Technical Documentation for *Mako* ROV

Sidwell Friends School, Washington D.C., USA

Team Members

CEO: Gabriel Abrams, 12th

CFO: Anton Chen, 12th

COO: Deanna Paukstitus, 12th

CTO: Chase Brown, 12th

Head Engineer: Ilaria Luna, 12th

Driver: Amar Johnson, 12th

VP of Marketing: Leo Schuck, 12th

VP of Reliability: Wilson Cai, 12th

VP of Safety: Reave Tekmen, 9th

Team Mentors

Darby Thompson: Robotics Faculty Member & Computer Science Teacher

Martin Suresh: Robotics Faculty Member & Computer Science Teacher

Sam Blazes: Robotics Faculty Member and Team Alumni

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Abstract

Future Gadget Lab is an underwater robotics company from Sidwell Friends School in Washington, DC. Our nine members, inspired by the United Nations' Sustainable Development Goals, are passionate about combating climate change and advancing eco-friendly technology through engineering and collaborative design.

Mako is Future Gadget Lab's second-generation underwater ROV. With an optimized acrylic frame, upgraded three-camera system, organized onboard electronics, an accelerometer, and a powerful claw, Mako is ready to tackle a variety of complex marine tasks.

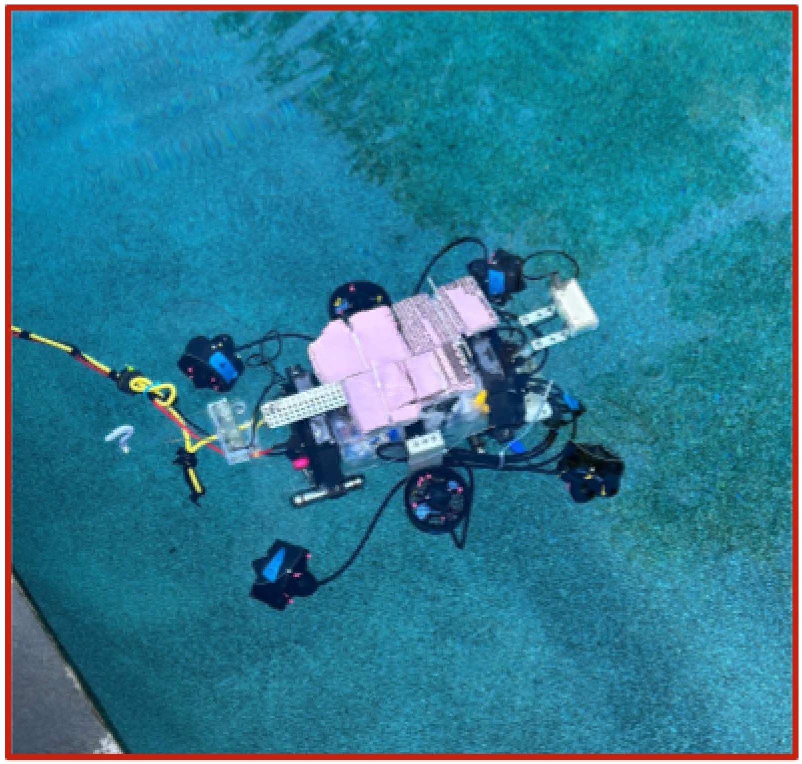

Figure 1: Mako's first test in the pool! (Photo taken by Ilaria Luna via iPhone)

After careful planning and budgeting, Future Gadget Lab has implemented extensive prototyping and testing to produce an ROV that can reliably perform in real-world conditions. This technical document details months of specialized design and Mako's resulting capabilities. Future Gadget Lab and Mako can make a tangible impact on climate efforts by installing sensors for long-term aquatic monitoring, maintaining renewable energy facilities, and identifying markers of invasive species.

Roles and Responsibilities

CEO – Gabriel Abrams, 12th

- Designed ROV frame; programmed drive control system for ROV

CFO – Anton Chen, 12th

- Designed float components; built autonomous program for float; managed finances

COO - Deanna Paukstitus, 12th

- Designed and built circuit for ROV; managed production of ROV and float

CTO - Chase Brown, 12th

- Designed float circuit, built autonomous program for float; evaluated which tech to reuse, build, or buy

Head Engineer – Ilaria Luna, 12th

- Built ROV frame; assisted in the waterproofing of the ROV
- **Driver – Amar Johnson, 12th**
- Drives ROV; created optimal drive plan; assisted in building of ROV, float, and props

VP of Marketing - Leo Schuck, 12th

- Outreach to Sidwell community; wrote documentation

VP of Reliability - Wilson Cai, 12th

- Assisted in building ROV, float, and props; ensured processes prioritized reliability and protected our environment

Head of Safety - Reave Tekmen, 9th

- In charge of waterproofing ROV; assisted in the production of the ROV, float, and props; designed safety checklist; assistant driver

Project Management

Company Profile

Future Gadget Lab is a student-led company specializing in submersible ROVs designed to combat climate change and its global impacts. Our 9-person team comprises engineers, researchers, and other personnel who double as drive team members. Despite assigned positions, the company's organizational structure ensures that every member can uniquely contribute to the design and construction of our products.

Scheduling and Planning

Future Gadget Lab was founded in January 2024. Each week, we met at the Sidwell Friends School's robotics lab on Fridays from 3:30 PM to 8:00 PM and on Sundays from 12:00 PM to 4:00 PM. As ROV progress continued, pool meetings for underwater testing and driving practice were scheduled on Saturdays from 11:30 AM to 4:00 PM. Following scheduled meetings, team members in attendance routinely reported progress and made plans for the next meeting to ensure that company personnel were always up-to-date on the ROV's development. Additionally, we have a Future Gadget Lab messaging chat, where we reflect on our work after every meeting to strengthen our team's unity and continue mapping out our objectives.

Progress Chart

Key:	Complete	In Progress	Incomplete
Color	Green	Yellow	Red

Tasks:	Jan.	Feb.	Mar.	Apr.	May.
Assigning Roles	Yellow	Green	Green	Green	Green
Evaluating Tasks	Yellow	Green	Green	Green	Green
Researching Past Competitive Teams	Yellow	Green	Green	Green	Green
Designing ROV Frame and Motor Configuration in CAD	Yellow	Yellow	Green	Green	Green
Gathering Necessary Materials	Red	Yellow	Yellow	Green	Green
Building Body of ROV	Red	Yellow	Yellow	Green	Green
Building Onboard Electronic Circuit	Red	Yellow	Yellow	Green	Green
Constructing and Waterproofing Float	Red	Yellow	Yellow	Yellow	Green
Setting up Raspberry PI Server	Red	Red	Yellow	Yellow	Green
Waterproofing Cameras	Red	Red	Yellow	Yellow	Green
Setting up Arduino	Red	Red	Yellow	Yellow	Green
Creating Main Driver Program	Red	Red	Yellow	Yellow	Green
Preparing Ethernet Wire and Tether	Red	Red	Yellow	Yellow	Green
Designing and Building Control Box	Red	Red	Yellow	Yellow	Green
Buoyancy for ROV and Tether	Red	Red	Red	Yellow	Green
Technical Documentation and Safety Report	Red	Red	Red	Yellow	Green
Pool Practice	Red	Red	Red	Yellow	Yellow

Design Rationale

Overview

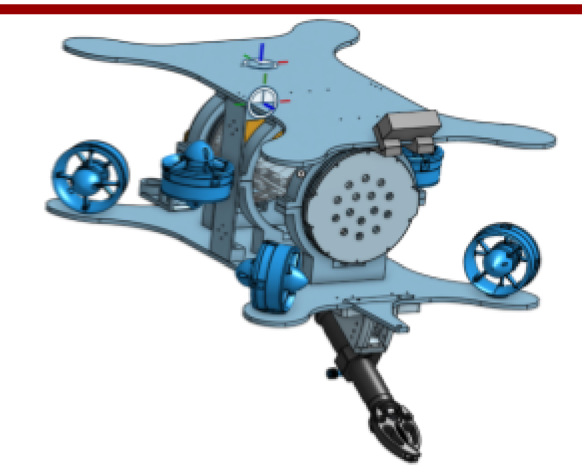

Figure 2: Mako's final design on OnShape. Diagram by Gabriel Abrams, via OnShape

Future Gadget Lab embarked on a long and meticulous design process to create an efficient and effective ROV. First, the company assembled a spreadsheet containing the technical documentation of successful MATE companies from previous years. In doing so, we found inspiration for our ROV and weighed possible benefits and detriments of various design options. Following the research phase, the company spent several weeks brainstorming and prototyping potential designs, in which each member shared their thoughts, knowledge, and ideas based on the mission specifications. Once adequately prepared, Future Gadget Lab spent significant time prototyping our ROV on the CAD Software *OnShape* to bring the company's vision of Mako to life. After settling on a finalized design, Mako's construction began.

Rather than a PVC-based frame, the company shifted towards an acrylic-based design that has been in the works for over a year. With just two acrylic sheets connected to an acrylic tube, Mako's simple structure is perfectly optimized for a sleek and strong design. Six motors affixed to the base allow the ROV to achieve omnidirectional movement. Finally, the company intricately wired Mako's onboard electronics and secured a gripper to the bottom of the frame.

Mechanical Design and Fabrication

In designing a stable frame to house Mako's technology, we balanced prioritizing size, cost minimization, and function. For instance, the team wanted the ROV to be large enough for stability but sufficiently lightweight for speed and maneuverability. Mako's main structure is thus optimized for these features while maintaining a sleek and minimalistic design.

The frame, Mako's home base, consists of a 6-inch acrylic watertight enclosure sealed with two waterproof caps. The structure is sandwiched between two 18-by-24-inch laser-cut acrylic sheets. This material is particularly cost-effective and sustainable as it was recycled from COVID-19 dividers. By reusing resources, Future Gadget Lab adheres to its core values of sustainability and environmental friendliness.

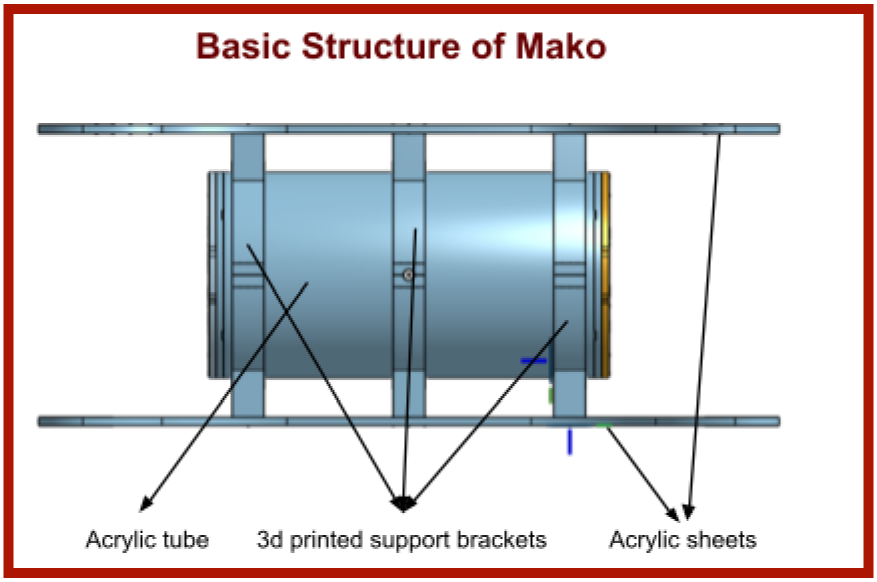

Figure 3: Key components and uses of the unique structure of Mako. (Diagram by Gabriel via Google Drawings and OnShape).

Rational Process and Trade Studies

After outlining key objectives for Mako to complete, company members began determining the exact hardware and components needed to complete the project. Many important decisions about Mako needed to be made, including the ROV frame's material, the propulsion system, and the intake mechanism. To make optimal decisions, we created a holistic evaluation of all options available by extensively researching their qualities. We organized the information into trade studies, as shown below:

Material Type	Relative Affordability	Strength-to-Weight	Manufacturability	In-Water Compatibility	Total Score
PVC Pipe	5	4	4	2	15
3D Printing Plastic (PLA, PETG)	4	1	4	1	10
Aluminum Pipe	1	5	2	4	12
Acrylic Sheet	4	4	5	5	18
HDPE Sheet	2	2	3	4	11

Propulsion Type	Relative Affordability	Thrust	Integration Compatibility	In-Water Compatibility	Total Score
Bilge Pump 800 GPH Motors	4	1	3	2	10
Bilge Pump 1250 GPH Motors	4	2	3	2	11
Blue Robotics T100 Thrusters	2	4	4	5	15
Blue Robotics T200 Thrusters	1	5	4	5	15
(Vertical only) Inflatable buoyancy bag	2	2	1	4	9

Intake Mechanism Type	Relative Affordability	Effectiveness	Versatility	Integration Compatibility	In-Water Compatiblity	Total Score
Passive intake	5	2	3	5	4	19
Servo-powered claw	4	4	4	4	2	18
DC Motor-powered claw	3	3	4	3	4	17
Fluid-powered claw	3	4	4	2	3	16
Piston/Linear actuator-powered claw	1	5	5	4	4	19

Analyzing these tables helped inform the purchasing and construction decisions for the Mako. Ultimately, we used the materials and components that scored highest from each trade study.

Acrylic Sheets:

Mako's acrylic sheets are responsible for housing its claw, waterproof enclosure, and six motors. This design is a deviation from the basis of previous years, as most of Future Gadget Lab's ROVs were constructed from PVC pipe. However, in the planning stages of Mako's construction, our engineers decided that acrylic provided the superior strength, durability, and lightness they aimed for. Lightness, in particular, was a big advantage of acrylic because it enabled faster underwater movement.

Watertight Cylinder:

The watertight cylinder is a fundamental part of Mako, providing a simple and spacious space to store all its onboard electronics. Protecting them from devastating water damage while minimizing their spatial footprint was a top priority, and the cylinder allows them to be safely encased while providing a key role in the ROV's structure.

Although hosting onboard electronics—and thus, the cylinder—increases Mako's size, our engineers find their technical advantages a worthwhile tradeoff. Special attention, such as selecting lightweight frame materials, was paid to improving Mako's maneuverability in exchange.

Metal Cylinder Caps:

The cylinder features two metal caps that provide a barrier between the water and the electronics. To join "underwater" wires with "indoor" wires, the caps include 20 openings sealed with metal penetrators and o-rings to avoid compromising waterproofness. When installing the caps, it was paramount that the o-rings were thoroughly cleaned of any dust and debris that could cause water to seep into the Mako's electronics. Because of this, the crew spent significant meeting time cleaning the caps.

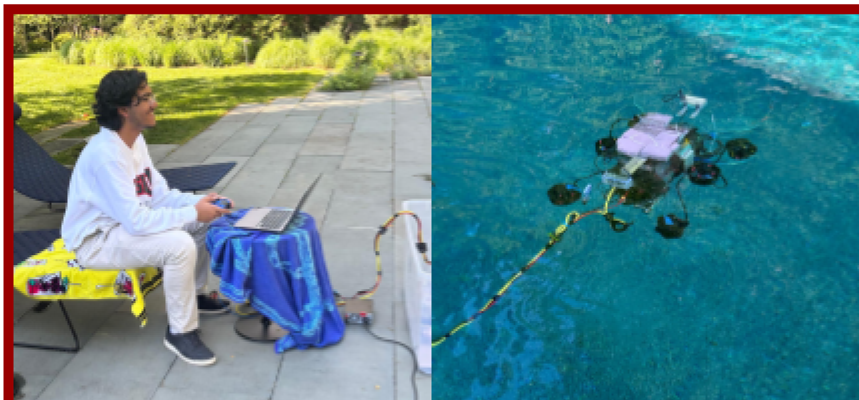

Figure 4: Amar Johnson practices driving. Mako in action!
(Photos taken by Ilaria Luna via iPhone)

Propulsion

Mako is equipped with four *Blue Robotics* T100 and two T200 Marine Thrusters to achieve pure omnidirectional movement. Producing over 5 lbs of thrust, each motor has the perfect torque and speed for our ROV's movements. Two motors are placed on each side (one per corner) of the ROV's front and back sides.

Figure 5: Blue Robotics T100 Thruster

A unique aspect of Mako is that its 4 motors responsible for horizontal movement are angled inward. This is done to allow Mako to horizontally strafe left and right in addition to moving forward and backward. Additionally, the two additional motors on the left and right sides of the ROV are responsible for vertical movement.

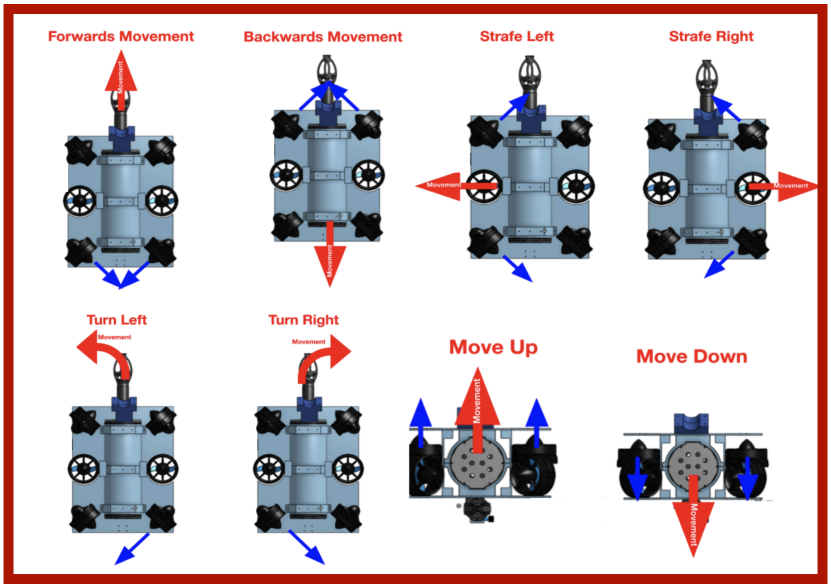

Figure 6: Different thrusts and motor uses, and their contributions to omnidirectional movement (Diagram constructed by Chase Brown via Google Drawings)

Payload & Claw

In past years, our engineers designed and built their own claws in-house. However, this year, we understood that a more reliable and stronger claw would allow us to complete missions more efficiently. Thus, Mako features Blue Robotics' Newton Subsea Gripper.

We chose this claw for two main reasons. Firstly, its robust design aids in Mako's completion of strenuous tasks; it has a high grip force of 28 pounds and a maximum jaw opening of 2.44 inches. Secondly, the claw integrates easily into our onboard electronics system, taking PWM signals as input.

Figure 7: Blue Robotics Newton Subsea Gripper With 3D-printed improvements

As testing of the claw began, we discovered that its thin profile made certain tasks more difficult to complete, such as removing the pin to release the hydrophone. To adapt to these tasks, 3d printed claw sections were added to thicken the profile. This new design allows Mako to complete mission objectives much more efficiently.

This year our engineering team also designed a hook mechanism to capture jellyfish polyps. Initial designs did not keep the polyps on securely to be delivered to the surface, so we added blunt barbs to the hooks. This design ensures that the polyps can be collected without being damaged or damaging the surrounding environment.

Onboard Electronics

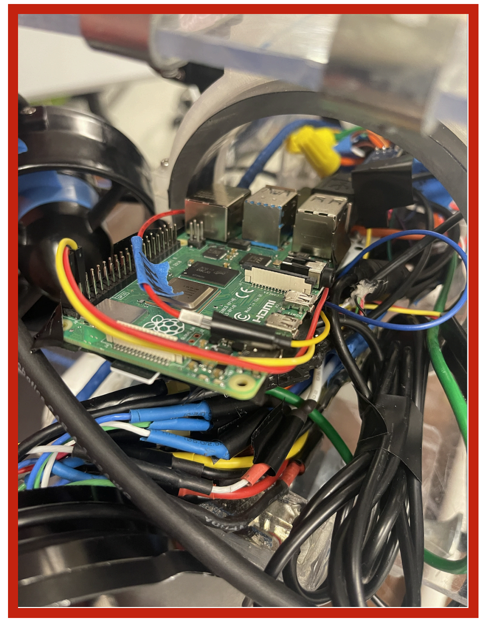

Figure 8: The Raspberry Pi 5, a key component of our on-board electronic system (Photo taken by Gabe Abrams via iPhone)

Mako's "brains" comprise a meticulous onboard electrical system. This approach differs from previous years, where surface-based electronics were the primary source of the ROV's input and output. In the planning stages of constructing and designing Mako, we discussed the benefits and detriments of both electronics setups. For example, onboard electronics prevent power and signal loss over time, and inputs are sent from the controller to the ROV. Onboard electronics also allow the ROV to be driven with more accurate inputs and signals. This ensures that Mako can be helmed with precision as it completes tasks. On the other hand, onboard electronics can be expensive and challenging to set up and construct. Future Gadget Lab devoted much of the month-long ROV design period to troubleshooting the onboard electronics to get them where they are today.

Cameras

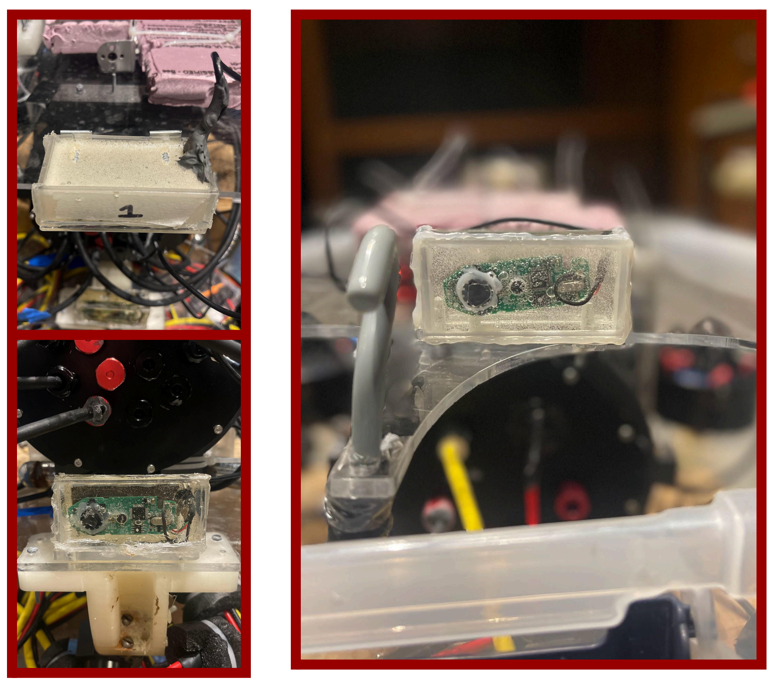

Figure 9 (top left), Figure 10 (bottom left), & Figure 11 (right): Cameras facing the claw, the front end of the ROV, and the back of the ROV coated in thick layers of epoxy resin. (Photos taken by Anton Chen via iPhone)

In the past, Future Gadget Lab used one generic fishing camera to provide our drivers with a view of the underwater terrain. The image quality was mediocre at best. Often, interference in the camera wire would cause the monitor to display a distorted view or a plain white image. To improve image quality for Mako, we took advantage of its onboard electronics by plugging three Logitech C270 HD web cameras into the Raspberry Pi. The image information thus goes through the

Ethernet cable, greatly reducing susceptibility to interference and improving image quality. Similarly, the Logitech cameras are less expensive and simpler to operate, bolstering Mako's cost-effectiveness.

In past years, we have used 2 cameras: one facing outward on the front of the ROV, and another facing down toward the claw. We have since learned that utilizing 3, particularly one facing outward on the back of the ROV, is extremely useful for navigation and preventing tangling with the tether.

Mako's cameras are waterproofed in clear, acrylic boxes and filled with epoxy resin. The Logitech technology provides the best image quality at a reasonable cost.

Tether

Consisting of three wires, each extending 93 feet, Mako's tether connects the electronics onboard to the pilot on land. The team placed polyethylene foam disks around sections of the tether, approximately one foot apart, to achieve a slight positive buoyancy and prevent Mako from being weighed down underwater. This keeps the tether's mass from negatively impacting the ROV's operation.

Figure 12: Our negatively buoyant tether. (Photo taken by Ilaria Luna, via iPhone)

We securely attached the tether to the top of the ROV to relieve its strain and to ensure that the ROV cannot loop itself around the tether. Additionally, on the surface, the unused segments of the tether are wrapped around a spool. These two steps decrease the risk of the tether getting tangled below and above water. During ROV operation, two drive team members work to manage control of the tether, minding its position both underwater and on the surface to avoid tangling, tripping risks, and negative interference with the aquatic environment.

Buoyancy

To achieve neutral buoyancy, Future Gadget Lab equipped Mako with an acrylic frame and styrofoam padding. Additional weights fastened along the ROV's bottom were used to balance the claw. Mako's uniform weight distribution allows it to remain upright while underwater, improving thruster steering accuracy.

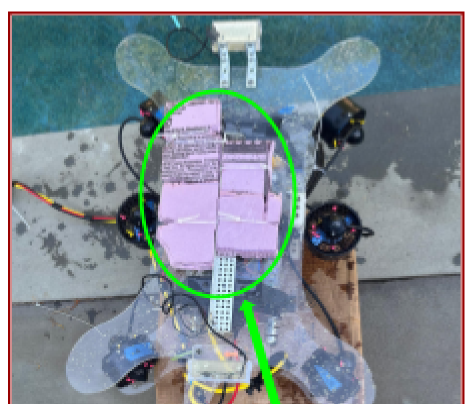

Figure 13: The pieces of styrofoam keep the ROV neutrally buoyant and prevent any roll while underwater. (Photo taken by Ilaria Luna via iPhone)

Systems Approach

In designing Mako, Future Gadget Lab began by analyzing the specific tasks that the ROV needed to perform and selected components based on those requirements. Multiple tasks required lifting large or heavy objects that would affect our ROV's balance, and others called for moving small, more precise materials. We thus looked for components that could meet our performance needs while being cost-effective. The results of our efforts are detailed below.

Motors/Thrusters:

Mako's four T100 and two T200 thrusters provide maximum movement through the water, especially when carrying and delivering cargo. The quantity of motors was a critical discussion point in the early stages of designing Mako; tasks are timed, so it was paramount that the ROV was quick, nimble, and powerful.

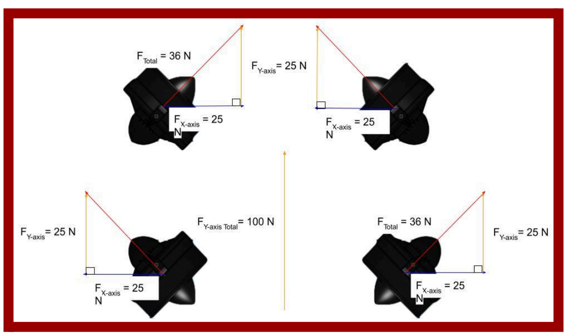

Figure 14: Calculations for Horizontal Thrust. Diagram constructed by Gabriel Abrams, via Google Drawings

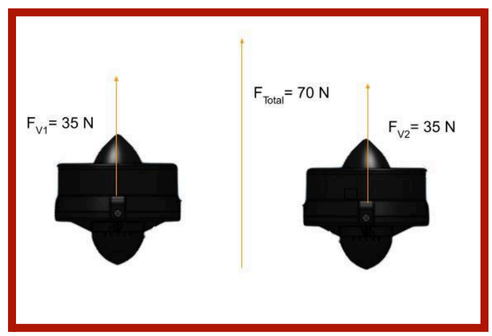

Figure 15: Calculations for Vertical Thrust. Diagram constructed by Gabriel Abrams, via Google Drawings

Drive System:

A PS5 controller is used to steer Mako in forward or reverse mode, which can be toggled by a button. In addition, the driver can switch between fast and slow drive settings. This allows the driver to travel large distances in short periods and make fine maneuvers when the ROV arrives at the target site.

The driver accesses the cameras through a webpage on the Mac laptop. On this webpage, the driver can select to view a specific camera (in a large format) or all cameras simultaneously. The webpage also lists the acceleration values in all 3 dimensions, giving extra insight into the ROV's movement.

PlayStation Drive Controller:

The programmers designed the driver's controls with intuition and ease in mind. The driver controls the ROV's x-axis and y-axis movement through the left joystick of the PS5. The driver also controls the rotation of the ROV by the x-axis of the right joystick and the vertical propulsion by the y-axis of the same joystick. They open and close the claw with the right and left triggers. Finally, the driver can switch between fast and slow modes by pressing "X" on the PS5 controller and between forward and reverse modes by pressing "square."

Software and Electronics

Control System

Mako's control system consists of a Raspberry Pi 5, an Arduino Mega 2560, and a Mac Laptop. A 20-meter Ethernet cable connects the Raspberry Pi to the laptop on the surface. The Arduino is connected to the Raspberry Pi by a USB Type-B cable. Three Logitech C270 webcams are also connected to the Raspberry Pi through USB cables.

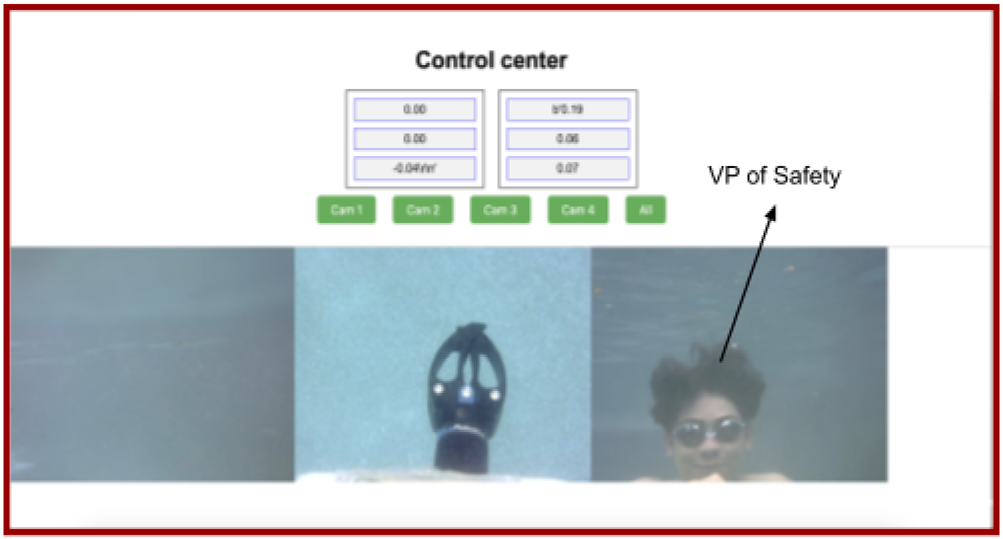

Figure 16: Gabe Abrams ('25) and Reave Tekmen ('28) testing the camera system on the Raspberry Pi (Photo by Gabe Abrams via iPhone)

To control Mako, three computer programs run simultaneously. On the surface, the laptop runs a program that takes input from a PS5 controller and converts the data into motor output for six T100 thrusters and one claw. The program then sends this information over the Ethernet cable to the Raspberry Pi onboard Mako. The program on the Raspberry Pi is a Flask server that waits to receive input from the laptop. When it receives a post message, it takes this data and passes it to the Arduino Mega over a serial connection. The program on the Arduino Mega takes the motor info and sets the thrusters' and gripper's power.

The thrusters receive a serial PWM signal ranging from 1100-1900 microseconds. A PWM signal of 1500 microseconds stops the motors from spinning, 1900 sends full power to the motor to go forward, and 1100 sends full power to the motors to go backward. The claw similarly takes a serial PWM signal ranging from 1100-1900 microseconds.

The program on the laptop converts the data from the PS5, ranging from -1 to 1, into the proper serial output. The engineers created a slow mode – activated by a button on the controller – to allow the driver to make finer movements with the ROV when necessary.

The Flask server on the Raspberry Pi uses Open-CV to read the 3 Logitech C270 cameras. The driver can choose between seeing one camera at a time and all cameras by pressing buttons on the control center website.

An accelerometer resides on Mako to measure acceleration in the x, y, and z directions. This data is sent to the control center to be displayed in the control center. The left column of numbers marks the target acceleration values, and the right column denotes the real acceleration values.

While the control system is more complex than previous years, it provides the driver with more confidence and precision in handling the ROV.

System Integration Diagram (SID)

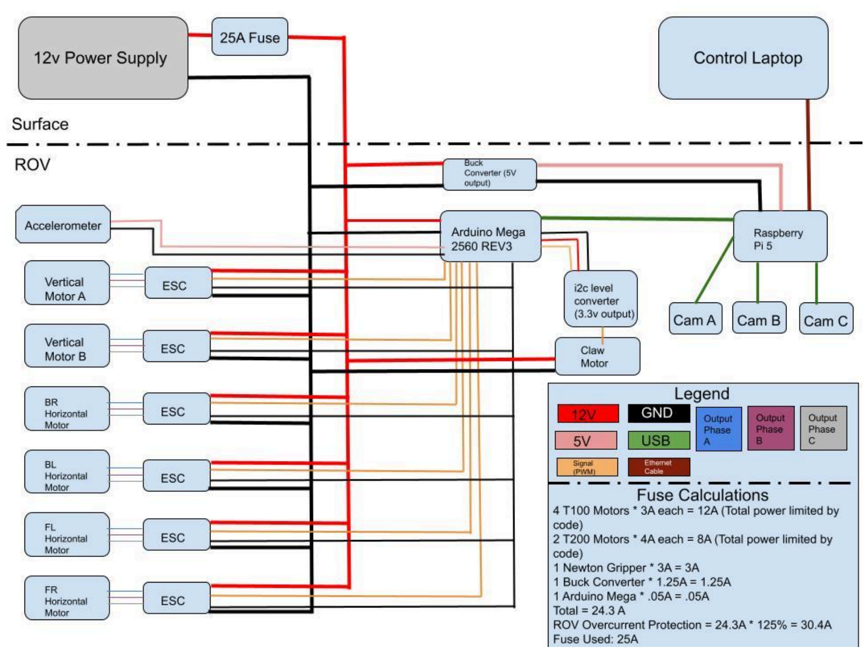

Figure 17: System Integration Diagram, Diagram Constructed by Gabriel Abrams via Google Drawings

Safety

Philosophy & Safety Precaution Chart

Safety was our team's top priority while constructing our ROV. We believe a safe workplace is crucial to creating a good product, especially when working toward a deadline. Safety procedures, while seemingly time-consuming on paper, save time in practice. Safety measures ensure that the ROV remains undamaged, avoiding tedious replacement, and allow all team members to work comfortably, accelerating the ROV's development.

In addition to physical safety, we firmly believe in the importance of creating an environment supportive of all ideas and encouraging of taking (safe) risks. To develop an ROV that is truly unique and innovative, it is necessary to think outside the box and try things we have not done before. Throughout the entire design process, we strove to listen fully and respectfully to all ideas shared, judging fairly whether Mako would benefit.

The table below includes common tasks that team members participate in, outlines the risks that come with them, the safety precautions we take, and the proper response to an injury.

Tasks	Hazards Posed	Precautions and Responses
1. Using power tools 1.1 Using a soldering iron & heat gun 1.2 Electrical motors (i.e electric drills)	**1. Chemical & Physical Hazard** 1.1 May result in severe burns or fires. Possible exposure to rosin fumes can cause irritation and sensitization of the eyes and respiratory tract. 1.2 May result in bruises, cuts, or scratches. Moving parts create potential physical hazards	**1. General** - Wear protective goggles and be in the presence of a mentor - Keep hands away from the tip of the tool - Make sure everyone is aware that a Power Tool is being used - In the event of an injury, make sure to immediately turn off the power tool - Do not point the tool at anyone. 1.1 - Work in a ventilated area (outside or open all windows and doors) - Wear an air mask - Do not use or place tools near flammable materials - Use a soldering hand or have someone hold the object that is being worked on - Allow the tool to cool off properly before putting it away 1.2 - Use tools appropriately - Make sure to keep hands away from blades
2. 3D Printing	**2. Chemical & Physical Hazard** 2.1 May result in bruises, cuts, or scratches. Moving	**2.** 2.1 - Make sure the 3d printer is turned off and cooled down when cleaning the extruder or

Tasks	Hazards Posed	Precautions and Responses
	parts create potential physical hazards	removing prints from the bed - Remove the magnetic plate and then lightly bend the plate back and forth
3. Assembling the ROV 3.1 Assembling and building the ROV	**3. Physical Hazard** 3.1 Physical harm could be caused if electronics are not properly assembled or organized. An electronic shock or burn could be caused by improper wiring, etc.	**3.** 3.1 - When working on electronics, always ensure that the ROV is turned off - Make sure electronics are in a well-ventilated area to stop overheating - Always plan out wiring and make sure to cover it - Make sure there is a fuse attached to limit the ROV - If the fuse blows, make sure to replace it as soon as possible
4. Handling the ROV 4.1 Sharp edges 4.2 Transporting ROV	**4. Physical Hazard** 4.1 Sharp edges may cause cuts or scrapes if not properly concealed 4.2 Incorrect handling of the ROV may cause falls that could result in physical damage	**4.** 4.1 - All sharp edges of our ROV are covered - Make sure all edges are shaved down to not - Secure all loose parts 4.2 - Have multiple members carry the ROV to ensure security - Do not carry the ROV if you are unable to
5. Testing the ROV 5.1 Water enclosure	**5. Chemical & Physical Hazard** 5.1 Dangers of being next to a water source	**5.** 5.1 - All members are capable of

Tasks	Hazards Posed	Precautions and Responses
	include drowning. Additionally, if the electronics are not properly waterproof, there may be electrical shocks	swimming in case someone falls in the pool - Make sure that there is a leak sensor that shuts down all electronics if water comes in contact to limit electrical shocks - Cover all exposed wires and electronics

Electrical Safety

Considering the significance of electrical safety, we have taken extra precautions to prevent damage and injury. For instance, we banned all food and drink in our workspace to reduce electrocution risk. In preparation for driving in the pool, we repeatedly vacuum tested Mako's central chamber, which houses its electronics, to mitigate potential water damage caused by debris. Furthermore, we ensured that the technology needed for driving the ROV, such as the laptop, controller, and power box, was always a safe distance from the pool deck to prevent any chance of electrocution or harm to our electronics.

Mechanical Safety

Many mechanical tools, such as drills and saws, can be harmful if misused. To avoid danger, we believe all company members should know how to safely and properly operate equipment. Each of us was taught how to operate saws and all the power tools, such as drills and drill presses.

While drilling, for example, we safely cleared the surrounding area and confirmed that the operator wore safety glasses and proper clothing that would not get caught on the drill bit. Similarly, every 3D print was supervised by someone with prior experience, often a member who owned a 3D printer themselves.

Safety is a top priority at Future Gadget Lab, and we aim to do our due diligence in not taking it lightly.

Safety Features

Our ROV includes many safety features that protect both the user and the ROV's environment. Mako's safety features include shrouded thrusters to prevent aquatic life (or human parts) from being caught in them, screw-close casing for underwater electronics, and epoxy-sealed controls to avoid damage to out-of-water electronics. Our ROV is primarily constructed from non-corrosive materials, and all joints are secured to ensure that no parts of the ROV unexpectedly detach. Additionally, by reducing sharp edges and points, such as elongated zip ties, Mako is safe to touch and handle.

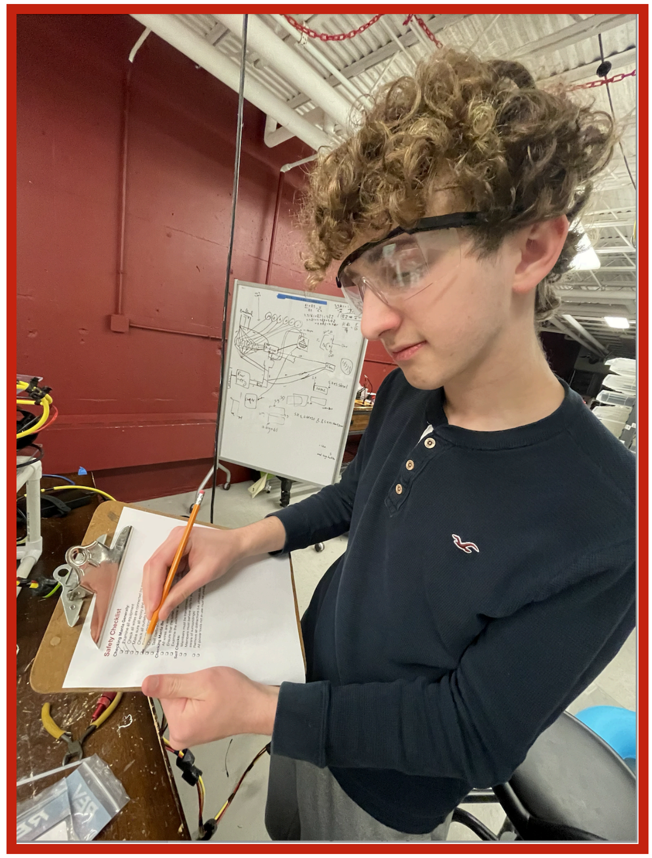

Figure 18: Gabriel Abrams checking boxes like a boss… because even superheroes wear safety goggles! (Photo taken by Chase Brown via iPhone)

Safety Checklist

Preliminary Check:

- ❏ Examine all equipment
- ❏ Check all wires are connected (no exposed wires)
- ❏ Make sure all epoxy and adhesives are dry
- ❏ Check all outlets before using power
- ❏ Ensure motors are centered in their mounts
- ❏ Check all screws and PVC connections
- ❏ Test calibration on electronics

Checking Mako Before Entering the Pool:

- ❏ All wires are waterproofed
- ❏ Ensure that the tether is untangled and ready for use
- ❏ Examine the electronic area for water before providing power

Self Checks:

- ❏ Members must be trained on how to use tools before attempting any projects
- ❏ Members must behave appropriately for the lab environment (i.e. no roughhousing, being aware of surroundings)
- ❏ Remove all distractions (i.e. phones) before using power tools
- ❏ All power tools not in use must be unplugged

Critical Analysis

Testing Methodology

Due to the complexity of the electronics and the risk that came with any chance of error, most of our testing was done with the ROV above water and in the lab. This allowed us to find and examine critical flaws with our ROV without causing any harm to the electronics.

Our implementation of this strategy especially allowed us to limit the amount of time troubleshooting when practicing in the pool and spend more meeting hours driving Mako. Even though we ran into unforeseen problems while practicing in the water, our process prevented electrical components from being damaged when repairing the ROV.

Figure 19: Ilaria, Gabriel, Reave, and Chase calculating the buoyant force of the float (Photo by Gabriel Abrams, via iPhone)

Troubleshooting Strategies and Techniques

Throughout the season, Mako frequently underwent repairs, which required us to devise techniques to make the troubleshooting process as efficient as possible. For instance, with the electronics' intricacy, accidents could stem from one particular item or a combination of many pieces out of sync. Thus, we found it helpful to isolate each individual component before any attempt was made to repair the damage. Isolating each aspect was the only way we could avoid "band-aid" solutions, discover the root of each problem, and execute based on it.

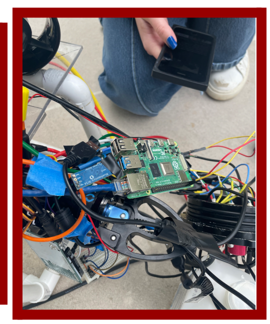

Figure 20 (left): Gabriel ('25) testing all 6 motors.
Figure 21 (right): The electronics during the troubleshooting process. (Photos by Deanna via iPhone)

Prototyping and Testing

Mako went through several phases of construction-based and electrical prototyping. To devise an appropriate frame for our ROV, Future Gadget Lab utilized the CAD software OnShape to prepare several different designs before landing on the one most ideal for our objectives. Additionally, electrical diagrams were first drawn on whiteboards and built in several prototype segments before eventually being sized up and implemented onboard Mako.

When prototyping, our most important priorities were safety and functionality; we wanted to design an ROV that we could confidently say had no weaknesses or underdeveloped features while also adhering to appropriate restrictions for activity in vulnerable ocean environments. Through many months of trial and error, all of our ROV's characteristics serve to improve it harmoniously rather than colliding with one another.

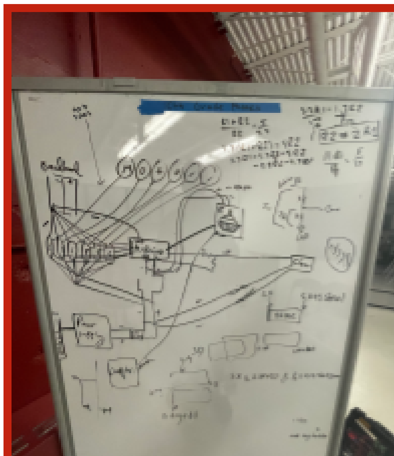

Figure 22: Whiteboard containing sketches of electronic configuration, as well as calculations for the electronics (Photo by Chase Brown via iPhone)

Much of this can be attributed to the scrupulous testing phases Mako underwent throughout the construction process. Testing began long before our ROV was complete; to ensure that prototype builds were well-equipped for the season's tasks, they were assessed in a dunk tank to evaluate how they maneuvered an underwater environment before we either returned to the drawing board or proceeded with them. Electronics, too, were tested separately from the frame with numerous different power sources to ensure that they contained no faults. Only when both aspects were 100% done were they combined, which kept us from the tumultuous process of having to narrow down little issues when testing the assembled product.

In its final few weeks of development, Mako was piloted for hours at a time in a pool to ensure it exhibited no physical breakdown or electrical exhaustion. Testing allowed us to push Mako to its limits, leading to a final product that was ultimately effective, safe, and appealing to potential consumers.

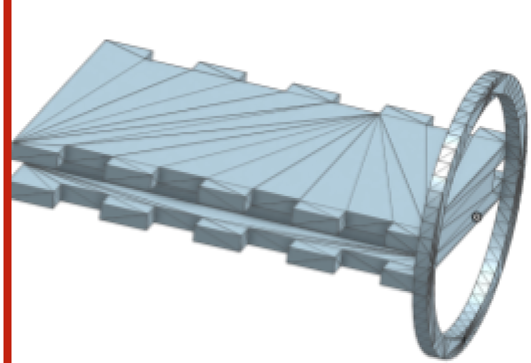

Figure 23: CAD design for electronics tray, via OnShape

Accounting

Budgeting

Income				
				Amount
Sidwell Friends School Grant				$1,000.00
Budgeting				
Category	**Type**	**Description/Examples**	**Projected Cost**	**Budgeted Value**
ROV Frame	Partially Reused, Partially Purchased	Acrylic frame, Watertight enclosure	$400.00	$400.00
Propulsion	Reused	T100 and T200 Thrusters	$800.00	$0.00
Tether	Reused	Fathom Tether	$245.00	$0.00
Microprocessor + Microcontroller	Partially Reused, Partially Purchased	Arduino Mega, Raspberry Pi 5	$150.00	$100.00
ROV Control System	Purchased	Playstation controller	$100.00	$100.00
Sensor	Purchased	Accelerometer, Cameras	$100.00	$100.00
Non-ROV device	Purchased	Buoyancy engine, Watertight enclosure	$250.00	$300.00
Travel Expenses	Donated	Transportation, housing, food	$11,200.00	$0.00

Project Costing

Product	Quantity	Category	Purchased/Reused	Amount spent	Estimated market value
ROV					
Acrylic Sheet - 0.220 in.	2	ROV Frame	Reused	$0.00	$175.96
Fathom ROV Tether	1	Tether	Reused	$0.00	$245.00
Newton Subsea Gripper	1	Intake	Reused	$0.00	$680.00
Watertight Enclosure for ROV/AUV (6″ Series)	1	ROV Frame	Purchased	$200.00	$200.00
End Cap - Aluminum 5xM10 hole	2	ROV Frame	Purchased	$110.00	$110.00
T100 Thruster	4	Propulsion	Reused	$0.00	$476.00
T200 Thruster	2	Propulsion	Reused	$0.00	$516.00
Adafruit TDK InvenSense ICM-20948	1	Sensor	Purchased	$14.95	$14.95
Arduino Mega 2560	1	Microcontroller	Reused	$0.00	$49.65
Raspberry Pi 5	1	Microprocessor	Purchased	$80.00	$80.00
Playstation 5 DualSense Controller	1	ROV Control System	Purchased	$74.99	$74.99
Logitech C270 Camera	3	Sensor	2 Reused, 1 Purchased	$24.99	$74.97
Non-ROV Device					
ESP8266	1	Microcontroller	Purchased	$7.99	$7.99
NEMA 17 Stepper Motor	1	Buoyancy Engine	Purchased	$13.99	$13.99
Dome - Optically Clear Acrylic	1	Hull	Purchased	$40.00	$40.00
Watertight Enclosure Cast Acrylic Plastic -- 300mm (11.8')	1	Hull	Reused	$0.00	$230.00
End Cap - Aluminum 5xM10 hole	1	Hull	Reused	$0.00	$34.00
400 Point Solderless Breadboard	1	Electronics	Purchased	$1.17	$1.17
4 AA Battery Holder	2	Electronics	Purchased	$5.98	$5.98
Duracell Rechargeable AA Batteries, 4 Count Pack	2	Electronics	Purchased	$26.78	$26.78
Bar02 Ultra High Resolution 10m Depth/Pressure Sensor	1	Sensor	Purchased	$75.00	$75.00
I2C Level Converter	1	Electronics	Purchased	$28.00	$28.00
500mL syringe	1	Buoyancy Engine	Reused	$0.00	$3.33
Miscel. (DONATED)					
Travel Expenses	7	Miscellaneous	Donated	$11,200	N/A

Budget Grant	**$1000.00**
Projected Expenses	**$1000.00**
Total Actual Expenses	**$703.84**
Total Estimated Market Value	**$3163.76**
Selling Cost	**$3499.99**

Conclusion

Acknowledgments

We would like to express our heartfelt thanks to the MATE ROV competition for providing us with this exciting educational opportunity. We thank Sidwell Friends School for access to lab space, equipment, and generous funding. We are especially grateful to our mentors—Darby Thompson, Martin Suresh, and Sam Blazes—for their time, patience, and invaluable guidance. We would also like to thank the Abrams family for kindly offering their pool for ROV testing purposes. Thank you all for supporting Future Gadget Lab; we could not have done this without you.

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