geneseas

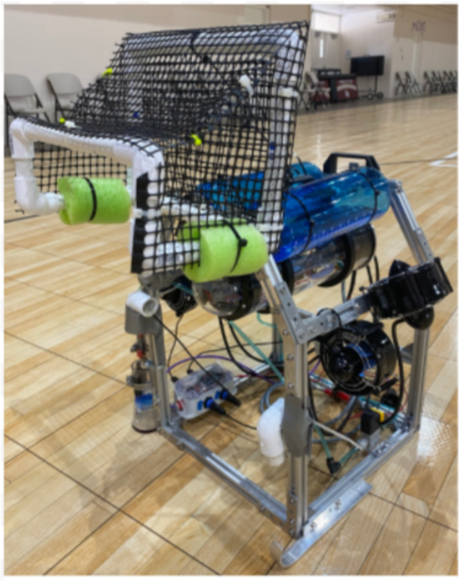
ST. FRANCIS
FEMBOTS

~enhydra~

St. Francis Catholic High School
Sacramento, CA, USA

Competition Team Members	Roles
‘21- Riley Glenn	CEO
‘21- Olivia Hazeghazam	CFO
‘22- Meredith Garcia	Lead Mechanical Trainer, Structural & Flotation Designer
‘22- Lauren Jones	Lead Software Developer & Trainer
‘23- Morgan Jones	Pneumatic System Designer & Advanced Tool Developer
‘23- Norah Zhou	Tether Manager & Advanced Tool Developer
‘24- Lauren Grindstaff	Manufacturing & Mechanical Support
Kitara Crain	Coach
Maurice Velandia	Coach

Crew:
Jaedyn Alford ’22, Sophie Harris ’23, Lily Kilgore ’23, Allie Dinh ’23, Ava Warren ’23, Emily Kroettinger ’23, Emmy Asperger ’23, Alicia Del Toro ’24, Elise Blomquist ’24, Evelyn Cortez ’24, Isa Gutierrez ’24, Jiana Reyes ’24, Reese Lopez Fahrenholz ’24, Siena Marois ’24



Enhydra

Geneseas Team

Table of Contents

I. Introduction

A. Abstract

Geneseas' second innovation, *Enhydra*, is an underwater Remotely Operated Vehicle (ROV) designed to perform a variety of tasks within global oceanic and freshwater environments like the Delaware River and Bay. *Enhydra* is equipped with tools capable of tackling the ubiquitous problem of plastic pollution, reducing the consequences of climate change on coral reefs, and maintaining healthy waterways.

Geneseas is a three-year old company, however, our twenty-person workforce has several years of experience producing robots. *Geneseas* is a female-operated company with the skill to produce custom-designed ROVs to meet specific requests. All designs are produced using advanced manufacturing capabilities, including precision machining with a Computer Numerical Control (CNC) mill and 3D printing. *Geneseas'* employees worked in small teams to create specific parts of *Enhydra* and to integrate their features to create a reliable ROV. We are excited to diversify our portfolio with the production of *Enhydra*.

Enhydra is the result of months of planning, research, analysis, manufacturing, and testing under strict safety protocols. This ROV was designed to meet specialized size, weight, and power requirements. Its features, in addition to dynamic thrust reconfiguration and multi-functional tools, enable *Enhydra* to execute its tasks successfully and efficiently.

This technical document describes the design and development process that makes *Enhydra* the best ROV to assist the global community in tackling the real-world problems of plastics in our ocean, climate change's impact on coral reefs, the consequences of poor environmental practices on our inland waterways, and to fulfill MATE's Request for Proposals (RFP).

II. Design Rationale

A. Design Evolution

Enhydra is the second phase in the evolution of *Geneseas'* product line. *Geneseas* designed *Enhydra* by drawing upon our experience from other ROVs tailored to meet customers' needs and from the company's previous year's performance. Analyzing the successes and shortcomings of our previous ROV and researching new designs enabled employees to make significant improvements to the ROV.

The company focused on three design principles: simplicity, serviceability, and reliability. Every manufacturer must consider make versus buy decisions during the product development process. *Geneseas* considered this decision for each component using a matrix that weighed the cost, time, and capability of the company to build the part. To maximize *Enhydra's* simplicity and reliability, *Geneseas* chose to buy and integrate versus custom build when components required special manufacturing processes that exceed *Geneseas*' manufacturing capability and experience. With our company's limited womanpower and industry knowledge, we believe this approach would produce a competitive ROV for your consideration.

Geneseas integrated component-level testing thoroughly into our design and development testing processes, such as the water tightness of our electronics housing. This ensures that when we operate *Enhydra* in the water, the electronics remain safe.

A test-bench (identical to *Enhydra*'s electronics) was also created to assist employees with troubleshooting and testing software and electrical systems before integration onto *Enhydra* was completed. This test-bench allowed for parallel development of electronics, software, and mechanical departments.

Since it is *Geneseas*' second year in the Marine Advanced Technology Education (MATE) competition, most of our former concepts were utilized and built off of. For example, *Geneseas* reused the T-slotted aluminum extrusion frame material used in our previous ROV, *Vaquita*. This material's slotted design allows for easy adjustments and mounting. Design review was completed on two key areas that needed improvement based on our performance the previous year; maneuverability and the vision system. Maneuverability, thruster design, programming, and weight design were reevaluated and improved. The vision system has changed from a self-made multiplexer to a 4 channel video board.

Enhydra's systems and features are discussed in detail in the following sections.

B. Mechanical Design and Manufacturing Process

The mechanical design of *Enhydra* began with the company brainstorming ideas for the core ROV on whiteboards and paper. Key points of consideration included size, weight, safety, simplicity, serviceability, reliability, manufacturability, and cost. Then, to decide between designs for the tools, *Geneseas* employees utilized a matrix to select the design that best fit the RFP requirements. That design was then delegated to a *Geneseas* employee who oversaw the prototyping, completion, and integration of that component into the software, mechanical, and electrical systems.

The manufacturing process started with an employee prototyping the component out of cardboard to test whether the component would perform the task as designed while meeting the desired design principles, like size requirements and efficiency. Once the component was ready for preliminary manufacturing, a detailed design was created using Computer-Aided Design (CAD), pen and paper (Figure 1), and plastics. After this model was tested and approved, the part was manufactured either on the CNC mill or by hand using a 2D pattern. To produce a component on the CNC mill, the CAD models were converted into "G-code" tool path files using EstlCam, a Computer-Aided Manufacturing package. The "G-code" was then loaded into the CNC's control software. Components not suitable for the CNC mill were manufactured by a *Geneseas* employee who took 2D patterns from CAD and glued them to the appropriate material as a guide for cutting and drilling.

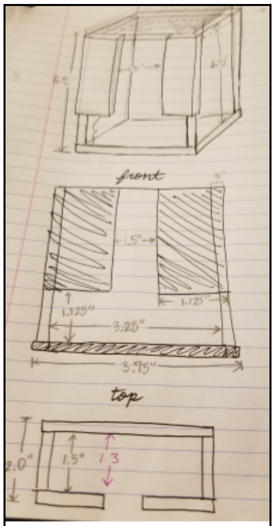


Figure 1. A detailed design of the frame on pen and paper, before CAD.

C. Mechanical Components

Frame

Geneseas chose 20 x 20 mm extruded aluminum[1] for the frame of *Enhydra* (Figure 2) because it is cost-effective and makes construction simple and efficient. This versatile material allowed *Geneseas* to adapt the design of the frame as needed for tools. The outer frame of *Enhydra* is a 35.56 x 53.34 x 48.26 centimeter rectangle with a trapezoidal top made using T-slotted aluminum extrusion and was designed to meet the RFP's strictest size requirements. Additional horizontal bars on either side of the ROV are rotated thirty degrees and make up the base of the trapezoidal top. This design choice allowed for the optimization of the three main areas: the top trapezoidal half, the thruster mounts, and the bottom rectangular half.


Figure 2: Frame

The top half of the frame was designed to establish underwater stability by placing major buoyancy components high on the ROV. The slotted extrusion frame allowed *Geneseas* to design two custom high-density polyethylene (HDPE) electronics housing cradles that can be precisely adjusted for stability. This design aspect places the buoyancy component of the electronics housing high in the ROV structure. Furthermore, this creates a large area in the lower half of *Enhydra* for the placement of tools.

In addition, the slotted frame allows the aluminum thruster mounts to increase the stability and versatility of the ROV. The thruster mounts are secured to the rotated bars on either side of the ROV, making the center of buoyancy and the center of thrust close to each other. These bars are rotated thirty degrees.

Finally, this design allowed the bottom half of the ROV to maximize tool space. This area holds the mission video system, the pneumatic system, and the tools made by *Geneseas'* employees.

As a safety measure, all of *Enhydra's* frame corners are rounded off to prevent sharp corners from injuring any team members servicing or repairing it. There are two handles mounted to the top of *Enhydra* to aid in the deck crew's retrieval. A carabiner also connects to the back handle, which provides a strain relief point and ensures that the tether cannot pull out of the ROV.

Electronics Housing

Enhydra's electronic components are enclosed in a Blue Robotics [2] watertight acrylic tube with a diameter of 10.16 cm and a length of 29.85 cm. *Geneseas* chose this enclosure because the transparency of the clear acrylic tube allows for an easy and quick visual inspection of the electronic components within the housing. In addition, at the bow, *Geneseas* chose a Blue Robotics acrylic dome end cap, which allows for larger visibility for the camera mounted at the end of the internal tray. This design choice makes it easier to navigate *Enhydra* underwater using the front-facing camera in the dome end cap.

For the stern of the enclosure, *Geneseas* chose to make-versus-buy an endplate to provide *Geneseas* the freedom to optimize connectors layout (Figure 3). This custom-designed aluminum end plate was engineered to fit the Blue Robotics tube while providing eleven holes for connectors. The center and top hole contain two

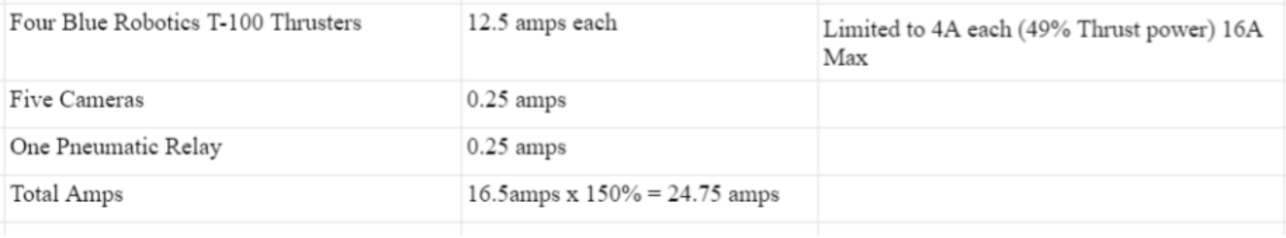
SubConn connectors, which were bought-versus-built for their efficiency in passing video, power, and communications from the Remote Piloting Station (RPS) to the ROV. The other eight holes contain Blue Robotics penetrators, which were bought-versus-built for their watertight connection between the electronics inside the housing and the thrusters, tools, and camera systems on the ROV. The test plug, which occupies one of these holes and is labeled with "OK," allows for the enclosure to be deemed airtight before being placed in the water with a simple vacuum test. This vacuum test checks if the enclosure maintains a steady vacuum for a predetermined amount of time.

Inside the housing, *Geneseas* designed and manufactured a custom tray to maximize accessibility and safety over the originally purchased Blue Robotics tray. This buy-vs-build decision allows serviceability without the time-consuming removal of the flange system. Although *Enhydra* has only one tray, both sides of the tray are used. One side has the Electronic Speed Controllers (ESCs) and the camera, while the other side has the Arduino Mega Board. This design allows the tray to both be compact and hold all the necessary electrical components needed while allowing the ESCs and the signal components to be separated so that interference is limited. The ESCs are secured and mounted on a stand-off increasing airflow so they will not overheat. The camera is mounted at the end of the tray on a servo-driven mount, which rotates 180 degrees upward and downward; increasing the field of view of the main navigation camera. This makes it easier for the pilot to navigate the surroundings of the ROV.

Figure 3. Custom-designed aluminum end plate.

Thrusters

Geneseas designed *Enhydra's* thruster layout to maximize power efficiency and design simplicity. The ROV has four Blue Robotics T-100 thrusters, which are mounted in a modified arcade drive design[3]. *Geneseas* originally considered using six thrusters for *Enhydra* in order to use vector drive to navigate underwater. However, after considering the ROV size and power limitations (Figure 4), *Geneseas* employees decided that four thrusters would be the simplest, most efficient option. Because *Enhydra's* power is limited to 12 volts, *Geneseas* had to limit *Enhydra's* power to the four thrusters through programmatic controls.



Four Blue Robotics T-100 Thrusters	12.5 amps each	Limited to 4A each (49% Thrust power) 16A Max
Five Cameras	0.25 amps	
One Pneumatic Relay	0.25 amps	
Total Amps	16.5amps x 150% = 24.75 amps	

Figure 4. Power Budget

For design simplicity, two thrusters are mounted on the side for horizontal movement, and these horizontal thrusters are placed at the center of mass to prevent pitching. The other two vertical thrusters are mounted at thirty-degree angles, which directs the thrust away from Enhydra's tools and the bottom of the ROV, optimizing vertical movement. This thruster design allows the ROV to move forward, backward, up, down, and with slight left-right motion.

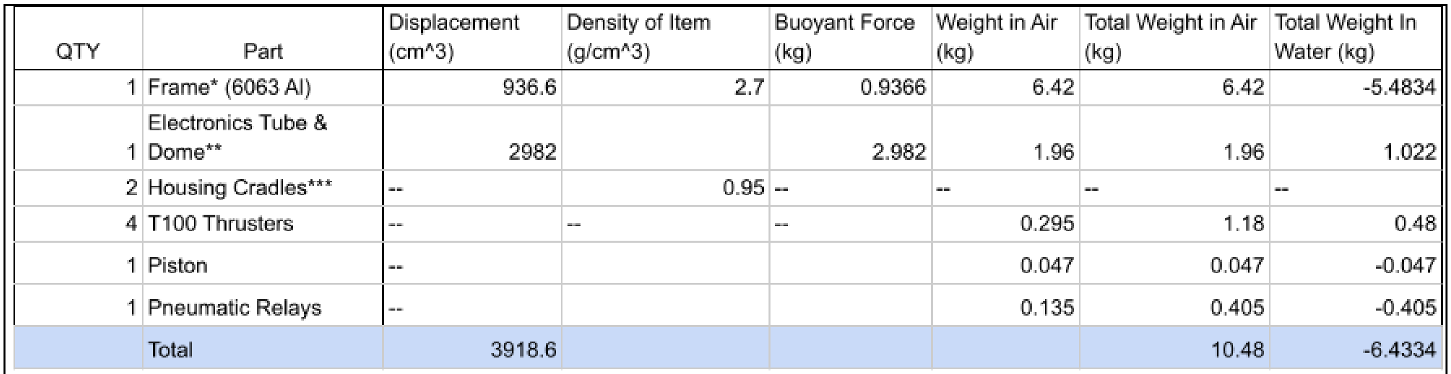
Additional safety features of *Enhydra's* thrusters include labels and thruster guards. Fan guards were modified to fit on either side of the thruster to become thruster guards. These thruster guards were tested and have a minimal effect on thrust. With thruster guards, the safety of officials and personnel is ensured.

To make movement easier and simplified, a variety of changes were made to the joystick. Joystick dead zones--areas around the center of a joystick that do not respond to movement--were tested to determine the most perfect values used by each 3-dimensional axis for ROV movement. When the joystick is in the default position, a power-limiting algorithm is executed and the thrusters do not turn on.

Geneseas developed and designed code so power could be managed better. We determined how much voltage is to be delivered to each part of the ROV and how much voltage would be lost through the wiring of the tether and ROV. This code is used so that when certain combinations of moving the joystick, power is cut from certain thrusters not needing to be used at the time. This enables the ROV to use more power towards its thrusters that need to be used at the time and to be able to maintain consistent movement.

Buoyancy

To regulate weight and buoyancy, *Geneseas* employees utilized a Buoyancy Calculator Spreadsheet. Employees created this spreadsheet using Archimedes' Principle [4] to calculate the displacement and buoyant force (Figure 5). The results aided in the determination of what material to use for different parts of *Enhydra*. Comparing the buoyant force to the weight of the ROV allowed us to look ahead and determine whether the ROV would be positively or negatively buoyant. At 2982 cm^3, the electrical housing is the largest buoyancy component.



QTY	Part	Displacement (cm^3)	Density of Item (g/cm^3)	Buoyant Force (kg)	Weight in Air (kg)	Total Weight in Air (kg)	Total Weight In Water (kg)
1	Frame* (6063 Al)	936.6	2.7	0.9366	6.42	6.42	-5.4834
1	Electronics Tube & Dome**	2982		2.982	1.96	1.96	1.022
2	Housing Cradles***	--	0.95	--	--	--	--
4	T100 Thrusters	--	--	--	0.295	1.18	0.48
1	Piston	--			0.047	0.047	-0.047
1	Pneumatic Relays	--			0.135	0.405	-0.405
	Total	3918.6				10.48	-6.4334

Figure 5. *Enhydra's* weight and buoyancy budget.

When the ROV was not neutrally buoyant, *Geneseas* employees adjusted the designs of different tools. For example, when the ROV was too light and not sinking, employees ran calculations through the buoyancy and weight charts to see if a certain piece could be changed from plastic to a heavier material like aluminum.

Stainless steel water bottles are attached along the length of the tether. The deck crew can adjust the position and buoyancy of the bottles to minimize the tether's effect on the ROV while also keeping the tether floating above the ROV. This prevents the tether from becoming entangled during ROV operations.

Located on the top of the ROV are two 2500 mL Nalgene water bottles. They are secured to the frame by zip ties. They have the potential to displace up to 3.2 kg of water. The amount of water the bottles displace is adjustable, as water can be added to the bottles by unscrewing the lids, which are easily accessible from the front of the ROV and allow high serviceability.

D. Electrical Systems

Remote Piloting Station (RPS)

Figure 6. Geneseas' RPS.

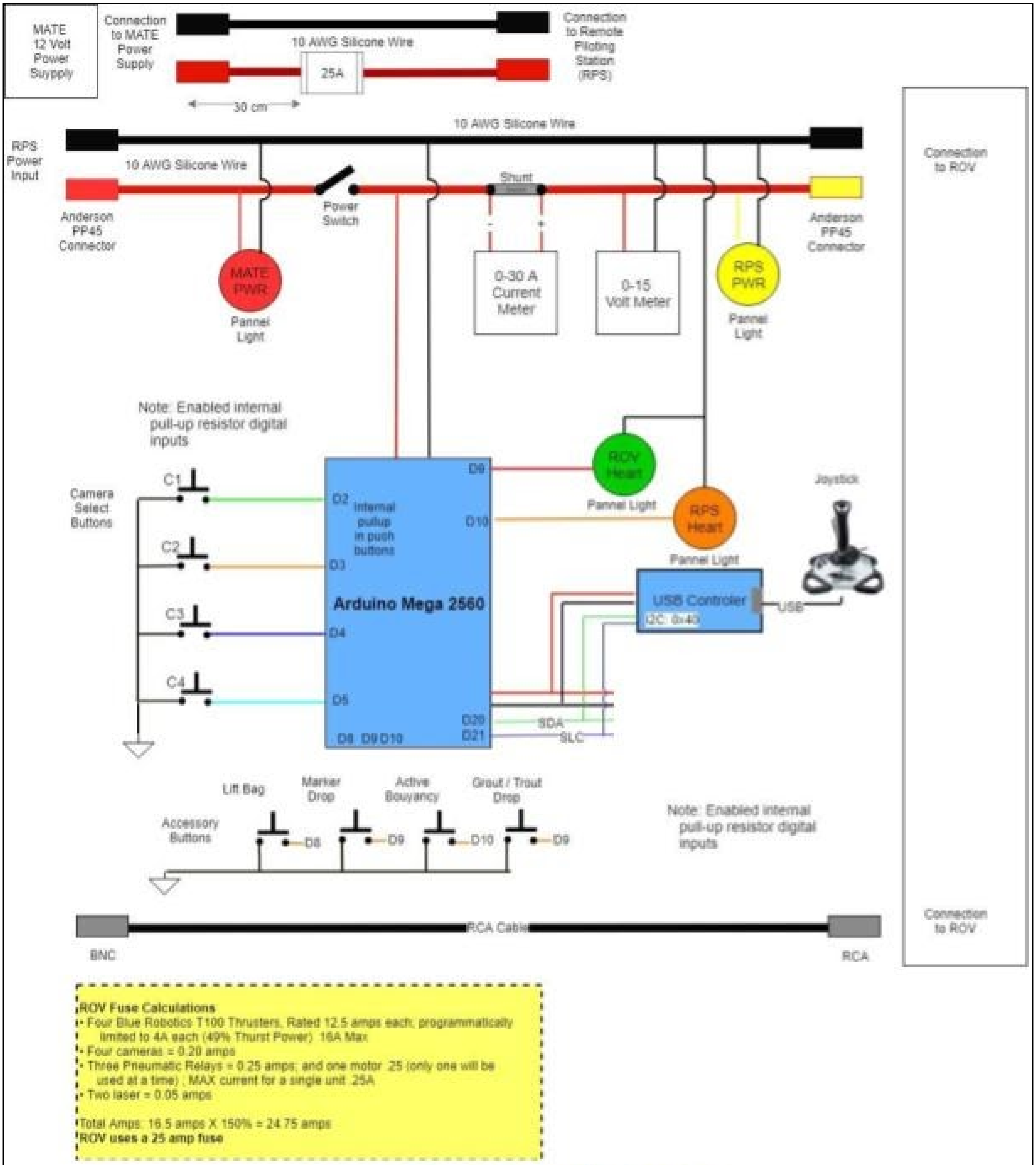
The Remote Piloting System (RPS) was designed using the key design principles of simplicity, serviceability, and reliability.

For reliability, the RPS was designed and built inside a DEWALT tough system ® DS130 toolbox. This configuration allows easy deck setup while protecting the RPS's components during transport.

For simplicity, *Geneseas* designed the RPS with industry-standard ports, quickly identifiable indicators, and an efficient layout. This layout consists of a top panel displaying voltage, amps, pneumatic system pressure, power, and ROV indicator lights. In addition, the top panel includes the emergency power switch and five buttons that allow the pilot to easily operate tools on *Enhydra*. The RPS also supports one monitor for the navigation camera, another monitor for mission cameras, and uses a USB joystick to control the ROV via the Arduino Mega. *Geneseas* employees made several layouts for the top panel of the RPS to check which one was the most efficient and useful.

For serviceability, the RPS was designed with a quick-release top that reveals the individually serviceable bottom panel. The bottom panel of the RPS holds the Arduino Mega, which is mounted with screw-in pin-outs. The bottom tier also contains the shunt for the amp meter, the USB connections and monitor connectors, the power connectors, the tether connectors, and all of the wiring for the top panel to the bottom compartment. We changed the length of the bottom panel from last year's RPS to enlarge it to 16 inches to create a more organized and easy-to-understand environment as well as having enough space for the video balun housing for our new camera system. The back of the RPS contains all the connections from the tether. These connections include Anderson Powerpole 45 for power, two 6.35mm (0.25 inch) pneumatics airlines, Mod 8 jack, and three CAT 6 ethernet connectors.

A testbench and System-Integration Design (SID) (Figure 7, see next page) were used to make sure that all the electronics in the RPS were wired correctly by using the test bench to stimulate the ROV.



Note: Enabled internal pull-up resistor digital inputs

Note: Enabled internal pull-up resistor digital inputs

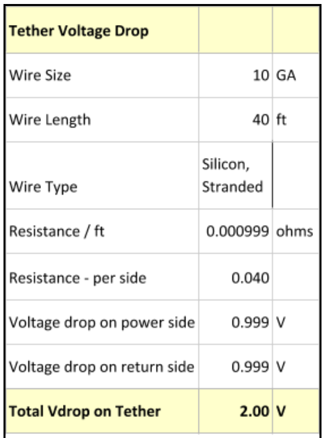
ROV Fuse Calculations
- Four Blue Robotics T100 Thrusters, Rated 12.5 amps each; programmatically limited to 4A each (49% Thurst Power) 16A Max
- Four cameras = 0.20 amps
- Three Pneumatic Relays = 0.25 amps; and one motor .25 (only one will be used at a time) ; MAX current for a single unit .25A
- Two laser = 0.05 amps

Total Amps: 16.5 amps X 150% = 24.75 amps
ROV uses a 25 amp fuse

Figure 7. RPS electrical SID.

Tether

Enhydra's tether was designed under the rationale of durability and serviceability. The tether includes signal, power, and pneumatic lines that run from the RPS to the ROV. The distance was determined by using a Voltage Drop Calculator (Figure 8) to find the optimal length, wire gauge, and wire type. *Geneseas'* employees determined the 10 gauge power cable needs to be 12 m to maximize the 25 amp fuse-limited current draw. As shown in Figure 8, the voltage drop across the tether is just under 2 V. This gives *Geneseas* efficient and reliable transfer of power and signals from the RPS to the ROV while providing enough length to reach the given tasks.



Tether Voltage Drop		
Wire Size	10	GA
Wire Length	40	ft
Wire Type	Silicon, Stranded	
Resistance / ft	0.000999	ohms
Resistance - per side	0.040	
Voltage drop on power side	0.999	V
Voltage drop on return side	0.999	V
Total Vdrop on Tether	**2.00**	**V**

Figure 8. Tether Voltage Drop Calculator.

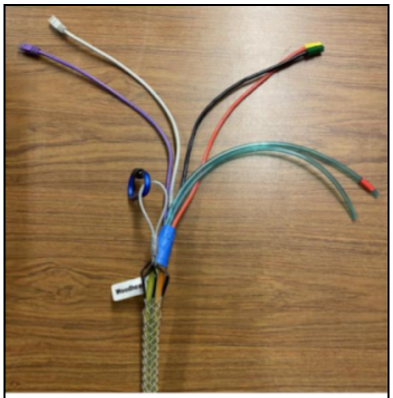


Figure 9. *Geneseas* tether containing 2 10 AWG power lines, 2 CAT 6 ethernet cables, and 2 6mm pneumatic line.

Enhydra's tether (Figure 9), includes a two-line closed-loop pneumatic system, which uses compressed air to transport air to the ROV's tools and back. *Enhydra's* tether uses two CAT 6 Ethernet cables; one to transmit serial data signals between the RPS and the ROV and for our navigation cameras, and the other for our mission cameras. The two category 6e ethernet cables are used to transmit serial data signals between the RPS and the ROV**.** The two 10 AWG silicone power lines maintain great flexibility while minimizing the voltage drop through the tether. With a projected 16.5 amp current draw from the ROV, it was necessary to select 10 AWG wire to maintain a minimum of 10 volts at the ROV. A durable woven nylon sheathing protects the tether components but allows disassembly if service is needed.

Electronics

Enhydra's electronic system was designed with the priorities of simplicity, serviceability, and reliability. The ROV electronic components include four Blue Robotics Electronic Speed Controllers (ESCs), Arduino Mega Board, 140-degree field of view camera, RS422 serial signal, four-channel video board, and solid-state relays.

Tether power was connected to the ROV electronics housing through SubConn connectors. This was a purchase decision due to the safety and reliability factor that manufactured connectors offer. The Arduino connects to the ESCs and to the four-channel video board through the Bulgin connector (outside of the housing) which powers the four mission cameras. The RS422 serial signal was selected to increase range and increase noise immunity between the ROV's Arduino and the RPS. The Arduino also connects to the silicon relays that control pneumatic solenoids and motors for the mission's tools. The main navigation camera connects to a video balun which converts the composite video signal to match the signal characteristics of the CAT 6 ethernet cable.

Geneseas tested the navigation camera on a testbench before mounting on the ROV and used the SID (Figure 10) to wire the components in the electronics tray correctly, as well as to go through testing and troubleshooting through this method. As development progressed, the SID and testbench were also updated. The testing showed the RS422 serial signal and the composite video could be transmitted over the same CAT 6 twisted pair cabling without interfering with each other.

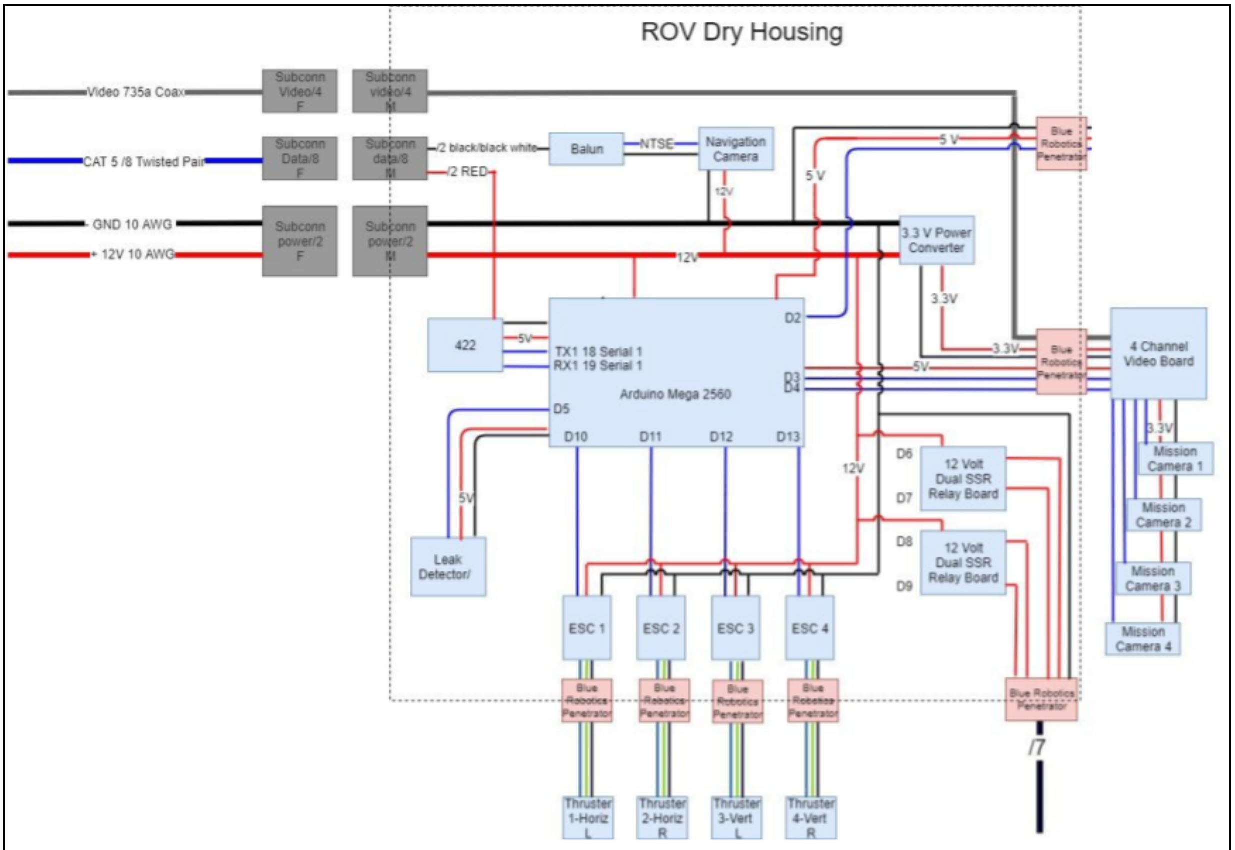


Figure 10. Electronics SID.

Submersible Connectors

Enhydra uses a combination of a two-pin SubConn power connector, an eight-pin SubConn Micro Circular connector, four Bulgin 400 series miniature power connectors, and eight Blue Robotics cable penetrators to successfully supply power and control signals through the tether to the ROV. Various SubConns were chosen according to their cost, size, and functionality. To minimize the power loss as much as possible, the company used each SubConn's power rating as the primary factor in deciding which SubConn's to use. Subconn connectors allow the ROV, RPS, and tether to be stored separately. This prevents damage to the ROV system components and makes transport easier. To reduce the cost of *Enhydra*, *Geneseas* decided to use the Blue Robotics cable penetrators for devices that are permanently attached to the ROV, such as thrusters. Lightweight, small, and affordable Bulgin connectors are used for accessory connections on the ROV.

E. Pneumatics

Enhydra's pneumatics system is used to power a single action spring return piston using air that is regulated on-deck to 2.76 bar (40 psi). The air is sent to the tools through a 6.35mm (0.25 inch) pneumatic line that was chosen over 3.18mm (0.125 inches) in order to increase the volume of air flowing to the ROV. A solenoid that acts as a safety valve is housed on *Enhydra* and can be controlled by the co-pilot via a button on the RPS. The solenoid is attached to a check valve, preventing the backflow of water. There is a 2/2 way valve located between the solenoid and the piston that has a small hole that releases air after the piston is deployed, allowing the piston to return to its original position. *Enhydra*'s pneumatics SID is shown in Figure 11.

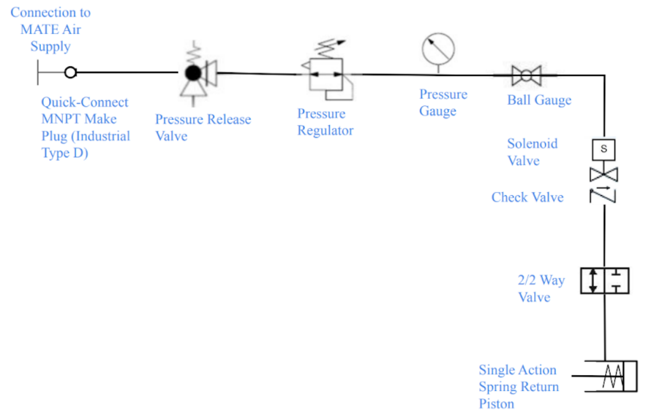


Figure 11. *Enhydra's* Pneumatics SID

F. Top-side and Bottom-side Software

Both the top-side and bottom-side platforms are programmed in C/C++ language on Arduino Mega 2560 controllers, which are in constant communication with one another. A continuous heartbeat, or blinking RPS light, signals that the ROV and the RPS are receiving and transmitting information. If communication is lost, *Enhydra* enters into safe mode until communication is reestablished. In safe mode, thrusters, actuators, and all other accessories are disabled.

As with last year, *Geneseas* purchased Arduino Megas for its software units. *Geneseas* decided to utilize the knowledge and experience acquired from the previous competition and explore Arduino software further. Purchasing Arduino Megas is more time and cost-efficient than building original software units, and using the same platforms for top-side and bottom-side limits complexity. The identical controllers allow for the utilization of EasyTransfer, through which the bottom-side and top-side platforms can easily receive and transmit packets to each other.

The RPS top-side platform reads joystick and button inputs from the RPS and displays telemetry data. Using such data, it executes primary calculations and transmits values to the ROV for thruster, controller, and actuator control. These processes include the conversion of joystick inputs to milliseconds and their transfer bottom-side to the ESCs. As a safety feature, the top-side software utilizes range-checking to limit thruster power draw.

This year, *Geneseas* has added power limiting functions, which allow for the conservation of power when the pilot is driving the ROV in a direction that does not need a certain thruster. For instance, if the pilot intends to drive up towards the surface, the power to the horizontal thrusters would be shut off and transferred to the vertical thrusters, allowing the ROV to smoothly drive through the water at a faster speed and not wasting power.

Taking user operation into consideration, *Geneseas* included a Pilot Inversion feature in the top-side software, to allow any side of the ROV to operate as the "front." The user can switch between front, back, port, and starboard orientations using four joystick buttons. Upon pressing one, the joystick input is reconfigured to correspond with the selected orientation. For instance, upon pressing the “port” button and moving the joystick forward, the ROV will move left, in the forward direction from the port side perspective.

The ROV bottom-side platform receives information from top-side to update its thrusters, controllers, and actuators. It employs arcade drive to control the ROV thrusters from a single joystick, allowing for smooth movement in the forward, backward, and vertical directions and for rotation left and right. It also reads data from the ROV’s temperature sensor and transfers it top-side.The Arduino Mega 2560s process control functions sequentially (Figure 12):

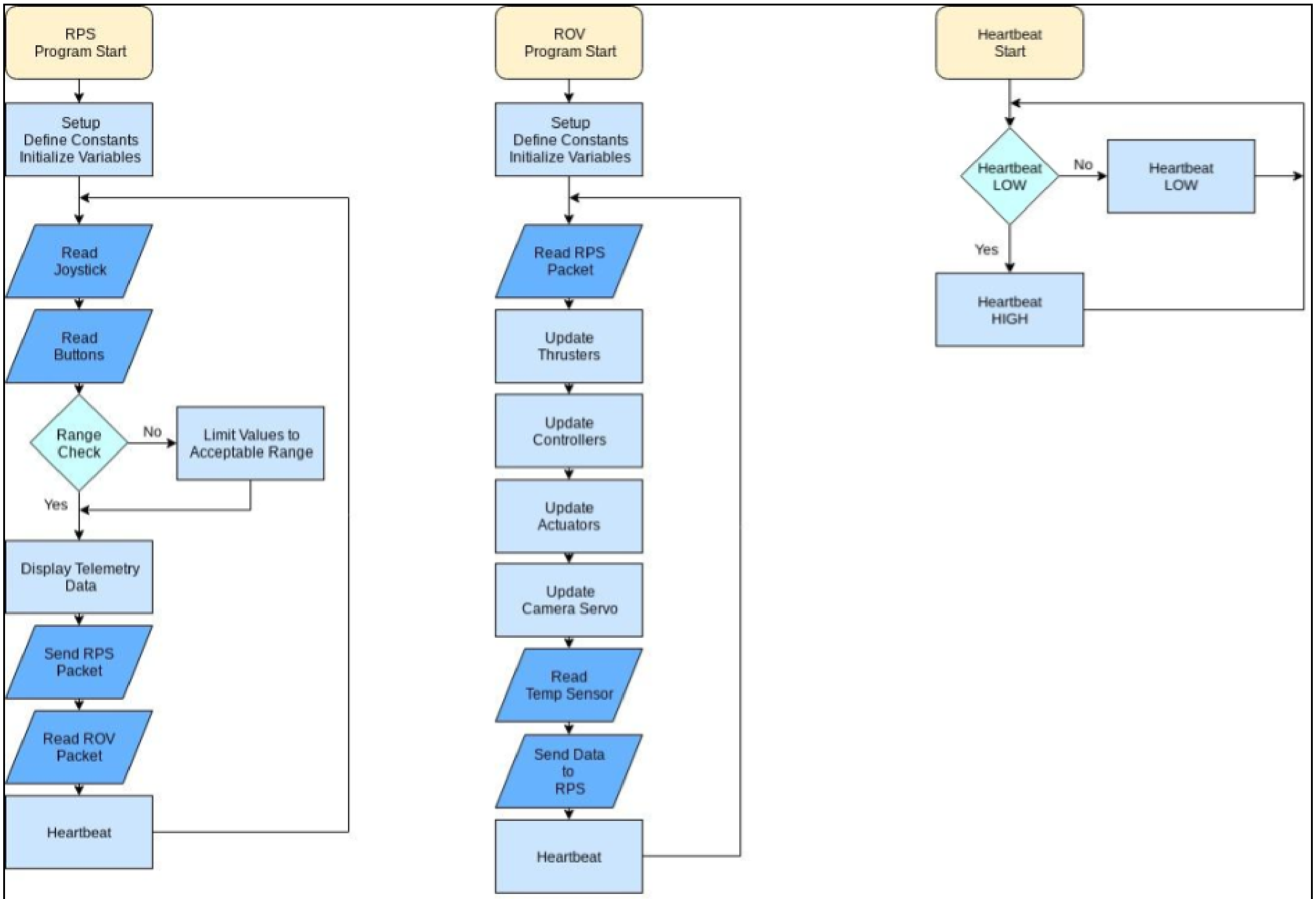


Figure 12. Software Flowcharts.

G. Mission Tasks

Hook

The hook is used to pull the Ghost Net pin, remove the Ghost Net from the water, cull the Sea Star outbreak, take the Sponge sample, deploy the Mussel Quadrat, and to remove and replace the Eel Traps. The hook is a simple aluminum bracket bent into a J shape. It is attached to the bottom of the frame and its position is adjustable to minimize the mission run time. This is one of *Enhydra*'s simplest and most versatile tools.

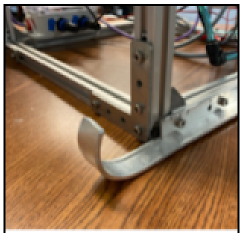


Figure 13: Hook

Ping Pong Ball Tool

For one of the tasks, *Geneseas* designed a contraption that allowed us to trap debris on the surface in an enclosed area. Our custom tool is made up of a heavy duty plastic mesh that is bent to create a unique triangular shape. This tool is attached to the front of the ROV. The tool works by moving over the debris and then trapping them in a higher area that prevents the debris from floating away when our ROV goes back underwater. When the ROV gets to the side of the pool, we can then successfully extract the floating debris.


Figure 14: Ping pong ball tool

Imaging Software

In order to autonomously stitch a photomosaic of the underwater subway car, *Enhydra's* camera system is able to take screenshots of the pilot's view under the water. A python program takes these screenshots and iterates through each, cropping them and uploading them to an Adobe Photoshop program. The algorithm uses two options: color coordination or it places each screenshot in order based on the order that the photos have been taken. The screenshots are then "stitched" together showing all four sides in a row with the colored tape matching on each edge. The user is able to move around the final components of the photoshop document, and then save to a .JPG file.

Ziploc Bag Tool

The Ziploc bag tool, meant to retrieve the debris from the bottom of the pool, was developed with a focus on simplicity. The main component of this tool is an adhesive glue set in a stamp pad. The glue pad is screwed into the bottommost extrusion of the ROV.

The Ziploc bag tool includes a bolt adhered to the base of the stamp pad. This allows for quick attachment and removal of the adhesive glue pad to the ROV. The pilot aligns the glue pad with the weighted Ziploc bag at the bottom of the pool. The glue pad will firmly adhere to the Ziploc bag, and the bag will be brought to the surface. A member of *Geneseas* will then retrieve the Ziploc bag by unscrewing the tool and taking it off entirely, and finally removing the bag from the adhesive glue.

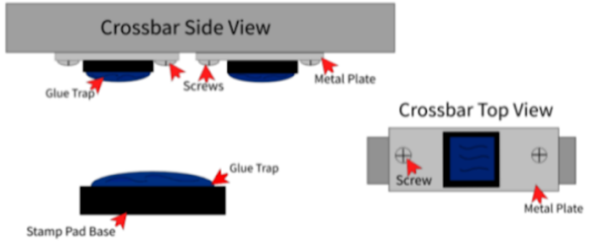


Figure 15: Ziplock Bag Tool

Coral Tool

Figure 16: Coral Tool

Geneseas developed the coral tool, meant to pick up and move coral fragments, with attention to size constraints and efficiency. The tool is mounted on the outer front right corner of the frame, which maximizes the pilot's depth perception. The coral tool can be broken down into three main functions: the maneuverability cone, the lined holder, and the ejecting piston (Figure 16).

A clear truncated cone at the base of the holder improves accuracy of the tool. The cone's base is the widest part, and narrows towards the top, which guides the fragment into the center of the holder.

The lined holder consists of an open-ended clear plastic cylinder with three brass wire brushes placed evenly along the width of the cylinder, held in place by an overlapping hose clamp. The hose clamp allows for the replacement of brushes as necessary. The wire brushes provide enough rigid support and friction against the fragment to firmly secure the fragment.

A single action spring return piston ejects the coral fragment into the outcropping. The piston is vertically mounted above the holder. A plastic spacer was fitted onto the bottom dead center of the piston's stroke, which ensures the fragment will eject straight down, away from the holder and the ROV.

III. Testing and Troubleshooting

Before integrating each component into the complete ROV, a *Geneseas* employee performed two different tests on the tool. The first test completed is a dry-prototype test, in which the prototype is tested with the prop, to show proof of concept. The tool was then built and tested with the prop underwater, but separate from the ROV. Once the tool was tested, any design changes were made, the device was then integrated into the ROV. The thrusters were also tested before being incorporated on the ROV. In a test tank, employees measured the thrust output of each thruster while monitoring electrical characteristics to ensure that the thrusters are consistent with each other and that none of them have any manufacturing defects. *Enhydra* was tested after each mechanism was added to ensure the two devices operate together correctly. This process isolates any problems to individual components as well as making integration of the ROV more efficient.

An example of a mission tool design issue was in the development of the coral tool. This tool went through various design iterations. Initially, an extending arm was going to be utilized to improve the pilot's accuracy. However, this design was too large to accommodate size and weight constraints, and employees determined that this aspect of the tool should be simplified as much as possible. Several different prototypes were tested until a truncated cone was chosen as the final accuracy component because of its simplicity and consistency. After the basic frame of the ROV was complete, the core ROV was pool tested to check the software and electronics systems. Parallel improvements of software, electronics and mission tools proceeded from this point. Once several tools were integrated onto the ROV, mission strategy and pool practice began. The objectives of testing were to correct any remaining mechanical and electrical flaws, improve pilot and crew operation, and test for reliability. As more tools were completed, leveling the ROV and adjusting the buoyancy became part of the ongoing integration process. This is where the adjustable frame design showed its value: the ability to move components along the extruded aluminum rails was a great asset, allowing for quick adjustments. The result of this work allowed the team to achieve nearly 30 hours of pool testing.

IV. Safety

A. Safety Philosophy

Safety is *Geneseas'* primary concern. The company values the safety of its employees, contractors, customers, and the public; thus it employs and enforces proper safety protocol in the development, testing, and operation of its products. The company educates its employees on back (lifting) safety, electrical safety, tool safety, hazardous materials handling, and housekeeping, and further extends this safety ethic to *Enhydra* and its aquatic environment through the safety features incorporated into the ROV design.

B. Lab Protocols

Geneseas requires its employees to practice basic safety by wearing close-toed shoes, tied hair, and PPE when machining, soldering, or working with the ROV. Safety glasses are a constant in the lab, and antistatic wrist straps, masks, and ear plugs are used accordingly.

As part of *Geneseas*' training process, mentors demonstrate safe usage of machines to new employees and supervise their use. Mentors instruct employees in properly securing equipment and parts, planning their work, and arranging their workspace to minimize the potential for accident or injury. Once new employees have demonstrated the ability to safely and responsibly operate the machines, they are permitted to work independently. Nonetheless, employees remain vigilant in policing each other to ensure everyone's safety.

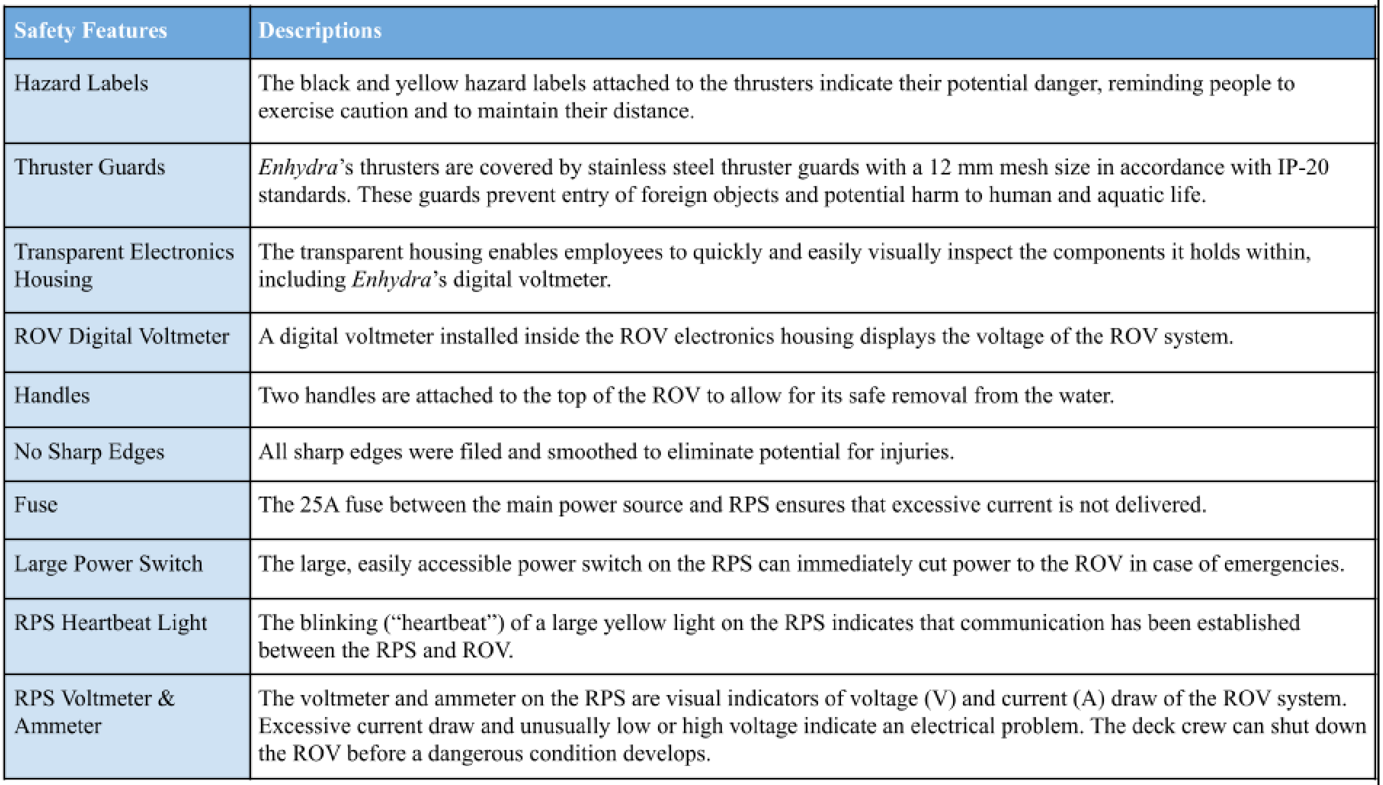
When working near water, employees exercise electrical safety by keeping electrical cords and electronic devices away from moisture. Only the tether is allowed on the pool apron, and the ROV is thoroughly dried after operations. The RPS, laptops, and pilot station are kept on an elevated platform.

Geneseas further maintains a safe work environment for its employees in the company's lab facility, which features a chemical vent hood that reduces employees' fume exposure while soldering. *Geneseas* also strives to maintain an organized workspace to ensure the efficiency and safety of all its employees. Upon finishing a task, employees promptly discard waste materials, scraps, and return tools and reusable materials to their proper places.

Though *Geneseas* ensures that first aid kits and fire extinguishers are readily available, the company aims to minimize their usage with preemptive safety measures.

C. Vehicle Safety Features

Enhydra's many safety features testify to *Geneseas*' integration of safety into its design process. The safety features incorporated into the ROV and RPS serve to prevent accident and injury and enable swift response to potentially dangerous situations.



Safety Features	Descriptions
Hazard Labels	The black and yellow hazard labels attached to the thrusters indicate their potential danger, reminding people to exercise caution and to maintain their distance.
Thruster Guards	*Enhydra*'s thrusters are covered by stainless steel thruster guards with a 12 mm mesh size in accordance with IP-20 standards. These guards prevent entry of foreign objects and potential harm to human and aquatic life.
Transparent Electronics Housing	The transparent housing enables employees to quickly and easily visually inspect the components it holds within, including *Enhydra*'s digital voltmeter.
ROV Digital Voltmeter	A digital voltmeter installed inside the ROV electronics housing displays the voltage of the ROV system.
Handles	Two handles are attached to the top of the ROV to allow for its safe removal from the water.
No Sharp Edges	All sharp edges were filed and smoothed to eliminate potential for injuries.
Fuse	The 25A fuse between the main power source and RPS ensures that excessive current is not delivered.
Large Power Switch	The large, easily accessible power switch on the RPS can immediately cut power to the ROV in case of emergencies.
RPS Heartbeat Light	The blinking ("heartbeat") of a large yellow light on the RPS indicates that communication has been established between the RPS and ROV.
RPS Voltmeter & Ammeter	The voltmeter and ammeter on the RPS are visual indicators of voltage (V) and current (A) draw of the ROV system. Excessive current draw and unusually low or high voltage indicate an electrical problem. The deck crew can shut down the ROV before a dangerous condition develops.

Figure 17. Vehicle safety features table.

In addition to these safety features of the ROV and RPS, employees organize and label the components and wires to make inspection, maintenance, and serviceability more efficient.

D. Operation and Safety Checklists

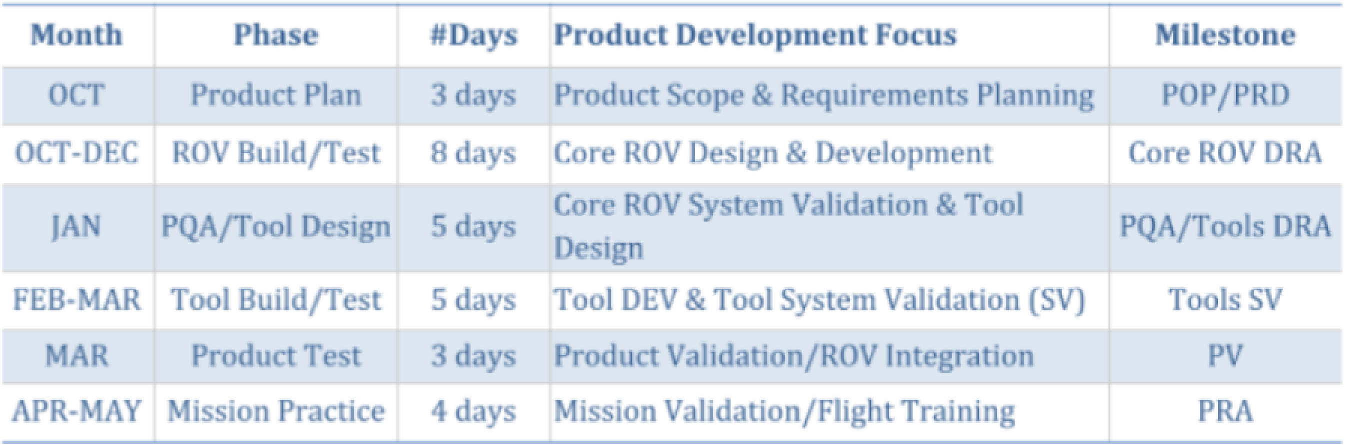
Geneseas has developed and utilizes operation and safety checklists (Appendix A) to ensure the safety of employees, customers, and bystanders/onlookers in the launch, operation, and retrieval of *Enhydra*.

V. Logistics

A. Scheduled Project Management

Geneseas used a project management process to assist with managing work assignments and overall project timelines. This year, *Geneseas* created an online hierarchical macro schedule for the overall production of the ROV. This schedule has lanes for each subsection of the ROV, which allows project leads to manage the progress of their individual components and optimizes the product development Plan, Build, Test, & Release (PBTR) process.

In addition, *Geneseas* held a stand-up meeting both at the beginning and at the end of each meeting in order to assess *Enhydra's* development and the production of the ROV's features and to assign new tasks. Instead of splitting up tasks based on specialties, we divided up subsystems, so each employee was in charge of a different section of the ROV, whether frame, electronics housing, thrusters, tools, or tether. Between workdays, employees continued to work on any daily production goals that were not met.



Month	Phase	#Days	Product Development Focus	Milestone
OCT	Product Plan	3 days	Product Scope & Requirements Planning	POP/PRD
OCT-DEC	ROV Build/Test	8 days	Core ROV Design & Development	Core ROV DRA
JAN	PQA/Tool Design	5 days	Core ROV System Validation & Tool Design	PQA/Tools DRA
FEB-MAR	Tool Build/Test	5 days	Tool DEV & Tool System Validation (SV)	Tools SV
MAR	Product Test	3 days	Product Validation/ROV Integration	PV
APR-MAY	Mission Practice	4 days	Mission Validation/Flight Training	PRA

Figure 18. ***Geneseas'*** **general monthly schedule.**

B. Budget and Project Costings

At the beginning of each season, *Geneseas* prepared a budget based on the prior year's expenses from our previous competition robot, team transportation, and competition meal expenses. This year, the company budgeted for spare parts (Arduino boards, daughter boards, thrusters, etc.) and small tools that they would need for MATE. By budgeting for spare parts, it allowed team members to learn and make mistakes.

Income was estimated based on funding from St. Francis Catholic High School and team member travel dues. To ensure effective use of a limited budget, all purchases are submitted as a Google purchase request form for review and approval by coaches. Receipts of new parts and all reused parts for *Enhydra* are entered into a project costing sheet each month and tracked against the budget. The 2020-2021 Budget and Project Costing report is shown in Figure 19.

Income	**Budget**	**Type**	**Production & Operations Budget & Cost Analysis**	**Project Cost**	**Difference**
St. Francis School Funding	$ 12,000.00	Income	Available Income	$ 13,500.00	
Employee Travel Expenses*	$ 1,500.00	Income	Production ROV Costs	$ 5,876.63	$ 2,173.37
Total Income	**$ 13,500.00**		Spare Parts & Tools	$ 667.19	$ 2,332.81
			Operations Costs*	$ 2,068.65	$ 881.35
*6 Employees *$250			**Funds Under/ (Over) Budget**	**$ 4887.53**	
Production Expenses	**Budget**	**Type**	**Description**	**Project Cost**	**Difference**
Frame & Housing	$ 1,000.00	Purchased	20x20 strut, hardware, Blue Robotics Tube dome, etc	$ 555.56	$ 444.44

Thrusters	$ 800.00	Purchased	4 T-100 Blue Robotics Thruster and ESC	$ 563.76	$ 236.24
RPS (Remote Piloting Station)	$ 1,000.00	Purchased	Dewalt box, Gauges, wire, buttons, connectors	$ 768.42	$ 231.58
Tether & Connectors	$ 1,000.00	Purchased	3 SubConn Connectors, wire, CAT 6, Pneumatic tubing	$ 865.66	$ 134.34
Electronics & Connectors	$ 1,000.00	Purchased	Electrical boards and chips, sensors	$ 899.04	$ 100.96
Electronics Rework	$ 100.00	Purchased	Extra wires, connectors, daughter boards		$ 100.00
Pneumatics	$ 400.00	Purchased/ Reused	Values, fittings, Piston (reused)	$ 389.01	$ 10.99
Mission Tools	$ 1,500.00	Purchased/ Borrowed	Laser & temperature probe were borrowed, all plastics, metals, motors, magnets were purchased	$ 635.24	$ 864.76
General Supplies	$ 750.00	Purchased	Glues, hardware, solder	$ 698.36	$ 51.64
Raw materials	$ 500.00	Purchased	Stock Material	$ 501.58	$ (1.58)
Raw materials		Donated	Polycarbonate, HDPE and Acrylic Plastics		
Production Budget	**$ 8,050.00**		**Total ROV Production Cost**	**$ 5,876.63**	**$ 2,173.37**
Spare Parts & Tools	**Budget**	**Type**	**Description**	**Project Cost**	**Difference**
Spare Parts	$ 1,500.00	Purchased	2 T-100 Thrusters, Electronics tray, o-rings, Arduino, ESC	$ 315.06	$ 1,184.94
Tools	$ 1,500.00	Purchased	soldering supplies, vacuum seal tool, etc	$ 352.13	$ 1,147.87
Spare Parts & Tools	**$ 3,000.00**		**Spare Parts & Tools**	$ 667.19	**$ 2,332.81**
Operations Expenses	**Budget**	**Type**	**Description**	**Project Cost**	**Difference**
Competition Meals	$ 600.00	Purchased	10 people *$15/meal*4	$ 600.00	$ -
Transportation & hotel subsidy	$ 1,200.00	Purchased	6 rooms *1 night*$200 (actually only needed 4 rooms)	$ 655.88	$ 544.12
Uniforms	$ 300.00	Purchased	T-Shirts for team and mentors	$ 259.15	$ 40.85
Mission Props	$ 400.00	Purchased	MATE mission props	$ 198.62	$ 201.38
MATE Entry Fee	$ 250.00	Purchased	MATE entry fee	$ 200.00	$ 50.00
Power Fluid Quiz Fee	$ -	Purchased	MATE power fluid quiz	$ 15.00	$ 15.00
Marketing	$ 200.00	Purchased	Report copies, display, brochure printing & software cost	$ 140.00	$ 60.00
Operations Budget	**$ 2,950.00**		**Operations Project Cost**	**$ 2,068.65**	**$ 881.35**
Total	**$ 13,500.00**			**$ 8,612.47**	**$ 4,887.53**

Figure 19. 2020-2021 *Geneseas'* budget and project costing.

VI. Conclusion

A. Challenges

Although our team has participated in robotics competitions before, it was only our third year working with MATE Robotics. With this in mind, *Geneseas* employees heavily researched the Jesuit High School team, as they are nearby and have many seasons of experience in MATE. *Geneseas* employees were not shy in seeking advice and mentoring from the Jesuit High School team and its mentors. A major challenge to the design of our ROV was that we were restricted to significantly less power at 12V and 25A than our mentor Explorer team. This power design constraint strongly influenced our design choices as we were required to make big design changes early on when it was determined that we would be operating at significantly lower power than our mentor team. This constraint influenced our thruster configuration and quantity (from 6 to 4) and our tether length (from 18.3 meters to 12 meters). We discovered that this power limit would not allow us to use our original vector drive design with six thrusters. After a mentor explained to us how power is calculated, we determined that our ROV can only supply power to four thrusters. Furthermore, we learned that we could narrowly use four thrusters because we do not have enough power for our thrusters to run at full power. This required us to use software to limit the thruster power use to remain within the power budget. In addition, the limited power caused us to make the ROV as small and light as possible to maintain mobility.

Geneseas' members decided with this switch to MATE, work should be done at Jesuit, since we did not have any mentors that could teach us the necessary information to be successful in MATE. It proved difficult to keep our supplies and equipment separated from Jesuit while sharing a common lab and workspace. We resolved this challenge by bringing over our own hand tools. Jesuit graciously lent us two large carts to store supplies and components for the ROV. All components were marked with a “SF”. We then grouped components by subsystems of the ROV. These procedures allowed us to maintain an organized environment, and minimized inefficiency within the workplace.

Another challenge we faced was distance learning because of COVID-19. For the last half of the 2019-2020 school year, due to the sudden quarantine and stay-at-home order, we were unable to meet and continue testing the ROV. Additionally, just after the COVID-19 pandemic started, we learned our coach was leaving at the end of the 2019-2020 school year. Trying to find a new coach in the middle of the pandemic and creating new team synergy during this distance learning phase was difficult. However, the team worked together to find a new coach and were focused on bringing our company back together under new leadership. It took several months to find a new coach and begin the process of bringing the team together again. Our team was unable to meet for several months and when we were finally able to meet in November, we had to do so virtually over Zoom. Due to the uncertainty of the virus, we had to be innovative and discover new ways to design and prototype new tools online. As a result, we started using applications such as Fusion360 and sketch.io to map out blueprints of possible tools. Then, using basic household items, we tested some designs in our own kitchens, bedrooms, and home pools, determining the functionality and feasibility of the design.

B. Lessons Learned

Geneseas employees developed many technical skills, including programming and electronics skills. With the switch to MATE, employees learned C, C++, Python, and had to decide on electrical components. This was a challenging endeavor to overcome during which many technical lessons were learned. Mentors and coaches provided valuable lessons on the programming and electrical systems, allowing team members to learn how to properly program and wire their electronics.

A non-technical lesson learned was to balance the team workload. *Geneseas* delegated tasks based on subgroups, focusing on specialties such as frame, electronics housing, programming, vision system, thrusters, tools, and tether. Within these subgroups, employees learned the value of engineering design processes, including independent idea formulation followed by team collaboration to weigh strengths and weaknesses of various design ideas. Subgroups also taught the importance of accountability, and communication between various subgroups. For example, members of tool groups had to communicate their needs to both the programming and vision systems members. *Geneseas* employees successfully facilitated communication, and created a productive and efficient working environment.

C. Future Improvements Reflection

A future improvement we plan to make is creating a formal management system to ensure we are on track in our production process. Although we used the PBTR task board early in the process, we later shifted away from this task board and towards a more general monthly schedule and a loose daily schedule. Using the flexible sticky-note PBTR task board would have allowed employees to move tasks around when needed and to easily visualize the schedule as it fluctuated. In the future, we can also record who is in charge of each task in order to establish a stronger sense of ownership and responsibility of a task. By organizing a better production schedule using this PBTR task board, we could allow for more practice time to improve our ROV.

D. Acknowledgments

- MATE Center and Marine Technology Society: Sponsoring this year's competition
- MATE II: Sponsoring this year's competition
- National Science Foundation: Their funding of the MATE competition
- Oceaneering International: Their support of the MATE competition
- St. Francis Catholic High School: Generous donation of funding, support, and laboratory space
- Jesuit High School: Pool time and facilities
- Coaches: Kitara Crain and Maurice Velandia: Their time, experience, dedication, knowledge and guidance
- TAP Plastics: Donation of stock plastic
- SolidWorks: Donation of SolidWorks 3D Software
- MacArtney Connectors: Providing connectors at a reduced rate
- Our Families: Their continued support and encouragement

E. References

Blue Robotics. “T100 Thruster Documentation.” Blue Robotics. Blue Robotics, 22 August 2015. Web. 21 March 2019.

Blue Robotics. “Watertight Enclosure for ROV/AUV (4″ Series) Documentation.” Blue Robotics. Blue Robotics, 22 August 2015. Web. 21 March 2019.

MATE. “2019 MATE ROV Competition Manual Ranger.” MATE. MATE, 3 March 2019. Web. 15 May 2019.

Mitsumi. “Aluminum Extrusion specifications.” Mitsumi. Mitsumi, 2018. Web. 21 March 2019.

Nave, Rod. “Buoyancy.” HyperPhysics. Georgia State University, 9 August 2013. Web. 21 May 2019.

The Imaging Source. “IC Measure - manual on-screen image measurement and image acquisition 2.0.0.161.” The Imaging Source. The Imaging Source, 22 January 2019. Web. 21 March 2019.

VII. Appendices

A. Operation and Safety Checklist

Pre-Power
- Area clear/safe (no tripping hazards or obstructions)
- Verify RPS power switches are off
- Tether laid out on the deck
- Tether connected and secured to RPS & ROV
- Tether strain relief connected to ROV
- Power source connected to RPS
- Visual inspection of electronics for damaged wires or loose connections
- Electronics housing sealed
- Fasteners tight on the electronics housing
- Vacuum test electronics housing (see Vacuum Test below)
- Vacuum port securely capped
- Thrusters free from obstructions

Vacuum Test
- Connect vacuum hand pump to the electronics housing
- Vacuum down the electronics housing to ~10 Hg
- Verify electronics housing holds ~10 Hg of pressure for 15 minutes
- Remove vacuum pump and securely cap vacuum port

Power-Up
- Verify RPS is receiving 12V nominal
- Control computers up and running
- Ensure deck crew members are attentive
- Call out, “power on!”
- Power on RPS
- Call out, “performing thruster test”
- Verify thrusters are working properly (joystick movements and thruster activity correspond)
- Verify video feeds
- Test accessories

ROV Launch
- Call out, “prepare to launch”
- Deck crew members handling ROV call out, “hands on!”
- Launch ROV, maintain hand hold
- Wait for release order

In Water
- Check for bubbles
- Visually inspect for water leaks
- If there are large bubbles, pull to surface immediately

ROV Retrieval
- The pilot calls, “ROV surfacing”
- Deck crew calls, “ROV on surface”
- “Hands On,” thrusters disabled
- Operation Technician (OT) powers down RPS
- OT calls out “safe to remove ROV”
- After securing the ROV on deck, deck crew calls out “ROV secured on deck”

Leak Detection
- Surface immediately
- Power down ROV
- Power down RPS
- Inspect ROV (may require removal of electronics)

Loss of Communication
- Cycle power on RPS to reboot ROV

- If no communication, power down ROV, retrieve via tether
- If communication restored, confirm there are no leaks, resume operations

Pit Maintenance

- Verify thrusters are free of foreign objects and spin freely
- Visual inspection for any damage
- All cables are neatly secured
- Verify tether is free of kinks
- Verify Pressure Regulator is set to 2.75 Bar (40 psi)
- Verify all pneumatics lines are properly connected to the air source, RPS, and ROV
- Activate pneumatics system and open main valve