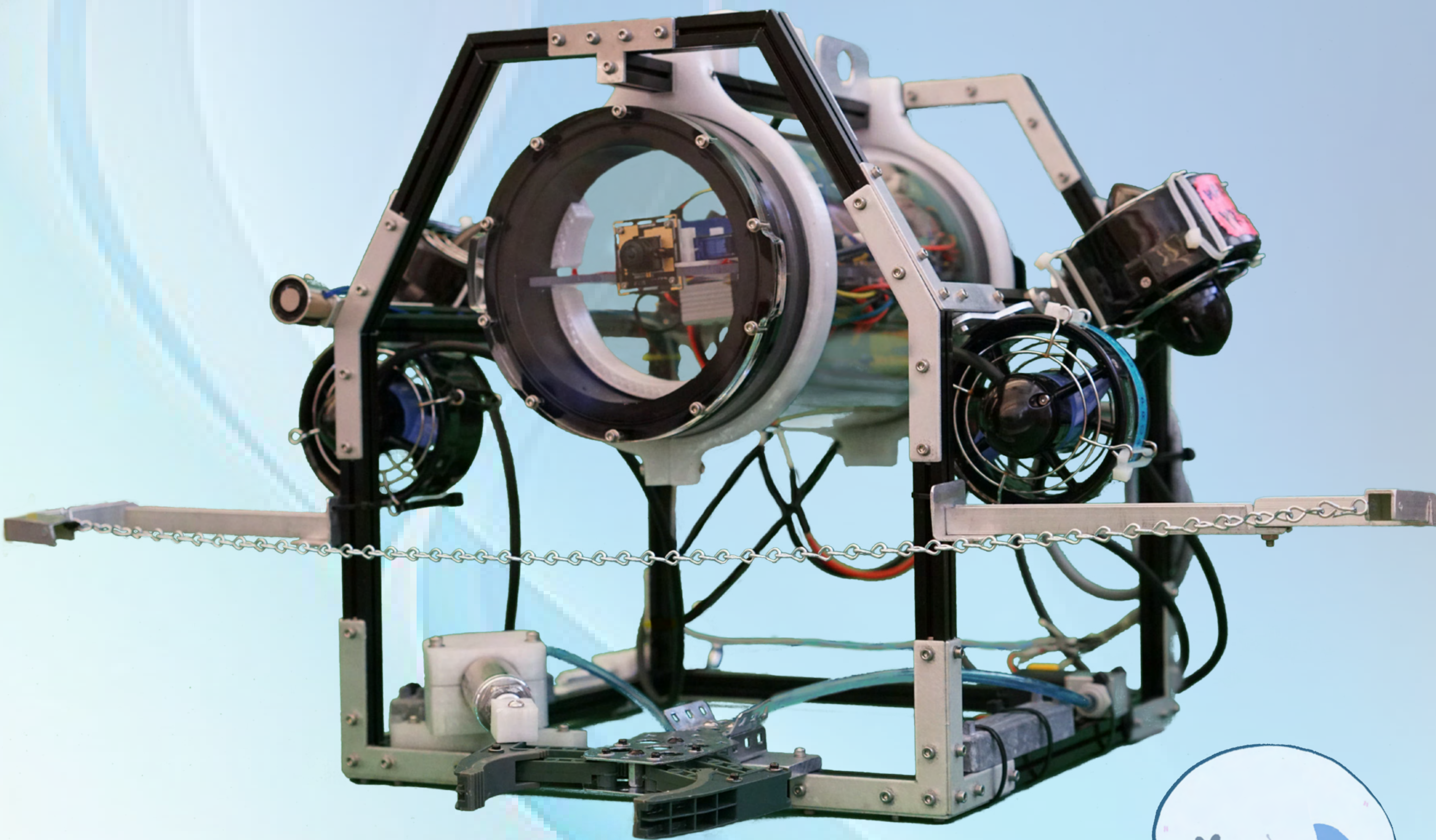

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Jaedyn Alford ‘22 - Vision
Meredith Garcia- ‘22 - Tools Lead
Lauren Jones- ‘22 - CMO; Overall Software Lead
Emmy Asperger ‘23 - Mechancial
Allie Dinh ‘23 - Control Software Lead
Morgan Jones- ‘23 - CEO; Vision Lead
Norah Zhou- ‘23 - CFO; Electrical Lead
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Isa Gutierrez ‘24 - Tools
Siena Marois ‘24 - Software
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I. INTRODUCTION

A. ABSTRACT

Geneseas' third generation Remotely Operated Vehicle (ROV), *Beluga*, is the company's newest and most technically advanced product. *Beluga* is fully equipped with custom designed tools, giving it the ability to perform specific mission tasks in oceanic environments around the world. *Beluga's* customization and mission efficiency enables the ROV to accomplish and support the UN Sustainable Development Goals.

Geneseas, a four year-old company, has doubled our workforce from ten to twenty-one experienced women engineers who produce submersible robots. *Geneseas'* all-female company harnesses their skills and passion to develop custom-built ROVs to meet specific design requests. The team has meticulously crafted *Beluga* through careful planning, research, analysis, manufacturing, and testing under strict safety protocols.

Geneseas employees work in small subteams creating specific parts of *Beluga* and integrating their features to deliver a reliable ROV. Given the UN sustainability objectives, *Geneseas* focused on enhanced pilot visibility and mission precision. This includes newly developed enhancements including a graphical user interface (GUI), a digital camera system, and a pneumatic gripper. These custom features ensure *Beluga's* capability to execute its tasks successfully and efficiently.

This technical document describes the design and development of *Beluga*, our most advanced ROV, capable of aiding the global community in achieving the UN Sustainable Development Goals: marine renewable energy, offshore aquaculture, blue carbon, and monitoring conditions in Antarctic waters.

Figure 1. *Geneseas* Team Members
Photo by Mark Honbo

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II. DESIGN RATIONALE

A. DESIGN EVOLUTION

Intensive redesign and detailed customization led *Geneseas* to develop their most technologically advanced ROV, *Beluga*. Analyzing the successes and shortcomings from our previous ROVs and researching potential new solutions enabled employees to make significant improvements in this third generation design. *Beluga's* unique design builds upon the core capabilities of previous iterations, adding significant new enhancements while remaining focused on our three core design principles: safety, serviceability, and reliability.

Geneseas' commitment to safety is accomplished through close monitoring of *Beluga's* sensor readings displayed on the Remote Processing System (RPS), enabling the ROV pilot and copilot to quickly detect and address abnormalities in the event of a system failure. *Beluga* utilizes safety elements such as thruster guards, sturdy handles, and an emergency power off button to protect ROV operators and reduce the risk of injury for deck crew. However, *Beluga* features more than just safety sensors, it also features a sonar sensor and liquid level sensor of the buoyancy engine Ridley, aiding in successful mission completion.

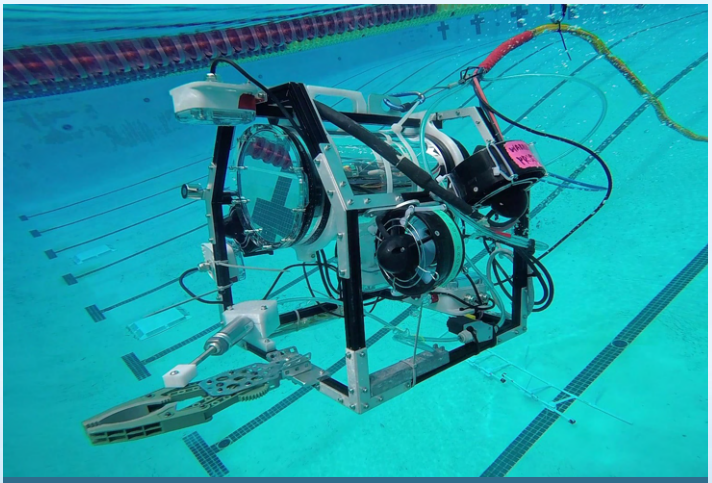

Figure 2. *Beluga* with Tools
Photo by Lauren Jones

Geneseas implemented component-level testing into our development and design process. This allowed our team to verify specific component functionalities and implement improvements prior to testing. This diligent design, manufacturing and testing process accelerates the development of our design and ensures the safety of our team.

A careful and holistic review of previous ROV designs enabled *Geneseas* to identify and focus on specific areas for improvement. The third generation ROV was designed to improve and enhance the functionality of the camera and display system, maneuverability, and electronics capabilities.

Modifications to previous years ROVs include replacing a 4-inch tube used in earlier ROVs with a larger 6-inch cylindrical enclosure. This larger electronics housing provides room for additional connectors on the endplate and increases space for electrical components. Additional evolutions to the ROV core design include the decision to construct *Beluga's* frame out 15 x 15 mm extruded aluminum as opposed to the 20 x 20 mm extruded aluminum used in previous designs. This materials change resulted in a lighter, more hydrodynamic, and more maneuverable ROV. One of the most significant advancements featured on *Beluga* is the use of an advanced digital camera system as opposed to the analog camera system featured in previous designs. The new digital camera system makes use of USB cameras to increase reliability and maximize *Beluga's* mission efficiency through improved image recognition. The implementation of a digital camera system and the switch from 20mm to 15 mm extruded aluminum for the frame improved *Beluga's* overall functionality while decreasing the price of manufacturing. Last year, *Geneseas* spent $152.32 on 20 x 20 extruded aluminum which decreased to $99.42 this year after switching to 15 x 15 mm. *Geneseas* also spent $538.50 on the analog camera system last year which decreased to $486.56 with a digital camera system.

B. MECHANICAL DESIGN AND MANUFACTURING PROCESS

Geneseas focuses on the core design principles of safety, serviceability, and reliability when manufacturing components of the ROV. At the beginning of each year, the team meets to determine the key goals for the year and which components should be altered or kept. At this meeting the team discussed aspects of the new ROV such as the frame, camera system, and number of thrusters, weighing the pros and cons of each decision. The team made a Design Matrix (Figure 3) to efficiently evaluate the options for each system. *Geneseas* employees used the Design Matrix to select the designs that best fit mission 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.

Part	Thrusters	Camera System	Electronics Housing	Frame Material
Aspects to Consider	**4 thrusters or 6 thrusters** 4 thrusters Pros: reliable code already developed, allow for advancements in established code Cons: lacks horizontal movement capabilities 6 thrusters Pros: allows for vector drive system and improved movement Cons: advanced code that will take months to develop and could result in problems this season	**Analog or Digital Cameras** Analog Pros: familiarity with analog system Cons: unreliability, leaking housing, issues interacting with image recognition software, poor video quality Digital Pros: higher quality cameras, increased image recognition abilities Cons: Something new that might not function as intended.	**4 inch tube or 6 inch tube** 4 inch tube Pros: Familiar with the impact the tube will have on the buoyancy of the ROV as a whole Cons: Limited space on the endplate, cramped electronics within the housing, no space to add new features 6 inch tube Pros: Allows for more room on the endplate, more space for electrical components Cons: Uncertain impacts on overall ROV buoyancy	**15 x 15 mm Extruded Aluminium or 20 x 20 mm Extruded Aluminium** 20 x 20 mm Pros: Experience building with this material, have pre-designed brackets, we have left-over T-slot nuts Cons: heavy, bulky, and more expensive 15 x 15 mm Pros: lightweight, more hydrodynamic, and less expensive Cons: New material, must design new brackets to maximize surface area
Final design decision	**Continue to use and make improvements to the 4 thruster design while working on the development of the 6 thruster system to use in the following season.**	**Pursue the Digital Camera system for increased image recognition abilities while simultaneously building an analog system as a back up.**	**Use the 6 inch cyllindrical tube to optimize space within the Electronics housing and create extra room on the endplate for more connectors and penetrators.**	**Use the 15 x 15 mm extruded aluminium so the new ROV will be lighter, more hydrodynamic, and able to be manufactured at a lower price.**

Figure 3. *Geneseas'* Design Matrix
Photo by Lauren Jones

The manufacturing process began with a brainstorming session in which a team determined the requirements the part had to meet and began to develop a plan on how to accomplish these design goals. These brainstorming sessions occurred at the beginning of the season and encouraged inter-team collaboration to successfully accomplish goals. These brainstorming sessions tasked members with coming up with design concepts, a defined timeline, and determining a parts list. The next phase of the design evolution was the initial prototype in which an employee prototyped the component out of cardboard to test whether the component would perform the task as intended.

Once the component was ready for preliminary manufacturing, a detailed design was created using Computer-Aided Design (CAD) through the online Onshape software. This online design process allowed for multiple people to work on and provide input for the construction of specific components. Once the CAD design for the prototype was complete, the 3-D model was reviewed by another person to verify correct measurements and key design features before it was 3-D printed, printed on paper to use as a guide for cutting and drilling, or converted into G-code to be used to manufacture a component on the CNC mill. After the components were manufactured, the different parts were assembled and a testing procedure was generated.

Geneseas members worked to develop special props to be used to test the functionality of prototypes. These props ensure that the component functions as intended before it is secured onto the ROV for underwater testing. The team who built the prop closely monitored its underwater testing and noted changes that had to be made to create an improved final product. The team then returned to the lab and cycled through the prototype, build, test, and release process.

This meticulous design and manufacturing process allows *Geneseas* Team members to cycle through multiple iterations of components before finalizing a product to use on the ROV. By using such an intensive process, *Geneseas* team members ensure the efficiency of components and are able to make completely customized products that best suit the mission requirements.

C. MECHANICAL COMPONENTS

FRAME

This year, *Geneseas* switched from using 20 x 20 mm to 15 x 15 mm extruded aluminum to construct *Beluga's* frame (Figure 4). This decision makes the ROV more hydrodynamic and lowers the cost, weight, and raw material consumption by 44%. The smaller size makes the ROV more compact and easier to handle. While this design enhancement provided the benefits of a smaller frame, team members had to design new custom brackets to provide the same amount of strength as those from the 20 x 20 mm extruded aluminum frame despite the new frame's decreased surface area. The extruded aluminum features channels, giving *Geneseas* the ability to use T-slot nuts to attach tools, cameras, and thrusters. This new compact design reduces *Beluga's* weight and size, improving the ROV's overall versatility and adaptability.

The outer frame of *Beluga* is 310 x 310 x 367 mm featuring a trapezoidal top manufactured using T-slotted aluminum extrusion (Figure 4). Additional horizontal bars on either side of the ROV are rotated thirty degrees to make up the base of the trapezoidal top. *Geneseas* created many designs in CAD and opted to use a pentagonal shape for the frame. This frame shape maximized space for the electronics housing while also allowing room in the bottom half of the ROV for tools.

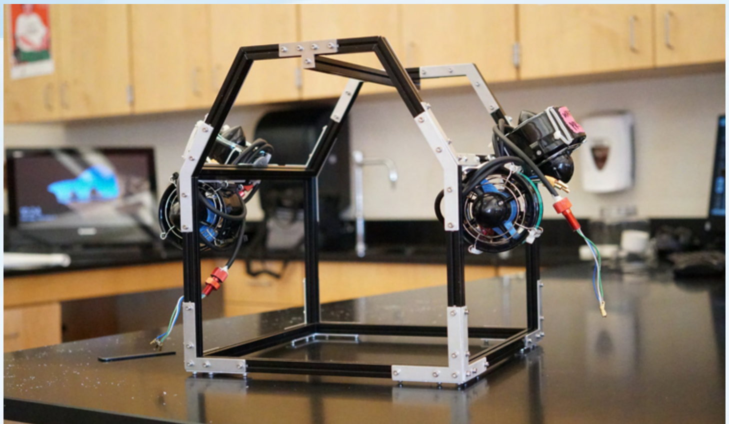

Figure 4. *Beluga's* Extruded Aluminum Frame
Photo by Lauren Jones

The top half of *Beluga's* frame was designed to establish underwater stability by placing major buoyancy components high on the ROV. The Blue Robotics 6" electronics housing tube sits at the top of the ROV in custom 3D printed polycarbonate cradles that can be adjusted for stability.

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 to direct thrust away from the center of the ROV and the lower tool deck.

Finally, the design leaves the bottom half of the ROV to be used for tools. This lower tool deck area features the mission video system, the pneumatic system, and the tools manufactured by *Geneseas'* employees.

As a safety measure, all of *Beluga's* frame corners are rounded off and filed to prevent sharp edges from injuring any team members servicing or repairing the ROV. A 3D printed polycarbonate handle mounted on the top of *Beluga* aids the deck crew's retrieval of the ROV. A carabiner also connects to the tether, which provides a point of strain relief and ensures secure tether attachment to the ROV during missions.

ELECTRONICS HOUSING

Last year, *Geneseas* used a 4" tube. This year, *Beluga* is equipped with a 6" Blue Robotics watertight acrylic tube with an outer diameter of 165 mm and a length of 298 mm (Figure 5). The larger tube creates space for a more organized electronics tray and a cleaner end plate. The 6" tube provides an abundance of positive buoyancy compared to the previous 4" model which required more modification to make the ROV neutrally buoyant. Due to the increased amount of space it provides and increase in buoyant force, the 6" tube was determined as the optimal housing for *Beluga's* electronic components.

This Electronics Housing contains *Beluga's* critical electronic components. *Geneseas* chose this enclosure because the transparent acrylic tube allows for quick and efficient visual inspection of the electronic components within the housing.

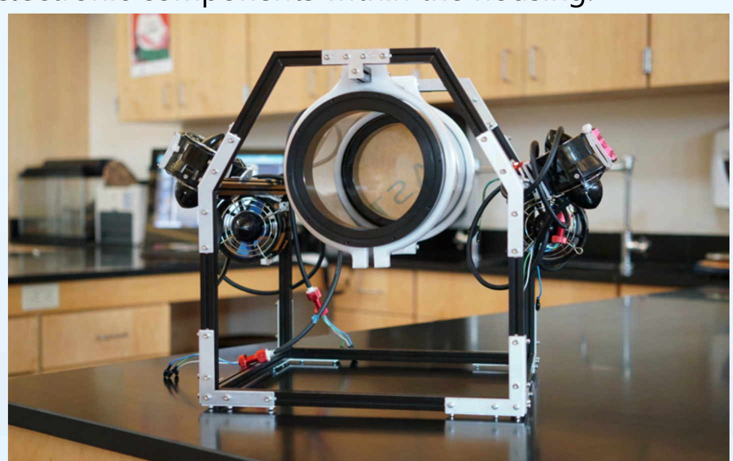

Figure 5. *Beluga's* Acrylic Electronics Housing Tube
Photo by Lauren Jones

Additionally, at the front of *Beluga*, *Geneseas* chose a clear Blue Robotics acrylic end cap. The transparent end cap allows the camera mounted at the end of the internal tray to have a larger field of view, making it easier to navigate *Beluga* underwater.

For the back of the enclosure, *Geneseas* chose to manufacture an endplate as opposed to purchasing one. Custom making the endplate granted *Geneseas* the ability to optimize the layout of the connectors (Figure 6). This custom-designed aluminum end-plate was engineered to fit the Blue Robotics tube while providing twelve holes for connectors. A Bulgin Ethernet connector is placed at the center of the endplate. This connector was purchased for its efficiency in transmitting video and communication from the Remote Piloting System (RPS) to *Beluga.* The two McMaster-Carr cord grips threaded into the bottom of the endplate were bought for their reliability.

The other eight holes contain Blue Robotics penetrators, which were selected for their watertight connection between the electronics inside the housing and the thrusters, tools, and camera systems mounted on the ROV. The pressure testing vent, which occupies one of these holes, allows for the enclosure to be vacuum tested and deemed airtight before being placed in the water. This vacuum test checks if the enclosure is maintaining a stable pressure of 10 mmHg for ten minutes.

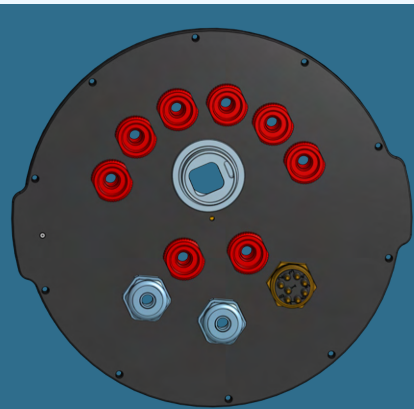

Figure 6. Custom-designed aluminum end plate
Photo by Lauren Jones

Inside the housing, *Geneseas* designed and manufactured a custom tray to maximize serviceability and safety. This decision to construct a custom tray allows for easy accessibility without the time-consuming removal of the flange system. *Beluga* has one tray that utilizes both sides to maximize space. One side houses the Electronic Speed Controllers (ESCs) and the camera, while the other features the Arduino Mega Board. This allows the tray to be both compact and hold all necessary electrical systems, while separating the ESCs and the signal components to limit interference. The ESCs are secured and mounted on a stand-off, increasing airflow to prevent overheating. The camera is located at the end of the tray on a servo-driven mount, which rotates 90 degrees upwards and downwards, therefore increasing the field of view for the main navigation camera and allowing for more efficient Pilot navigation.

The tray is connected to the aluminum endplate by a custom 3D printed bracket with four holes for reliable fastening. At the front, the electronics tray sits in another custom bracket designed to keep it stable during transportation and mission operation.

THRUSTERS

Beluga's thruster layout was designed to maximize power efficiency and maneuverability. Four Blue Robotics T-100 thrusters, mounted in a modified arcade drive system allow for enhanced piloting capabilities. *Geneseas* originally considered using six thrusters for *Beluga* in order to use vector drive to navigate underwater. However, after considering the ROV size and power limitations (Figure 7), *Geneseas* employees concluded that four thrusters would be the optimal, most efficient option. Since *Beluga's* power is limited to 25 amps, the power to the four thrusters is restricted through programmatic controls.

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

Figure 7. Power Budget
Photo by Lauren Jones

For an effective design, two thrusters are mounted on the side to provide horizontal movement and are placed close to the center of mass to prevent pitching. The other two vertical thrusters are mounted at thirty-degree angles to optimize vertical movement, while still directing the thrust away from *Beluga's* tools and the bottom of the ROV. This thruster design allows the ROV to move forward, backward, up, down, and rotation.

Beluga's thrusters include safety features such as thruster guards and safety labels to protect and ensure the safety of crew members operating the

ROV. These thruster guards were tested and have a minimal effect on movement thrust. Fan guards were modified to fit on either side of the thruster, preventing injuries.

To make movement more efficient, a variety of features were added to the joystick. Joystick dead zones – areas around the center of a joystick that do not respond to movement – were tested to determine optimal values for each axis for optimal piloting. When the joystick is in the default position, a power limiting algorithm is executed so the thrusters do not turn on unintentionally. Thruster and joystick sensitivity were also improved by adding calculations to adjust the speed of the thrusters, in accordance with how far the joystick moves.

Geneseas developed and wrote custom code to efficiently manage power. Team members determined how much power is to be delivered to each part of the ROV and the amount of voltage drop on the tether. When high-power combinations of joystick movement are used, the code dynamically reduces power to particular thrusters to ensure the ROV remains within the power budget. This power management system enables the ROV to provide all available power to thrusters in every movement configuration.

BUOYANCY

To regulate *Beluga's* weight and buoyancy, *Geneseas* employees utilized a Buoyancy Calculation Spreadsheet (Figure 8). Employees calculated the displacement and buoyant force using Archimedes' Principle[4]. The calculations guided the decision of which materials to use for different parts of *Beluga*. Comparing the buoyant force to the weight of the ROV allowed *Geneseas* to establish whether the ROV would be positively or negatively buoyant. At 6912

Part	Displacement (cm^3)	Density of Item (g/cm^3)	Weight in Air (kg)	Bouyant Force (kg)	Resultant Bouyant Force (kg)
Frame	547.79	2.75	1.509	0.55	0.96
Electronics tube	6912.07	0.36	2.516	6.89	-4.38
Cradles	180.28	1.19	0.215	0.18	0.04
Thrusters	750.32	1.05	0.788	0.75	0.04
Tools	425	2.03	0.8624	0.42	0.44
CEH+Cameras	535.29	1.96	1.05	0.53	0.51
Weight Added	40.98	12.2	0.5	0.04	0.46
Total	9391.72	0.79	7.44	9.36	-1.93

Figure 8. *Beluga's* weight and buoyancy calculation
Photo by Lauren Jones

cm^3, the Electronics Housing is the largest buoyancy component featured on the ROV which makes it positively buoyant.

Because the ROV in naturally positively buoyant, *Geneseas* employees adjusted the buoyancy by adding two 250 gram weights to the bottom extrusion of the ROV, making it neutrally buoyant. This easily accessible and highly serviceable buoyancy system allows *Geneseas* employees to customize and adjust the buoyancy when different tools are added or removed.

Another component which affects the overall buoyancy is the tether. The tether features stainless steel water bottles, attached along the length to allow for adjustable buoyancy. The deck crew can modify the position and weight of these bottles by increasing or decreasing the amount of water within each bottle. This minimizes the tether's effect on *Beluga* while also keeping the tether afloat above the ROV, preventing it from becoming entangled during mission operations.

D. ELECTRICAL SYSTEMS

REMOTE PILOTING SYSTEM (RPS)

The Remote Piloting System (RPS) seen in Figure 9 was designed using the key design principles of safety, serviceability, and reliability. The RPS is the topside control box used to power and control *Beluga* and its various components.

Figure 9. *Beluga's* Top-side Remote Piloting System (RPS)
Photo by Lauren Jones

For reliability, the RPS was designed and custom-built inside a DEWALT Tough System® DS130 toolbox. This configuration permits a straightforward deck setup that protects the RPS's components during transport. *Geneseas* designed the RPS with industry-standard ports, identifiable controls, and an effective layout. This layout consists of a top panel and an easily accessible bottom panel. The top control panel displays voltage, current, pneumatic pressure, and power indicator lights. These sensors allow the Co-pilot to monitor the power and pressure status during the mission to ensure smooth operations. In addition, the top panel includes the emergency power-off switch and two buttons that allow the pilot to easily operate tools on *Beluga*. Some of these components, including the voltage and amp meters, were reused from previous years in order to reduce costs and prevent delays to the design process due to supply chain and shipping issues. The RPS also utilizes a laptop computer for all five camera feeds and a USB joystick to control the ROV via the Arduino Mega. A large external display can be attached for larger views of the camera feeds. *Geneseas* changed the length of the bottom panel from last year's RPS, extending it from 14 to 19 inches to utilize the entire length of the DEWALT box in order to create a more organized and stream-lined wiring system.

For serviceability, the top control panel was fitted with a handle that reveals the serviceable bottom panel. This bottom panel of the RPS holds the Arduino Mega, which is mounted with standoffs to protect the components on the bottom of the board. The bottom compartment contains wiring

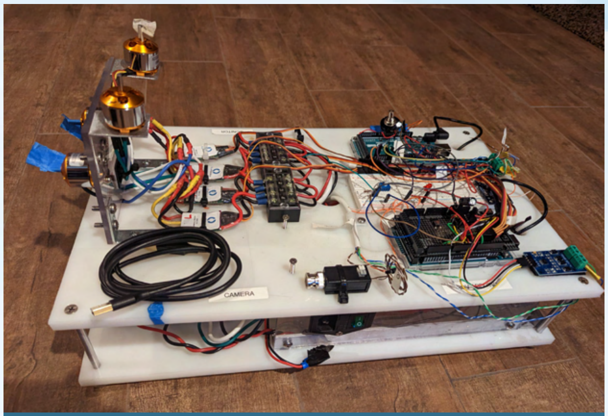

Figure 10. The Electronics Testbench
Photo by Lauren Jones

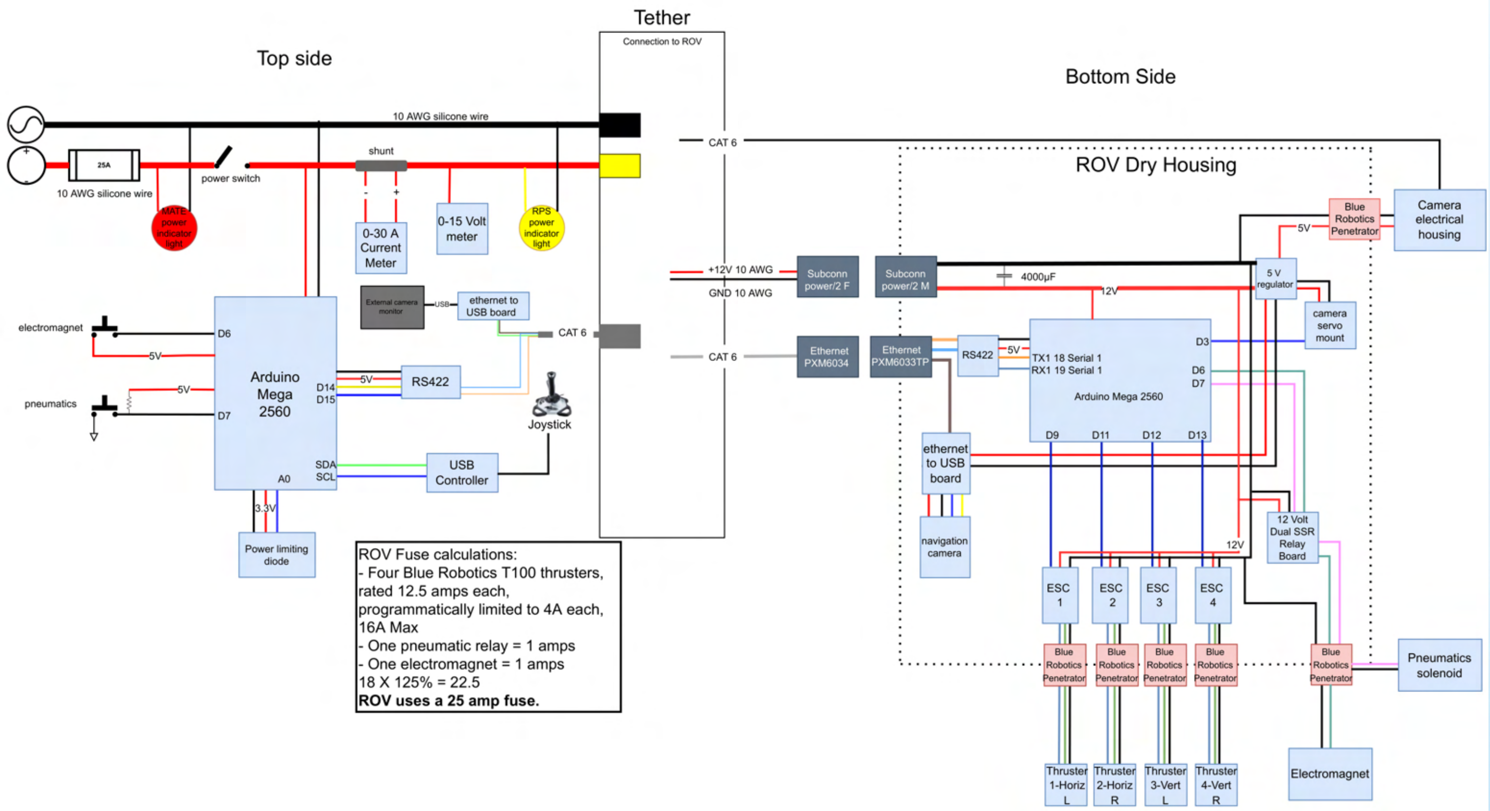

Figure 11. *Beluga's* Top-side and Bottom-side Electronics Housing SID
Photo by Lauren Jones

from the top panel and the shunt for the amp meter. The back and side panels of the RPS include ports for the monitor, USB, power, and tether connectors. The tether connections include Anderson Powerpole 45 for power, two 6.35mm (0.25 inch) pneumatics airlines, and two CAT6 ethernet connectors.

A testbench (Figure 10) and System-Integration Designs (SID) (Figure 11) simulate and document the ROV respectively, and were used to ensure that all the electronics in the RPS were wired correctly. The testbench replicates the ROV's electronic system and is used to test code compatibility and verify functionality before testing is performed on *Beluga*.

TETHER

This year, to improve cost efficiency, *Beluga's* tether was modified and improved replacing one CAT6 ethernet cables with two CAT6 ethernet cables to enable support of the digital camera system. The tether includes signal, power, and pneumatic lines that run from the RPS to the ROV. The length of the tether was determined by using a Voltage Drop Calculator (Figure 12) to find the optimal length, wire gauge, and wire type. *Geneseas'* employees determined the 10 gauge power cable needs to be 12 meters to maximize the 25 amp fuse-limited current draw. As shown in Figure 12, the voltage drop across the tether is just under 2 V. This design provides efficient and reliable transfer of power and signals from the RPS to the ROV, while allowing enough tether length for the ROV to successfully complete mission tasks.

Tether Voltage Drop	
Wire size	10 AWG
Wire length	50 ft
Wire type	stranded silicon
Resistance per feet	0.000999
Resistance per side	0.04
Voltage drop on power side	0.999 V
Voltage drop on return side	0.0009 V
Total Voltage drop	2.00 V

Figure 12. Voltage Drop Calculations
Photo by Lauren Jones

Beluga's tether (Figure 13), includes a two-line closed-loop pneumatic system, which connects to the ROV's tools and back up to the RPS. *Beluga's* tether includes two CAT 6 Ethernet cables; one to transmit serial data signals and the navigation camera feed between the RPS and the ROV and the second to transmit video feed from the ROV's four mission cameras.. The two 10 gauge silicone power lines maintain great flexibility while minimizing the voltage drop throughout the tether. With a projected 16.5 amp current draw from the ROV, it was necessary to select 10 AWG wires to maintain a minimum of 10 volts to the ROV. A durable woven nylon sheathing protects the tether components, but still allows for disassembly if service is needed. The bright neon yellow sheathing was chosen to increase visibility in the water and prevent entanglement.

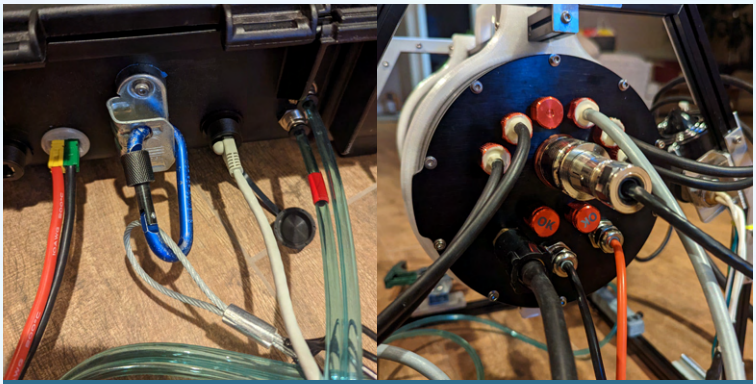

Figure 13. *Beluga's* tether connected to the ROV & RPS
Photo by Lauren Jones

Geneseas' tether manager responsible for the storage and maintenance of the tether as well as handling the tether during mission operations. The tether manager begins their duties during mission set-up, uncoiling the tether and connecting the top-side of the tether to the RPS and the bottom-side of the tether to the ROV making sure to attach strain relief first on both ends. When *Beluga* is successfully deployed, the tether manager works to provide slack on the tether to allow the ROV to move and feeds more or less of the tether depending on the location of the ROV, helping to prevent entanglement. The tether manager inserts and removes the ROV by placing one hand on the strain relief and the other on the upper handle. When the mission is completed, the tether manager disconnects the tether from the topside RPS and bottom side ROV and carefully coils it so it can be safely and compactly stored in the tether bag. These established protocols and good communication allow for successful and safe mission completion.

ELECTRONICS

Beluga's electronic system was designed with the priorities of serviceability and reliability. The Arduino utilizes 0.1" headers or most connectivity which provides easy serviceability while reducing the risk of a short circuit. The ROV's electronics tray is divided into the power side and the electronics side. The power side consists of 4 Electronic Speed Controllers (ESCs), an XT30 power distribution block, a screw terminal block, and a 12v to 5v converter. In addition, *Beluga* uses capacitors connected to the 12 volt supply to reduce the sudden voltage drop when the ESCs are turning on. The XT30 power distribution block was selected because of its simple and efficient design that optimizes the space on the electronics tray. These connectors allow for the easy removal and service of the ESCs and the capacitors if needed. In addition, the distribution block also powers another screw terminal block that is used for the Arduino, the power converter, and mission tools. The 12v to 5v converter connects to another XT30 distribution block on the electronics side of the tray.

The electronics side consists of an RS422 serial transceiver, an Arduino Mega, another XT30 power distribution block, a dual solid-state relay board, and all the components of the navigation camera. (See Figure 11) The XT30 powers the navigation camera and the servo mount. The RS422 was selected to increase noise immunity on the signals between the ROV's Arduino and RPS.

SUBMERSIBLE CONNECTORS

Beluga uses a combination of eight Blue Robotics cable penetrators, two McMaster-Carr cord grips, and a Bulgin bulkhead ethernet connector to successfully supply power and control signals to the ROV. Connectors were chosen according to their size and functionality. For power delivery through the tether, *Geneseas* uses a two-pin inline SubConn power connector which provides for a low resistance connection with significant power headroom. The Subconn and Bulgin connectors also allow the ROV, RPS, and tether to be stored individually, preventing damage to the ROV system components and making transportation safer. The two-pin inline power connector was reused from last year to reduce costs, while a new highly reliable, all metal Bulgin ethernet connector was selected due to past experiences with faulty connectors. To further reduce the cost of *Beluga*, *Geneseas* decided to use affordable and reliable Blue Robotics cable penetrators for devices permanently attached to the ROV, such as thrusters.

E. PNEUMATICS

Beluga's pneumatics system powers a single-action spring-return piston by using air that is regulated on-deck to 2.76 bar (40 psi). A pneumatic system pressure gauge is located on the RPS, which allows the Pilot to monitor the system and ensure a safe pressure in the system. The air is sent to the tools through a 6.35mm (0.25 inch) pneumatic line which increases the volume of air flow to the ROV, as opposed to a 3.18mm (0.125 inches) line. A solenoid housed on Beluga is controlled by the co-pilot via a button on the RPS. The solenoid is attached to a check valve, preventing the backflow of water, allowing it to properly function as a safety valve. *Beluga's* pneumatics system consists of a 2/2 way valve located between the solenoid and the piston. It contains a small hole that releases air after the piston is deployed, enabling the piston to return to its original position. *Beluga's* pneumatics SID is shown in Figure 14.

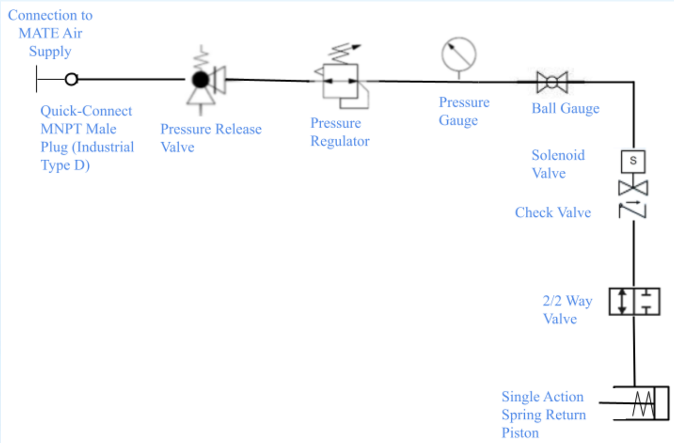

Figure 14. Beluga's Pneumatics SID
Photo by Lauren Jones

F. TOP-SIDE & BOTTOM-SIDE SOFTWARE

Beluga's top-side and bottom-side platforms are programmed in C/C++ on Arduino Mega 2560 controllers, which are in constant communication with one another. The blinking RPS light indicates that both the ROV and the RPS are receiving and transmitting data. If communication is lost, Beluga enters into its safe mode until communication is reestablished. In safe mode, the thrusters, actuators, and all other tools are disabled.

Geneseas purchased new Arduino Megas for its software units. *Geneseas* used the knowledge and experience acquired from the previous MATE competitions to further explore the Arduino software capabilities. The identical controllers allow for the utilization of EasyTransfer, an Arduino library, through which the bottom-side and top-side platforms can easily receive and transmit packets to each other.

The RPS top-side platform reads the joystick and button inputs from the RPS while. Using that data, primary calculations are executed and values are transmitted to the ROV for thruster, controller, and actuator control. These calculations include the conversion of joystick inputs to PWM on-time and their transfer bottom-side for control of the ESCs. As an additional safety feature, the top-side implements range-checking software to limit thruster power draw. In order to enable fine movements, *Geneseas* uses functions that may limit the amount of power thrusters receive when *Beluga's* pilot is controlling the ROV. The function calculates and fine-tunes the power needed to vary the sensitivity to joystick movements. The tuned thruster values are then assigned to each thruster and are sent to the ROV. This allows the ROV to make accurate movements when using tools that require precise alignment. Limiting thruster power also permits the ROV to swiftly glide through the water and decreases wasted power. The ROV bottom-side platform receives information from the 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 forwards, backwards, and vertically. The joystick also allows for seamless left and right rotation. The Arduino Mega 2560s process control functions sequentially (Figure 15):

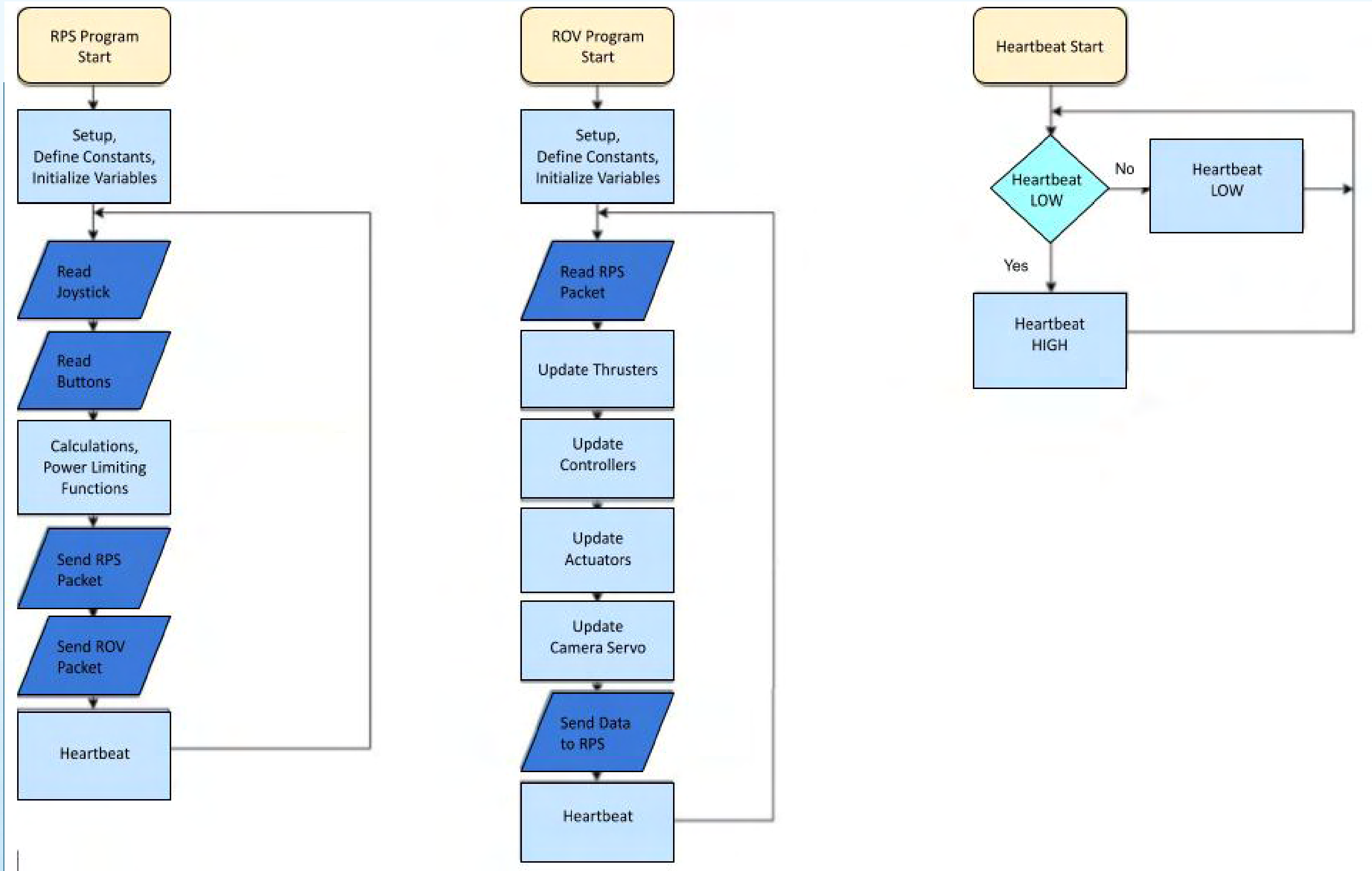

Figure 15. *Beluga's* Top-side and Bottom-side Software Flowcharts
Photo by Lauren Jones

G. DIGITAL CAMERA SYSTEM

While most ROVs use analog cameras, *Beluga* features a multi-stream, low-latency, fully digital camera system. During the past year, *Geneseas* worked to research, develop, test, and release this capability. The all-new camera system provides the pilot extremely clear video for navigation and tool use, and includes a digital video stream for advanced image processing. This will be the foundation for *Geneseas'* vision systems for years to come. The development began with a design review of the previous year's camera system. Team members identified several areas for improvement related to image quality, reliability and water tightness. The team unanimously decided to leave analog cameras in the past and focus on designing a new digital camera system.

Geneseas tested several camera options. Employees performed latency testing (Figure 16) and selected the Megapixel USB camera (Figure 17) which has an average latency of 127 milliseconds. The main navigation camera, which is attached to a servo to allow for an adjustable field of view was implemented first. The camera is connected to a USB to ethernet transceiver for video transmission up the tether.

Finally, the team developed the mission cameras. During investigation of a leak, *Geneseas* team members identified that the off-the-shelf camera housing has tapered walls to facilitate mold release during manufacturing. This resulted in leaking connectors. As a result, *Geneseas* created a custom fixture to hold the enclosure during drilling to compensate for the 2.5 degree taper and ensure a flush fit of the watertight connectors.

While *Beluga* features four digital mission cameras, the vision system architecture allows a practically unlimited number of cameras to be used. The camera hub features a four-port USB hub and a USB to ethernet transceiver. Each camera is enclosed in a waterproof case and mounted with a custom 3D-printed mount.

Figure 17. Megapixel USB Camera
Photo by Lauren Jones

The digital camera system features numerous custom manufactured, 3-D printed, and machined components to deliver an effective and cost efficient solution. By creating these custom parts, *Geneseas* team members were able to use off-the-shelf cameras to maintain affordability while creating an advanced vision system. This camera system solves the issues of the previous analog camera system through high resolution, low latency camera, a waterproof enclosure, and enhanced image processing abilities.

H. MISSION TASKS

ROV TOOLS

PNEUMATIC GRIPPER

Beluga's gripper tool design features custom mounting, a pneumatic actuator, and a VEX Robotics Claw Kit. This useful and multifunctional tool gives the pilot complete control to manipulate objects. It is used in many tasks, such as removing encrusting marine growth and interacting with the buoyancy module. The single-action spring return piston rod

Trial	Latency for Logitech USB Camera in seconds	Latency for Raspberry Pi Camera in seconds	Latency for Megapixel USB Camera	Latency for a a Logitech USB camera	Latency with 50 ft Ethernet Cable
1	0.116	0.311	0.117	0.177	0.116
2	0.116	0.25	0.119	0.12	0.23
3	0.116	0.302	0.12	0.115	0.116
4	0.118	0.239	0.119	0.116	0.115
5	0.116	0.308	0.119	0.117	0.116
6	0.115	0.306	0.058	0.118	0.116
7	0.116	0.306	0.111	0.116	0.116
8	0.115	0.31	0.117	0.06	0.116
9	0.058	0.301	0.121	0.116	0.12
10	0.117	0.249	0.116	0.387	0.116
Average	0.1103	0.2882	0.1117	0.1442	0.1277

Figure 16. Latency Testing Table
Photo by Lauren Jones

is fastened to one of the claw arms. Through the use of a toggle button included in the RPS, the piston is able to be deployed, closing the claw, and leaving it in the closed position as long as needed. Releasing the button will cause the piston to return and open the claw. In initial prototypes, the components were individually successful, but as a system it failed to operate smoothly. Using CAD, *Geneseas* team members designed a custom 3D printed piston mount that serves as a pivot point. A custom-made metal plate acts as a stationary mount for the claw, and together, these components allow the gripper to open and close efficiently upon Co-pilot command.

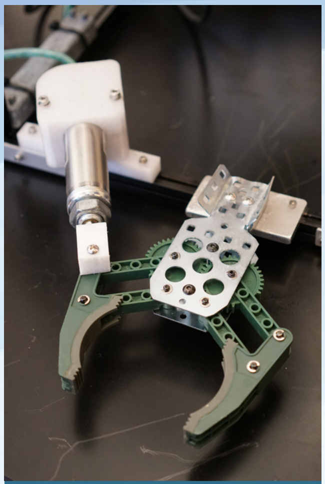

Figure 18. Pneumatic Gripper
Photo by Lauren Jones

MEASURING TOOL

The measuring tool is custom made from aluminum steel beams that are constructed in an L shape with an attached metal chain marked with metric measurements. This tool is mounted to the ROV using screws attached to an adjustable metal plate that is held against the ROV's base. The entire tool remains in view of *Beluga*'s main navigation camera. This measuring tool functions to properly determine the size of fish as the Pilot maneuvers the ROV in alignment with the object in need of measurement. A screenshot is then taken, and is manually observed in accordance to the measurements indicated on the chain, and a final measurement is recorded.

ELECTROMAGNET

Beluga uses one 12 volt neodymium electromagnet with a pull of 50 newtons in order to complete the task of retrieving ferrous objects in the oceans. This magnet is positioned at the bottom of the ROV to allow for the most efficient recovery of the ghost net pin. It is controlled by a button on the RPS which directs electric current to the magnet.

FLOTATION DEVICE

The buoyancy engine, *Olive Ridley*, was designed to adjust its buoyancy and complete the vertical profiles by ingesting and expelling water.

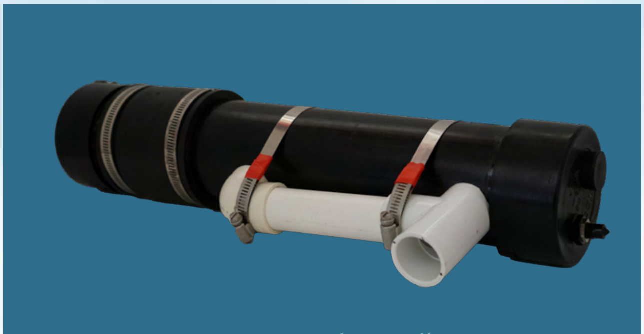

Figure 19. *Olive Ridley*
Photo by Lauren Jones

Ridley is able to do so through a servo-driven syringe. The servo driven syringe is powered by the Raspberry Pi 3B+ and features code that activates the motor, allowing the syringe to intake water thus making the engine negatively buoyant, causing it to sink. The motor is activated and moves upwards when the Buoyancy engine reaches the surface of the pool and a water-level sensor mounted at the top of the buoyancy engine reads dry. This intakes water into the syringe,

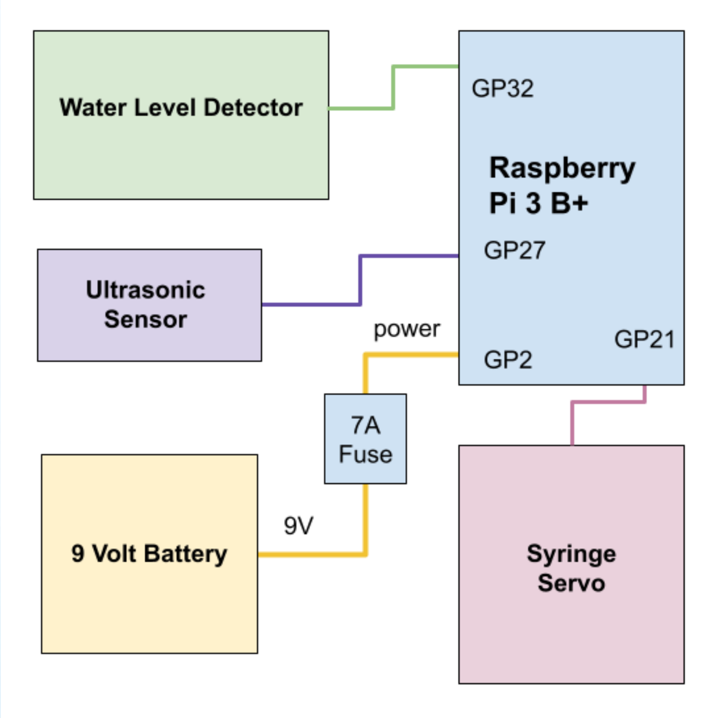

Figure 20. *Olive Ridley's* SID
Photo by Lauren Jones

allowing *Ridley* to sink. When *Ridley* sinks to the bottom of the pool, a sonar sensor indicates when contact has been made with the bottom. This triggers the servo to rotate downwards, expelling water from the engine, causing *Ridley* to become positively buoyant and float to the surface where it can repeat the process until two vertical profiles have been completed. The use of the water-level and sonar sensors ensure reliability and provide the deck crew with more information about the status of the buoyancy engine and its vertical profiles.

IMAGE RECOGNITION SOFTWARE

After switching to digital cameras this past year, *Geneseas* developed advanced image recognition techniques. The newly developed digital camera infrastructure allows *Beluga* to record high resolution videos and photos from multiple angles, which enables the building of future autonomous detection algorithms.

GRAPHICAL USER INTERFACE (GUI)

A Graphical User Interface (GUI) was developed – in python – for full software control of *Beluga's* vision and image recognition systems. The GUI displays five cameras–the navigation camera along with the four tool cameras–so the Pilot is able to have a full underwater perspective while operating *Beluga*. The GUI allows the user to choose from *Beluga's* five cameras, enlarging one onto a separate monitor for better pilot visibility. Using these cameras, screenshots can be taken; the user is able to choose from a list of these screenshots to open inside of the GUI. Once the picture is open, the user is able to perform different actions. These images can be drawn on, highlighting certain aspects of *Beluga's* underwater perspective. Rectangles can be placed on the screen, allowing the user to view certain underwater features on topside monitors.

An image recognition panel located on the side of the GUI, allows the user to execute an image recognition task, electronic calculations, and versatile image tools. *Beluga's* electronic math functions allow the operations team to efficiently calculate and solve equations during the mission run, such as calculating the movement of a float and the fish cohort. When choosing a task to complete, another python script runs in parallel, allowing the Pilot to still have visibility to complete other tasks while image recognition runs autonomously. The following image recognition software systems were developed in python and are executed using the side panel control of the GUI.

PHOTOMOSAIC OF ENDURANCE22

In order to autonomously stitch a photomosaic of the Endurance22 wreck site, *Beluga*'s camera system is able to take screenshots of the pilot's view underneath the water using the GUI. A python program takes these screenshots and iterates through each, cropping and uploading them to an Adobe Photoshop program. Each screenshot is placed based on the order in which the photos were taken. The screenshots are then "stitched" together, showing all eight quadrants in two rows. The program saves the photomosaic into a .JPG file, and then autonomously opens this file onto the screen for operational view.

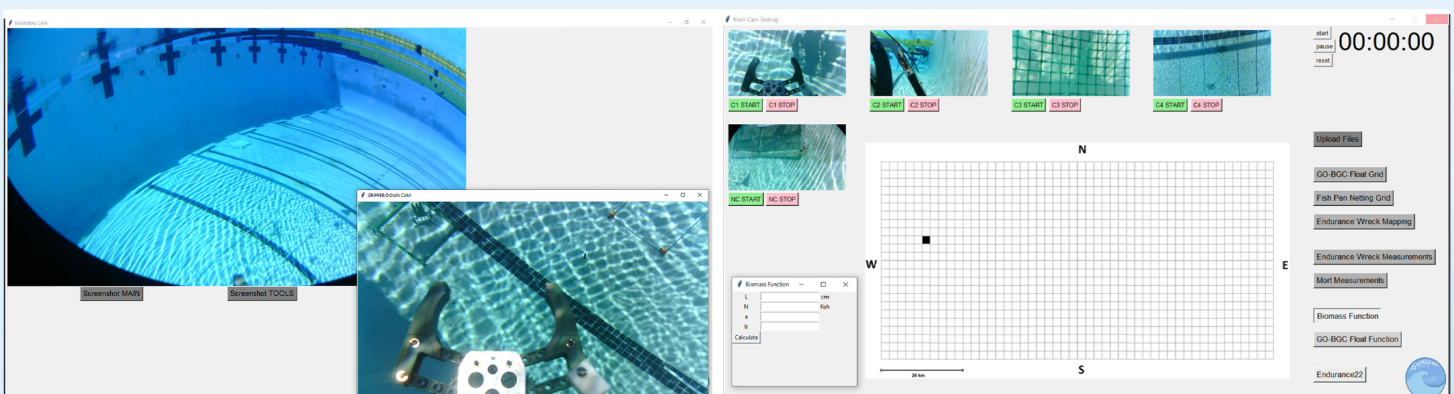

Figure 21. Graphical User Interface (GUI)
Photo by Lauren Jones

III. TESTING & TROUBLESHOOTING

Geneseas places great importance and spends numerous hours testing individual components and the ROV as a whole to verify functionality and continue development. 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 the thrusters are consistent with each other and that there are no manufacturing defects. This process isolates any problems to individual components and makes the integration of the ROV more efficient.

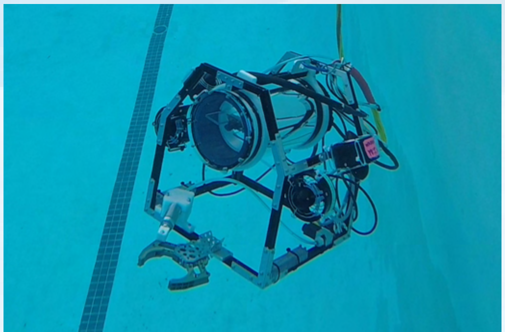

Figure 22. Pool Testing
Photo by Lauren Jones

After the basic frame of the ROV was complete, the core ROV was pool tested to verify the software and electronics systems worked as intended and *Beluga* could be easily and effectively piloted. Parallel improvements of software, electronics and mission tools proceeded from this point forward.

Before integrating each new tool onto the complete ROV, a *Geneseas* employee performed two different tests on the tool. The first test completed was 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, separately from the ROV. Once the tool was tested and any necessary design changes were made, the device was then integrated into the ROV.

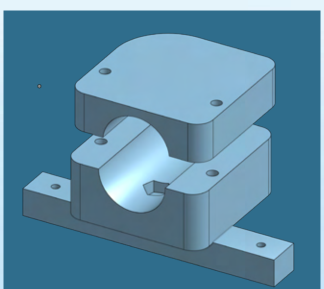

Figure 23. Piston Mount CAD
Photo by Lauren Jones

An example of a mission component that went through many design iterations was the gripper tool. Initially, there were stationary mounts to secure the gripper and piston to the frame. However, this design did not allow the system to function; when the actuator fired, the gripper arm was not able to close due to a lack of adjustment within the system. To fix this problem, we designated the piston side mount as our pivot point in the mechanical system. After several designs, a custom CAD piston mount was successfully manufactured and implemented.

Once several tools were integrated onto the ROV, mission strategy and pool practice began (Figure 24). 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 testing process. This is where the adjustable frame design showed its value: the ability to move components along the extruded aluminum rails was a key asset, allowing for quick adjustments. As a result of the researching, prototyping, testing, and implementation process, *Geneseas* built a robust ROV that was able to achieve nearly 80 hours of pool testing with minimal delays.

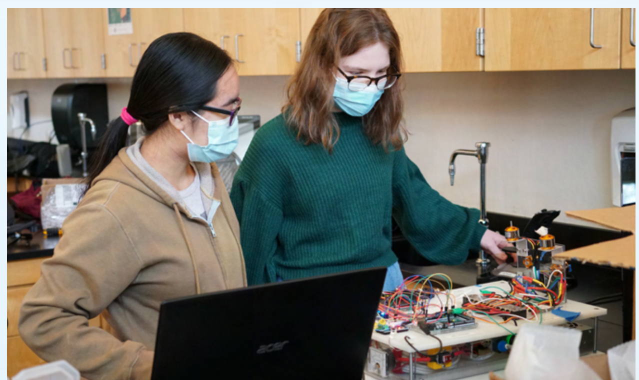

Figure 24. Programming Testing
Photo by Lauren Jones

The Software Team worked on code while the other subteams built the ROV in order to use time efÞciently. To accomplish this, the team built a test bench, adding on various electrical components such as motors and arduinos to stimulate the RPS and ROV. The test bench was an integral component to *Geneseas'* troubleshooting process. *Geneseas* team members were able to isolate the code and test it on the test bench after new sections were added, efÞciently locating potential bugs. This debugging process enabled the Software Team to locate and Þx software problems with the ROV while the rest of the team worked on other parts of the ROV. *Geneseas'* troubleshooting process is outlined in the Safety and

Operations Checklist (Appendix A). These testing and troubleshooting tactics and procedures have enabled Geneseas to quickly identify and solve issues with Beluga helping to maximize pool practice time.

IV. SAFETY

A. SAFETY PHILOSOPHY

Safety is *Geneseas* highest priority. 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. *Geneseas* continues to exceed safety guidelines outlined by MATE, creating and implementing original safety policies to ensure a safe and supportive learning and working environment. *Geneseas* maintains the safety of all employees and mentors through detailed and informative safety training focused on instructing employees how to avoid injuries and prevent accidents. The company educates its employees on lifting safety, electrical safety, tool safety, hazardous materials handling, and housekeeping. This safety ethic further extends to Beluga and its aquatic environment as demonstrated by the various 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, in addition to gloves, masks, ear plugs, and a recently adopted hard hat policy--all required to operate tools and handle certain materials while working in the lab.

Figure 25. Employee wearing safety gear while soldering
Photo by Lauren Jones

As part of *Geneseas'* training process, mentors and returning team members demonstrate safe usage of machines to new employees and supervise their use. Mentors and returning members 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. All employees remain vigilant in helping and reminding teammates to uphold the highest safety standards, ensuring everyone's safety.

Geneseas team members follow a detailed safety checklist when practicing in the water to ensure the safety of everyone on deck. The Pilot, Co-pilot, Safety Manager work in conjunction to adhere to the Safety Checklist and the protocols outlined in the Job Safety Analysis (JSA), ensuring the protection of all crew members. When working near water, employees exercise safety by keeping electrical cords and electronic devices away from moisture. *Geneseas* team members also use clear and direct communication between the pilot and the tether manager in order to reduce the risk of harm. Only the tether is allowed on the pool apron, and the ROV is thoroughly dried after all operations. The RPS, laptops, and pilot station are kept on an elevated platform to minimize any potential safety risks during pool operations.

Geneseas further maintains a safe work environment for its employees in the company's lab facility, which features a chemical vent hood to reduce 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. *Geneseas* ensures first aid kits and fire extinguishers are readily available, and through proper training, the company implements preemptive safety measures. These safety measures and methods of employee training have been very effective in educating employees on potential hazards and preventing the occurrence of preventable accidents or injuries.

C. VEHICLE SAFETY FEATURES

Geneseas' integration of safety into their design process is reflected in *Beluga's* many safety features. The safety features incorporated into the ROV and RPS to prevent accidents, avoid injuries, and enable swift responses to potentially dangerous situations.

Safety Feature	Description
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	*Beluga'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 *Beluga's* digital voltmeter.
ROV Digital Voltmeter	A digital voltmeter installed inside the ROV electronics housing displays the voltage of the ROV system.
Handles	A handle is attached to the top of the ROV to allow for its safe removal of 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 26. *Geneseas* Safety Checklist
Photo by Lauren Jones

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

D. OPERATIONS AND SAFETY CHECKLISTS

Geneseas develops and utilizes operation and safety checklists (Appendix X) to ensure the safety of employees, customers, and bystanders in the launch, operation, and retrieval of Beluga.

V. LOGISTICS

A. SCHEDULED PROJECT MANAGEMENT

Geneseas used a detailed project management process to assist with managing work assignments and overall project deadlines. This year, the *Geneseas* team met every Monday beginning in October and added Wednesday and Saturday meetings in January 2022.

Each subteam, responsible for an ROV subsystem, created a project planning spreadsheet at the beginning of the year and updated it throughout the year (Figure 27). This spreadsheet provided team members with a clear plan for tasks to accomplish at each meeting, materials needed to order, the timeline to order them, and the overall amount of time each task was expected to take. This spreadsheet kept subteams on schedule to ensure their components were ready for the initial in-pool test, taking place in February, and the initial tools test scheduled for March. The detailed schedules created by each subteam specify both the amount of time a task is expected to take and the date when the task will be worked on. Upon completion of the task, the task is checked off the list. This planning process helped advance the manufacturing of *Beluga* while allowing *Geneseas* team members to learn the value of effective time management.

In early January, the *Geneseas* CEO worked with coaching staff to determine pool availability and set dates and times for pool testing and pool practices. This was recorded in a spreadsheet that tracks the amount of pool practice and testing the team is doing (Figure 28). This spreadsheet allows the Leadership Board to evaluate if the team is on track and if the pilot has enough time to practice and perfect mission operations.

Through effective use of schedules and standup meetings at each practice to set goals and analyze progress, *Geneseas* team members were able to maximize lab time and improve communication amongst subteams. Intentional use of these planning protocols and procedures also enabled the team to optimize our most useful asset: new members. New team members joined tool development teams and have been invaluable in furthering the design evolution of tools. By integrating these members and teaching them to create and follow effective schedules, *Geneseas* was able to design *Beluga* to be highly specialized and capable of completing all mission tasks. This schedule has enabled *Geneseas* to effectively achieve mission requirements and set a structure and schedule for day to day operations, solving many previous operational issues.

Task	Amount of time needed to complete	Dates	Completed?
Latency Testing	4 hours	11/08/21 and 11/15/21	✅
Camera Decision and Parts ordering	3 hours	11/29/21	✅
Camera System Concept Review with Team	3 hours	12/06/21	✅
Nav Camera builid and wiring	3 hours	12/13/21	✅
Turn off autofocus on cameras	2-3 hours	01/10/22	✅
Building extra nav cam systems	3 hours	01/12/22	✅
Building servo motor for camera	2 hours for planning and ordering materials, 3 hours to create the 3d print, 1 hour for set up: 6 hours total	01/19/22	✅
Testing nav cam with code	2 hours	01/24/22	✅
Building Camera Box	4 hours for physical building, 2 hours water testing in bucket, 4 hours testing at depth: repeat 2 times: ~20 hours of build time	01/26/22, 01/31/22, 02/07/22, 02/12/22	✅
Camera box electrical	Soldering: 2 hours for first box: 6-7 hours total for soldering, set up and testing: 2 hours: total: 8 hours	02/14/22, 02/19/22	✅
Complete building of box:	Piece together boxes: 3 hours, vision testing: 2 hours, total: 5 hours	02/21/22	✅
Camera enclosure	Brainstorming and planning: 2.5 hours, 3D modeling 3 hours, Building: 4 hours, waterproof testing: 4 hours , total: 14 hours	02/23/22, 02/26/22, 02/28/22	✅
In pool testing and adjustments	4 hours	03/05/22	✅
Placement and mounting mission cameras	3 hours	03/12/22	✅
Total amount of time to be ready for initial pool test in February	14 hours	Completed: 01/24/22	✅
Amount of time to be ready for competition: must be done by mid March:	~ 65 hours (including time to get ready for pool test)	Completed: 03/12/22	✅

Figure 27. *Geneseas* Project Planning
Photo by Lauren Jones

Date	Number of hours in pool	Goals of pool practice
02/18/22	3 hours	Test functionality of core ROV
02/25/22	4 hours	Test thruster movements and pneumatic gripper tool
03/05/22	2 hours	Test functionality of camera system within the water
03/12/22	4 hours	Test pneumatic gripper tool and measurement tool
03/19/22	4 hours	Verify functionality of photomosaic image recognition program and continue testing tools
04/02/22	4 hours	Test gripper tools on manufactured props and note improvement that need to be made
04/09/22	6 hours	Testing gripper, measuring tool, buoyancy engine, and electromagnet functionality
04/11/22	6 hours	Testing tools on Task 1. Practicing each individual
04/12/22	6 hours	Testing tools on Task 2. Practing each
04/13/22	6 hours	Testing Tools on Task 3
04/14/22	6 hours	Testing tools on tasks 1, 2, and 3. Spending extra time on difficult tasks and tasks worth more points
04/15/22	6 hours	Begin 15 minute mission run throughs. Asses between mission and decide order and which tasks need more practice
04/16/22	6 hours	Practice 15 minutes mission run throughs as well as set up and takedown
04/18/22	6 hours	Practice 15 minutes mission run throughs as well as set up and takedown
04/19/22	6 hours	Practice 15 minutes mission run throughs as well as set up and takedown
04/20/22	6 hours	Spend time on tasks that need extra attention to perfect approach (about 3 hours). Dedicate rest of time to mission run throughs
04/21/22	6 hours	Spend time on tasks that need extra attention to perfect approach (about 3 hours). Dedicate rest of time to mission run throughs
04/22/22	6 hours	Spend time on tasks that need extra attention to perfect approach (about 3 hours). Dedicate rest of time to mission run throughs

Figure 28. *Geneseas* Pool Test Planning leading up to Regionals
Photo by Lauren Jones

B. COMPANY STRUCTURE AND TRAINING

Geneseas is a four-year-old company of twenty-one women. The all-female team is organized into 6 subteams, each responsible for a separate section of the ROV. These six subteams are Electronics, Mechanical, Movement Software, Image Recognition Software, Vision, and Tool Development. Each subteam is run by a team leader who develops a schedule, provides feedback, and determines the instruction process of the new members within their subteam. The leaders of the six respective subteams comprise the Leadership Board which works to collaborate on scheduling, project development, and design reviews. The Leadership Board heads the standups at the beginning of the meetings, specifying daily objectives and progress updates. The Leadership Board also works to lead closeouts at the end of each meeting, reviewing each subteam accomplishments and providing an update on the subteam's progress against the schedule timeline.

The Leadership Board is headed by the CEO who works to manage team progress and mentorship, create a schedule, and supervise documentation. The team CFO creates the budget and tracks it throughout the year. The CFO also creates an order form which the team uses to place orders. The team Chief Marketing Officer (CMO) works closely with the CEO on documenting team progress through photos, advertising, promoting the team, and creating team merchandise.

Geneseas utilizes a peer-to-peer system for the training of new employees. The training system involves returning employees mentoring newly-hired employees. This mentorship allows new team members to observe experienced employees operating tools and machinery as well as going through the design and development process. Experienced members are responsible for ensuring that new members know how to safely and effectively use equipment and follow lab safety protocols. Returning employees who have demonstrated leadership skills and technical expertise begin leading subteams, where they oversee the development of a specific section of the ROV, mentoring the new members who work in their subteam along the way.

Figure 29. *Geneseas* member explains RPS
Photo by Lauren Jones

Within each of these subteams, returning members are able to use their previous knowledge and experience to implement new ideas. The returning members also serve as mentors and guide the new members who are able to learn about the subsystem by shadowing and working with the subteam leaders. The subteam model has enabled *Geneseas* to make significant progress and advancements in multiple areas while simultaneously training new members and reinforcing the knowledge of returning team members as they develop their leadership skills.

C. COLLABORATIVE WORKSPACE

Geneseas uses a widely accessible cloud storage system, Google Drive, to share important information regarding scheduling, project design, and documentation. Using a shared Google Drive enables the team to collaborate on schedules and documentation, and access documentation from previous years for reference. This shared document repository centralizes company information, including training, past design proposals, and company operational processes, making it readily available to all employees and mentors.

Geneseas utilizes a team OnShape account to collaborate on drawings, projects, and assemblies. The shared OnShape resource allows all members of the team to access and edit CAD documents. This shared repository enables subteams and the team as a whole to approach prototyping with precision by importing created files of real parts that are being used on the ROV. The OnShape CAD software allows for more effective design reviews and teaches all members important skills in design, prototyping, and revision.

D. CODE MANAGEMENT

Just prior to last year's international competition, the software team could not access the ROV source code due to a hard drive malfunction. As a result of this, the team was determined to improve source code management. *Geneseas* chose to use Github, an online source code repository that ensures none of the code is lost. Github additionally allows members of the software team to collaborate smoothly by merging source code updates from multiple team members.

Github uses a push-pull model. Software team members can push (export) code into the online repository and pull (import) code onto their local computer. When code is pushed to Github, changes appear on a common code branch, which can further be merged into the main branch. The platform will also notify users if there is a merge conflict.

The software team utilizes Github for all of the source code, including: image recognition, motion control, communications software, and the buoyancy engine.

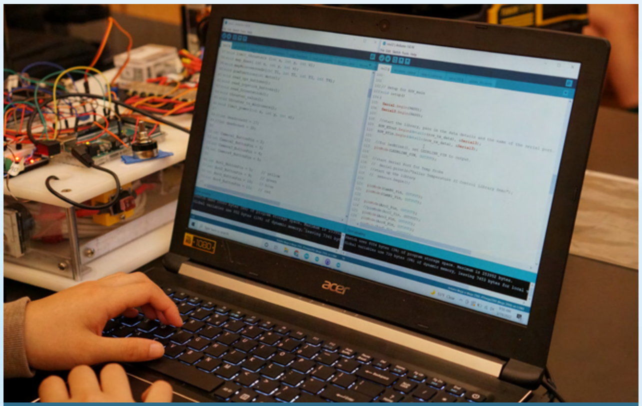

Figure 30. Preparing to push control code
Photo by Lauren Jones

The transition to Github has been incredibly successful in streamlining the software development process. This will be the foundation for the *Geneseas* software team for the foreseeable future.

E. BUDGET AND PROJECT COSTING

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. St. Francis High School provided Geneseas a $10,500 budget to cover materials and operations costs. Based on the previous years spending patterns, Geneseas allotted $4,500 to ROV production costs, $1,000 to spare parts and tools, and $5,000 towards operations expenses. To ensure effective use of our budget, all purchases are submitted as requests into a Google Form. The Coaches review the purchase request forms to review and approve purchases. Costs of new parts and all reused parts for Beluga are entered into a project costing sheet each month and tracked against the budget. The 2021-2022 Budget and Project Costing report is shown in Appendix 2. Geneseas stayed $4,697.90 under the budget by employing effective cost management strategies like seeking donations and carefully evaluating whether materials should be purchased, built, or reused.

When deciding how to source materials, Geneseas team members evaluated the overall market value for a specific item and compared it with the costs and benefits of manufacturing these products ourselves. Geneseas opted to purchase components such as the electronic enclosures and Arduino boards due to their reliability. Purchasing off the shelf components enables team members to ensure the reliability of the system. Geneseas tries to limit the amount of off the shelf components purchased and aims to manufacture the majority of our own components. Team members chose to manufacture parts such as the end plate of the electronics housing, gripper, and more for affordability and increased customization to fit the needs of the ROV. Building components like the gripper has enabled Geneseas to have complete control over the design and manufacturing process, ensuring that the final product is custom-made to perform specific mission tasks such as pruning seagrass or replacing sections of the inter-array power cable.

Geneseas focuses on sustainability and achieves this through reusing parts from previous ROVs. When deciding which parts to buy new or re-use, Geneseas evaluates the condition of the component by performing thorough testing and verifying functionality. This year, Geneseas reused several components such as four T-100 thrusters, a tether, and electronic components such as shunts and gauges. By reusing thrusters, Geneseas ensured reliability and ease of piloting associated with the effective T100 thrusters. Reusing materials also allowed Geneseas to maintain affordability and reliability by using parts that were thoroughly tested and well maintained from previous years. When materials were not able to be reused due to issues with reliability or functionality, they were re-purchased. Cost management strategies of custom building components, reusing reliable parts, and only purchasing materials with extreme reliability enabled the Geneseas team to produce a highly effective and affordable ROV.

VI. CONCLUSION

A. CHALLENGES

Geneseas encountered three major challenges this past year. First, *Geneseas* faced a challenge with access to the lab for our most complex machining operations. *Geneseas* typically shares the Jesuit lab and workspace, which is equipped with shop machinery such as a CNC machine, a digital milling machine, and 3D printers. However, this year we were unable to utilize this workspace until halfway through the build, which limited our immediate access to tooling and added time to the schedule. Planning and communicating the need for use of machinery and finding alternate manufacturing methods helped *Geneseas* work through this operational challenge.

Geneseas gained many new employees this season, which initially posed a challenge to scheduling and delegating tasks. Returning members were challenged with parallel development of mission tools, building the core ROV, and on-boarding of new members. On the other hand, new members were challenged with balancing learning and contributing simultaneously. This included understanding how the team works, learning new lab procedures, and training in mechanical, electrical and software basics.

Finally, *Geneseas* faced a challenge balancing the development of software with the software team expansion. This year, the software team expanded from one member to six members. Therefore, this subteam had to simultaneously mentor first year members while incorporating new code on the core ROV. This required adjustment to the operation of the software team which delayed the initial completion of the software.

B. LESSONS LEARNED

This year, *Geneseas* employees gained many technical skills including improved programming and electronics abilities. Team members learned how to code in C, C++, Python, and Java, and expanded their knowledge of electrical components that require waterproofing. 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. This year, the transition from analog to digital cameras was made, as well as new developments in graphical user interface, creating an advanced and robust ROV.

Several meetings at the beginning of the season were spent learning CAD software through the program OnShape. This training aided the tool development process by improving our company's ability to virtually preview and simulate prototypes, which led to more technical and professional design reviews. Employees gained an appreciation for technological applications within the design process, and these new skills undeniably strengthened the company.

A non-technical lesson learned was how 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

Figure 31. New members learning technical skills
Photo by Lauren Jones

programming and vision systems members. *Geneseas* employees successfully facilitated communication and created a productive, efficient and collaborative working environment.

C. FUTURE IMPROVEMENTS REFLECTION

Geneseas is focused on continuous improvement. *Geneseas* has an ambitious plan for new improvements to implement on next year's ROV. The plans include improving the ROV's electrical and mechanical capabilities by switching from Arduino to Raspberry PI, making our first-ever custom electronics boards, and implementing 6 thrusters. Implementing a Raspberry Pi will enhance image recognition and enable autonomous ROV control, and custom electronic boards will simplify wiring and improve electro-mechanical reliability. Finally, *Geneseas* plans to expand our 4-thruster arcade drive system to an improved, 6-thruster vector drive system. This will refine our movement and allow the ROV to move laterally to more effectively complete the mission tasks.

Geneseas also plans on taking more responsibility for the lab and workspace at St. Francis High School. The St. Francis lab space has been out of operation for the past four years. The *Geneseas* team plans to organize and upgrade the lab space during the summer of 2022 to enhance our design and manufacturing capabilities. Implementing a stricter and more efficient organization system and obtaining the resources necessary for a fully capable lab are top priorities for a lab redesign.

Another *Geneseas'* goal is to improve our teaching and mentoring process to foster team growth and development through improved communication. Large improvements in the mentoring process were made this year with the addition of team meetings that taught skills and concepts such as CAD software, soldering, and design process to all team members regardless of subteams. *Geneseas* plans on continuing to expand this important aspect of our professional development.

D. ACKNOWLEDGEMENTS

Geneseas would like to express our appreciation and gratitude for the opportunity to participate in the MATE program. Thank you to MATE Center and Marine Technology Society, Sponsor of the 2022 competition along with MATE II, the National Science Foundation, Oceaneering International, Ocean Infinity, and Reach the World for their continued support of the MATE competition and providing this incredible educational opportunity.

We would like to acknowledge the following for contributing to the success of our company:

- St. Francis Catholic High School for the generous donation of funding, support, and laboratory space.
- St. Francis Coaches: Kitara Crain, Maurice Velandia, and Marcus Grindstaff for your time, experience, dedication, knowledge and guidance. Your patience and commitment fostered a team environment focused on learning and fun.
- Jesuit mentors who have supported us with technical and non-technical advice through our design process. Thank you Jesuit *Rovotics* for the use of your pool and lab facilities.
- To Kitara Crain and Cheryl Kiyama for being role models who inspire and guide us to be "Women who change the world".

Additionally, *Geneseas* would like to recognize several sponsors and individuals for their generous support. Thank you to our sponsors who helped *Geneseas* this past year: TAP Plastics for the donation of stock plastic, SolidWorks for the donation of SolidWorks 3D Software and MacArtney Connectors for providing connectors at a reduced cost.

Finally and most importantly, we would like to express our heartfelt gratitude to our families for all of their guidance and support.

Figure 32. *Geneseas'* incredible coaches
Photo by Mark Honbo

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VII. APPENDICES

A. OPERATIONS & SAFETY CHECKLIST

Pre-Power (Pilot, Co-pilot, and Deck Crew)

- ☐ Area is clear and safe (no tripping hazards or obstructions)
- ☐ All team members are wearing safety glasses
- ☐ Verify RPS power switches are off
- ☐ Tether laid out on the deck and is free of damage
- ☐ Tether is connected and secured to the RPS
- ☐ Tether is connected to strain relief and secured to ROV
- ☐ Power source connected to RPS
- ☐ Verify electronics housing is properly sealed and fasteners are tightened
- ☐ Visual inspection of electronics for damaged wires or loose connections
- ☐ Vacuum test electronics housing (see Vacuum Test below)
- ☐ Vacuum port is securely capped
- ☐ Thrusters are free from obstructions

Vacuum Test (Deck Crew)

- ☐ Verify electronics housing and CEH are properly sealed
- ☐ Connect vacuum pump to the electronics housing and CEH
- ☐ Vacuum down the electronics housing and CEH to ~10 Hg and verify they hold this pressure for 10 minutes
- ☐ Remove vacuum pump and securely cap vacuum port
- ☐ Return vacuum hand pump to case

Power-Up (Pilot, Co-pilot, and Deck Crew)

- ☐ Verify RPS is receiving 12V nominal
- ☐ Control computers up and running
- ☐ Ensure deck crew members are attentive
- ☐ The Co-Pilot calls out, "power on!"
- ☐ Power on RPS
- ☐ Co-Pilot calls out, "performing thruster test"
- ☐ Test thrusters and verify thrusters are working properly
- ☐ Verify video feeds from navigation and mission cameras
- ☐ Ensure Cameras are positioned correctly
- ☐ Test electrical and pneumatic components that require pilot input (See Pneumatic System Test Below)

Inspect and Test Pneumatic System (Pilot, Copilot)

- ☐ Verify all pneumatics lines on RPS and ROV are properly connected to the MATE air supply.
- ☐ Verify that the compressor is switched on
- ☐ Adjust pressure regulator to 40 PSI
- ☐ Activate pneumatics system and open main valve
- ☐ Verify there are no leaks and pneumatic lines are securely connected while under pressure
- ☐ Activate pneumatic tools and verify the pressure returns to 40 PSI after the tool is shut off.

ROV Launch (Pilot, Co-pilot, and Deck Crew)

- ☐ Deck crew members handling ROV call out, "hands on!"
- ☐ Carefully place ROV in the water
- ☐ Check for bubbles
- ☐ Visually inspect for water leaks
- ☐ If there are large bubbles, pull to surface immediately and proceed with Leak Detection Protocol
- ☐ If no issues are detected call out, "prepare to launch"
- ☐ Deck crew members handling ROV remove their hands from the vehicle and call out, "hands off!"
- ☐ Co-pilot calls out "thrusters engaged" and pilot begins mission

ROV Retrieval (Pilot, Co-pilot, and Deck Crew)

- ☐ The pilot calls out, "ROV surfacing"
- ☐ Deck crew calls out, "ROV on surface. Disable thrusters"
- ☐ Co-pilot calls out, "thrusters diabled"
- ☐ Deck Crew call out, "hands on," and remove ROV from water
- ☐ Co-Pilot calls out, "safe to remove ROV"
- ☐ After securing the ROV on deck, deck crew calls out, "ROV secured on deck"
- ☐ Co-Pilot powers down RPS
- ☐ Team begins demobilizing

Leak Detection (Pilot, Co-pilot, and Deck Crew)

- ☐ Immediately power down the ROV and RPS systems and remove the ROV from the water if a mission is occurring
- ☐ Visually inspect ROV to identify the source of the leak. Do not disassemble any part of the ROV until the source of the leak is detected
- ☐ Install pressure testing equipment and use soapy water to verify the source of the leak.
- ☐ Create a plan and repair the leak
- ☐ Check all systems for damage and verify proper operation
- ☐ Document the source and cause of the leak and detail the corrective actions and design changes made.

Loss of Communication (Pilot, Co-pilot, and Deck Crew)

- ☐ 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
- ☐ If communication has not been restored, begin troubleshooting procedures and isolate the issue. Determine if the issue is with hardware or software.
- ☐ Document the problem and detail the corrective actions made to solve the problem.

Pit Maintenance (All Team Members)

- ☐ Pit is well organized and free of debris
- ☐ All tools, cables, and equipment are safely stored in their designated spaces and there are no tripping hazards
- ☐ Check electrical cords and correct any electrical hazards
- ☐ Check supplies and organize a shopping list if anything is needed for repair or upkeep.
- ☐ Verify RPS, ROV and tether are clean, dry and stored.
- ☐ Protective caps for electrical connectors are in place
- ☐ ROV, RPS and tether have been readied for use on the next mission run

Figure 33. Safety Checklist *Geneseas* uses when operating
Photo by Lauren Jones

B. BUDGET AND PROJECT COSTING

2022 Geneseas Beginning of Season Budget				
Source				**Amount**
St. Francis High School Grant				$10,500.00
Expenses				
Category	**Type**	**Description**	**Projected Cost**	**Budgeted Value**
Mechanical	Purchased	15 x 15 extruded aluminium, hardware, 6 inch Blue Robotics Tube	$500.00	$500.00
Thrusters	Reused	Reused Thruster form the previous years ROV	$800.00	$800.00
Electronics	Reused and Purchased	The materials for the RPS, tether, and electronics housing.	$1,450.00	$1,450.00
Vision	Purchased	Camera Enclosures, USB Camera Boards, USB to ethernet transcievers	$500.00	$500.00
Tools	Purchased	The materials to manufacture the gripper, measuring tool, and all of the other payload tools as well as the pneumatics system	$350.00	$350.00
Operations	Purchased	Team uniforms, Props, MATE entry fee, fluid power quiz fee, marketing display, spare parts, lab tools, raw materials, and general supplies	$3,100.00	$3,100.00
Travel Expenses	Donated and Purchased	The price of lodging at the competition	$3,800.00	$2,800.00
Total Income:	$10,500.00			
Total Expenses:	$6,302.10			
Total Expenses Reuse/Donations:	$2,150.00			
Total Fundraising Needed:	Non-Applicable			

Income Source	**Type**	**Description**	**Budget**			
St. Francis High School	Avaliable Income	Funding provided to Geneseas by St. Francis High School for operations and expenses	$10,500.00			
MATE Competition	Donated Income	A travel granted won by Geneseas at the regional competition intended to be used for travel and lodging expenses for the World Championship	$500.00			
Production Costs	**Type**	**Description**	**Budget**	**Project Cost**	**Difference**	**Running Balance**
Mechanical	Purchased	15x15 strut, hardware, Blue Robotics Tube, etc	$500.00	$471.00	$29.00	$471.00
Thrusters	Reused*	4 T-100 Blue Robotics Thrusters* and ESCs*	$800.00	$0.00	$800.00	$471.00
RPS (Remote Piloting Station)	Purchased / Reused*	Dewalt box, gauges*, shunt*, wire, buttons, connectors	$250.00	$161.15	$88.85	$632.15
Tether	Reused*	3 SubConn Connectors*, wire*, CAT 6 ethernet cables*, Pneumatic tubing*	$400.00	$0.00	$400.00	$632.15
Camera System	Purchased	Camera Enclosures, USB Camera Boards, USB to ethernet transcievers	$500.00	$486.56	$13.44	$1,118.71
Electronics & Connectors	Purchased	Electrical boards and chips, sensors	$700.00	$674.49	$25.51	$1,793.20
Pneumatics	Reused*	Values*, fittings*, Piston*	$100.00	$67.20	$32.80	$1,860.40
Mission Tools	Purchased	Laser & temperature probe were borrowed, all plastics, metals, motors, magnets were purchased	$250.00	$160.59	$89.41	$2,020.99
General Supplies	Purchased	Glues, hardware, solder	$600.00	$476.15	$123.85	$2,497.14
Raw materials	Purchased	Stock Material	$300.00	$254.00	$46.00	$2,751.14
Raw materials	Donated**	Polycarbonate**, HDPE** and Acrylic Plastics** donated by TAP Plastics	$100.00	$0.00	$100.00	$2,751.14
Total Production Costs			**$4,500.00**	**$2,751.14**	**$1,748.86**	**$2,751.14**
Spare Parts & Tools	**Type**	**Description**	**Budget**	**Project Cost**	**Difference**	**Running Balance**
Spare Parts	Purchased	2 T-100 Thrusters, Electronics tray, o-rings, Arduino, ESC	$500.00	$315.06	$184.94	$3,066.20
Tools	Purchased	soldering supplies, vacuum seal tool, etc	$500.00	$352.13	$147.87	$3,418.33
Total Spare Parts & Tools Cost		**Spare Parts & Tools**	**$1,000.00**	**$667.19**	**$332.81**	**$3,418.33**
Operations Expenses	**Type**	**Description**	**Budget**	**Project Cost**	**Difference**	**Running Balance**
Competition Transportation	Donated	Geneseas team members will travel to Long Beach in the St. Francis bus, donated for 6 days of use by St. Francis High School	$1,000.00	$0.00	$0	$3,418.33
Competition Meal Expenses and Lodging	Purchased/ Donated	Geneseas will be occupying 9 hotel rooms to house our team members and coaching staff for the duration of the competition some of this cost will be covered by the $500 stiped the team recieved for winning the Monterey Regional. Team members and their families will be responsible for contributing to paying for the cost of their food at team meals.	$2,800.00	$2,061.00	$239	$5,479.33
Uniforms	Purchased	T-Shirts for team and mentors	$300.00	$259.15	$40.85	$5,738.48
Mission Props	Purchased	MATE mission props	$425.00	$198.62	$226.38	$5,937.10
MATE Entry Fee	Purchased	MATE entry fee	$200.00	$200.00	$0.00	$6,137.10
Power Fluid Quiz Fee	Purchased	MATE power fluid quiz	$25	$25.00	$0.00	$6,162.10
Marketing	Purchased	Report copies, display, brochure printing & software cost	$250.00	$140.00	$90.00	$6,302.10
Total Operations Expenses		**Operations Expenses**	**$5,000.00**	**$3,706.54**	**$1,293.46**	**$6,302.10**
Total			**$11,000.00**	**$6,302.10**	**$4,697.90**	
Total Annual Budget: $9,500.00			* = indicates reused materials			
Total Annual Expenses: $6,302.10			** = indicates donated materials			
Total Amount Saved: $3,197.90						

Figure 34. & Figure 35. *Geneseas* 2022 Budget Project & Project Costing
Photo by Lauren Jones