectional area. Because the drag force is directly proportional to cross-sectional area (see 'The Drag Equation'), these two cables are responsible for 90% of the tether's total drag force. MTL Horizon's electrical engineers considered replacing the High Power cables with higher-gauge cables to minimize drag. They created two tether prototypes. Please refer to the chart below.



The Drag Equation
Photo Credit: nasa.gov

Prototype 1	Prototype 2
Two Ethernet cables wired in parallel	Two High Power cables wired in parallel
Four 24 AWG conductors per phase	Two 12 AWG conductors per phase

The company's electrical engineers calculated theoretical values for voltage drop for both prototypes. They used online charts to determine each prototype's ampacity (i.e. the maximum current the cables can carry continuously without exceeding their temperature ratings). The electrical engineers then used a multimeter to calculate the same values experimentally. Using the calculated voltage drop and ampacity values, and their knowledge of Redfin's propulsion system, electrical engineers used Blue Robotics' online charts to determine Redfin's net horizontal thrust for each prototype.

The first prototype produces a net horizontal thrust of 1.11 kgf, whereas the second prototype produces a net horizontal thrust of 3.15 kgf. MTL Horizon's electrical engineers made a trade-off. Despite the second prototype producing a greater drag force, the team chose it instead of the first prototype because it produces a net horizontal thrust that is nearly 184% greater.

		Prototype 1	Prototype 2
Voltage Drop (V)	*Theoretical Calculation*	1.27	1.27
	Trial 1	1.32	1.25
	Trial 2	1.37	1.24
	Trial 3	1.35	1.24
	Avg. Experimental Calculation	**1.35**	**1.24**
Ampacity (A)	*Theoretical Calculation*	4.62	18.6
	Trial 1	4.81	19.11
	Trial 2	4.72	18.98
	Trial 3	4.53	19.07
	Avg. Experimental Calculation	**4.69**	**19.05**

Tether Prototype Tests
Credit: A. Selvakumar

7: ACCOUNTING

Budget and Project Costing

During preseason, the company's CFO prepared a budget that was easy to follow. It included estimated expenses based on actual project costing from her previous experience with LHS Horizon. Because *Redfin*'s control system takes inspiration from previous projects, the company's project budget was easier to forecast; it allowed the CFO to focus on cost estimates for ROV enhancements, including the custom-cut Plexiglass chassis, custom watertight enclosure, and new tools. Furthermore, employee transportation and meal expenses, while noted, are listed separately; company employees are responsible for these costs.

Income:				
Source				Amount
Parent donations				3960.00
Cash donation (Amazon gift card)				100.00
Expenses:				
Category	**Type**	**Description/Examples**	**Projected Cost**	**Budgeted Value**
Production Expenses				
Electrical & Software	Purchase	Cables, Junction Box, Maestro, Penetrators, Potentiometers, Servo Mounts	1500.00	1500.00
	Re-use	Joysticks, Voltage Regulators, Arduino Mega	250.00	----
Mechanical	Purchase	Acrylic Sheets, Brackets	200.00	200.00
	Re-use	Hardware	50.00	----
Propulsion	Purchase		250.00	250.00
	Re-use	Thrusters, ESCs	1200.00	----
Payload Tooling	Purchase	Leak Sensors, Manipulators	25.00	25.00
	Re-use	Cameras	500.00	----
Vertical Profiler	Purchase	Enclosure, Penetrators, Pressure Valve, Servo, Syringe	500.00	500.00
	Re-use	HC-05 Bluetooth Module, Arduino Uno	200.00	----
Hardware & Materials	Purchase	Epoxy, Tape, Screws	100.00	100.00
	Re-use	Screws, Nuts	50.00	----
Operational Expenses				
Mission Props	Purchase	PVC/ABS, Plastic Sheeting, Electronics, Frogs, Fish, Etc.	400.00	400.00
	Re-use	PVC, Rope, Pool Noodles	170.00	----
MATE Fees	Purchase	Registration Fee, Fluid Power Quiz	275.00	275.00
Printing	Purchase	Marketing Display, Laminating	100.00	100.00
Pool Use	Donation	Pool Practices	1000.00	----
Food	Purchase	Meals	300.00	300.00
Team Apparel	Donation	Tee-shirts	400.00	400.00
Travel	Purchase	Travel to Colorado for MATE World Championship (Paid separately by individual families; does not factor into running balance)	15000.00	----
			22470.00	
			Total Income:	4060.00
			Total Expenses:	8070.00
			Total Expenses-Reuse/Donations	8480.00
			Total Fundraising Needed	-410.00

Budget
Credit: S. Soma

Type	Category	Expense	Notes	Amount	Running Balance
Cash Donated	General	Funds donated by parents	Used for vehicle construction	4400.00	3600.00
Cash Donated	General	Amazon gift card	Won at a previous competition	100.00	3700.00
Purchased	Mission Props	PVC pipe, PVC connectors	Used to build pool props	400.00	3300.00
Purchased	Electrical & Soft	Arduinos, cables, penetrators, etc.	ROV needs	1500.00	1800.00
Purchased	Mechanical	Acrylic plates, junction box	ROV needs	300.00	1500.00
Reused	Propulsion	Thrusters	ROV motors	15.00	1485.00
Reused	Payload Tooling	Manipulators	ROV manipulators	150.00	1335.00
Purchased	Vertical Profiler	Materials for vertical profiler	Used for task 3	400.00	935.00
Purchased	Hardware & Mat	Misc. materials	Used on ROV	400.00	535.00
Purchased	MATE Fees	Registration Fee, Fluid Power Quiz	Required for competition	275.00	260.00
Purchased	Printing	Copies and lamination	Needed for documenation	25.00	235.00
Cash Donated	Pool Use	Donation from Giant Fitness	Pool practices	1000.00	-765.00
Cash Donated	Food	Funds donated by parents	Snacks	100.00	-865.00
Cash Donated	Team Apparel	Tee-shirts	Shirts for competition	400.00	-1265.00
Cash Donated	Travel	Transportation: Meetings, Practices, Competition		300.00	-1565.00
Purchased	Travel	MATE World Championship	Paid separately by individual families does not factor into running balance.	15000.00	
Cash Donated	General	Funds donated by Beyond Aviation	Used for vehicle construction	500.00	-1065.00
Cash Donated	General	Funds donated by parents	Used for tee-shirts	360.00	-705.00
				Total Raised:	5360.00
				Total Spent:	5265.00
				Final Balance:	95.00

Project Costing
Credit: S. Soma

8: ACKNOWLEDGEMENTS & REFERENCES

We would like to start by thanking our benefactor, the Mt. Laurel Library, for giving us a friendly place to work. Thank you to Villanova University for hosting the 2023 MATE PA Regional Competition, and a big thank you goes out to all the volunteers who helped make the event possible. Thank you to all the MATE Center personnel who are coordinating the 2023 World Championship Competition in Colorado. We look forward to seeing you! A special thanks goes out to Mr. Dom Balducci at Giant Fitness for letting us practice in the pool. We would like to thank the Marine Technology Society at Rutgers University for providing advice and guidance regarding our vertical profiler. We also need to thank the Selvakumar family for letting us set up shop in their basement (and cleaning up after us after every work session!). Thank you to our coach, Ms. Maureen Barrett, who came out of retirement just for us! Finally, everything we have accomplished this year was made possible with the loving support of our families who not only served as chauffeurs extraordinaire, but also supported us throughout the competition season.

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