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HYDROMEDA

2023 - 2024

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Director of Safety	**Aru Chezhian**
Director of Software Engineering	**Naveen Mukkatt**
Float Director	**Spencer Franckowiak**

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ABSTRACT

We are Hydromeda, the MATE division of the underwater robotics organization founded by our CEO at the University of Texas at Dallas. For the 2024 MATE ROV Competition, we are excited to introduce VESPA, our first-ever Remotely Operated Vehicle (ROV). VESPA is designed to meet this year's mission objectives, which include maintaining energy infrastructure and supporting offshore aquaculture.

Named after the swift and agile vespa wasp, VESPA embodies a compact design while maximizing functionality. Our team utilized advanced mechanical and electrical CAD tools, along with robust simulation software, to ensure VESPA's exceptional performance. This project marks our first ever venture into ROV design and development, representing the culmination of relentless effort and innovation from our dedicated team members.

As first-time participants, our primary objectives for VESPA were to establish a reliable design foundation, achieve efficient power management, optimize mechanical structure, and have advanced vision and manipulation capabilities. Through rigorous testing and iterative development, VESPA has proven to be maneuverable, user-friendly, and dependable.

This document outlines our comprehensive engineering design process, highlighting our focus on continuous improvement, lifecycle management, and safety. We aim to share our experiences and methodologies with the broader ROV community to contribute to the collective advancement and performance of all teams in future competitions.

SAFETY

Philosophy

Safety is a top priority at Hydromeda. Whenever a design decision is being made, safety is the first consideration. An ROV is unusable if it harms its users. With all of our members, we encourage continuous improvement of safety practices as there is always room to strengthen and improve our safety protocols.

Standards

Hydromeda ensures safety in their manufacturing process by requiring gloves and safety glasses when handling power tools and working with unsafe chemicals. Respirators are required during any sanding, spray painting, soldering, or when dealing with fumes. While operating the ROV, safety is ensured by a ten minute leak test before any power is sent to the ROV, sectioning off the area around the tether, and clear communication while the ROV is operating in the water. When working with any electrical power, we follow strict guidelines such as ensuring low voltage and high voltage devices that are live are separated and powered off if disconnected, avoiding any possible injuries and damage to components. Most importantly, at each testing phase and launch, we follow our custom checklist and educate all members on common practices (Ex: Not stepping over the tether to avoid tripping), and emergency shutoff locations (Ex: When the VESPA is behaving erratically or leaking water into the enclosure)

Features

In order to ensure no excessive electrical current is run through the ROV, multiple safety features are incorporated in the design. One of the most important features we have is having a fuse and a circuit breaker in line. Having a 40 Amp circuit breaker behind a 30 Amp Fuse allows us to quickly trip the circuit if any electrical fires or abnormal behaviors occur. Not only does this protect the ROV components, but it also minimizes damages that can occur. Whenever any wiring is being handled by Hydromeda members, not only is the main power disconnected, but the 40 amp circuit breaker is tripped to minimize electrical hazards.

Both the ROV and the topside case have strain reliefs connected to the tether to isolate tension from the cable connectors. This keeps cables from coming undone in an unsafe manner, and also allows the ROV to be removed from the pool safely. In addition, thruster guards were designed with extra precaution to guarantee the safety of any appendages placed near the thrusters; with eighth-inch gaps, the guards exceed safety requirements.

Figure 1: Member wearing PPE

TEAMWORK

Company and Personnel Overview:

Hydromeda is the MATE division of the underwater robotics organization named RoboSub at UTD. RoboSub at UTD is not to be confused with the "RoboSub" competition. As a registered student organization at UTD, Hydromeda is committed to advancing underwater robotics through innovation, collaboration, and competition. Our team, composed of dedicated undergraduate students, is focused on designing, building, and competing with ROVs in the International MATE ROV Competition. Hydromeda is also in close partnership with the Humanoid, Biorobotics and Smart Systems (HBS) Laboratory which is led by Dr. Tadesse.


Figure 2: ROV Deployment Team

Given the interdisciplinary nature of our work, close collaboration and shared knowledge are vital to our success. To effectively manage our projects and ensure seamless collaboration, our team is organized into four specialized divisions:

Business: This division handles fundraising, sponsorships, budgeting, and marketing efforts. They ensure that the team has the necessary resources and visibility to succeed in competitions and outreach initiatives.


Figure 3: Team Inspecting electronics

Mechanical: Responsible for the physical design and construction of the ROV, the Mechanical division focuses on creating robust and efficient structures that can withstand challenging underwater environments.


Figure 4: Hydromeda 2024 Team

Software: This division develops the control systems and software applications that enable the ROV to perform its tasks. They design algorithms, and user interfaces, and ensure seamless integration with hardware components.

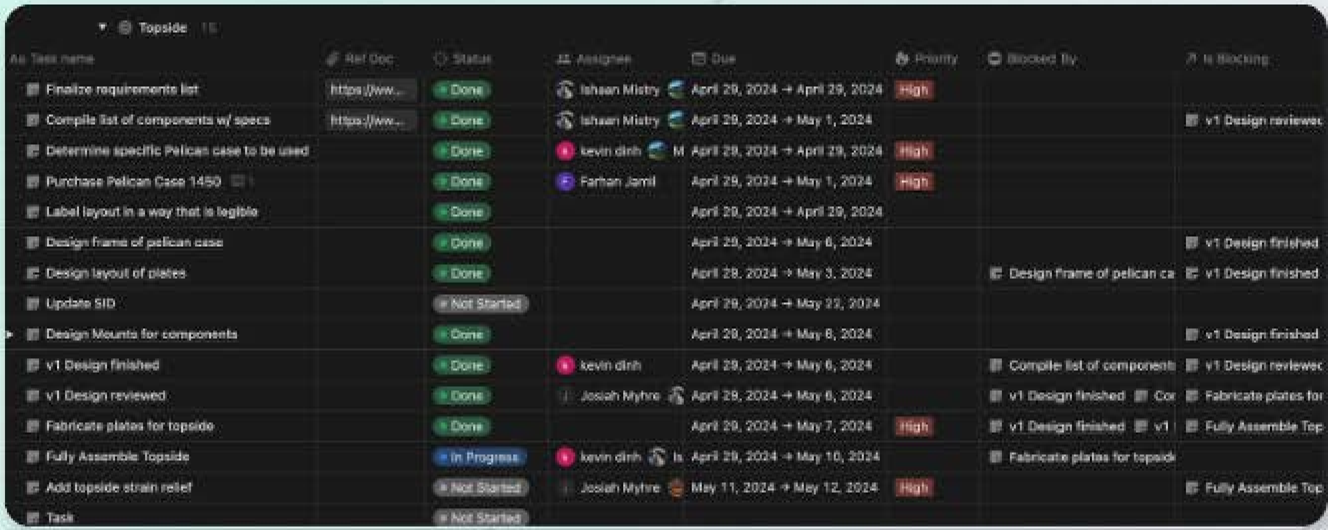
Electrical: The Electrical division is in charge of designing and implementing the electronic systems that power and control the ROV. This includes power distribution, sensor integration, and communication systems.

Project Management:

At Hydromeda, effective project management is essential to the successful development and deployment of our ROV, VESPA. The following strategies are used to ensure organization, efficiency, and continuous progress throughout the engineering process.

- **Iterative reviews:** We use an agile approach, dividing our work into 2-4 week sprints. After each sprint, we review progress, address challenges, and adjust plans. This iterative process allows us to continuously improve and adapt to new requirements or unforeseen issues.
- **Scheduling checkpoints:** We establish clear milestones and deadlines for each phase of the project. This includes setting specific goals for design, prototyping, testing, and final implementation stages. Regularly monitoring these milestones ensures that we remain on schedule and can address any delays promptly.
- **Notion software:** We utilize Notion to create detailed task lists and assign responsibilities to team members. Each task is clearly defined with specific deliverables and deadlines, ensuring accountability and clarity.
- **Team meetings:** We hold weekly team meetings to discuss progress, share updates, and resolve any issues. These meetings foster open communication and collaboration, ensuring that everyone is aligned with the project goals. Additionally, subgroup meetings are held as needed to focus on specific areas of development.
- **Documentation:** Maintaining comprehensive documentation is crucial for keeping the team informed and ensuring continuity. We use Google Drive and Notion to store design documents, meeting notes, and technical specifications.
- **Safe and effective protocols:** Throughout the development process, we implement quality assurance and testing protocols. Regular testing phases are scheduled to evaluate the ROV's performance, reliability, and safety. Feedback from these tests is used to refine and improve the design, ensuring that the final product meets high standards of quality. (See Appendix A3)

We emphasize continuous learning and mentorship within the team. Experienced members provide guidance and support to newer members, fostering a culture of knowledge sharing and skill development. This approach not only enhances the team's capabilities but also ensures that we are constantly evolving and improving our processes.



Topside 15

Task name	Ref Doc	Status	Assignee	Due	Priority	Blocked By	Is Blocking
Finalize requirements list	https://ww...	Done	Ishaan Mistry	April 29, 2024 → April 29, 2024	High		
Compile list of components w/ specs	https://ww...	Done	Ishaan Mistry	April 29, 2024 → May 1, 2024			v1 Design reviewed
Determine specific Pelican case to be used		Done	kevin dinh M	April 29, 2024 → April 29, 2024	High		
Purchase Pelican Case 1450		Done	Farhan Jamil	April 29, 2024 → May 1, 2024	High		
Label layout in a way that is legible		Done		April 29, 2024 → April 29, 2024			
Design frame of pelican case		Done		April 29, 2024 → May 6, 2024			v1 Design finished
Design layout of plates		Done		April 28, 2024 → May 3, 2024		Design frame of pelican ca	v1 Design finished
Update SID		Not Started		April 29, 2024 → May 22, 2024			
Design Mounts for components		Done		April 29, 2024 → May 6, 2024			v1 Design finished
v1 Design finished		Done	kevin dinh	April 29, 2024 → May 6, 2024		Compile list of component	v1 Design reviewed
v1 Design reviewed		Done	Josiah Myhre	April 28, 2024 → May 6, 2024		v1 Design finished Cor	Fabricate plates for
Fabricate plates for topside		Done		April 29, 2024 → May 7, 2024	High	v1 Design finished v1	Fully Assemble Top
Fully Assemble Topside		In Progress	kevin dinh Is	April 29, 2024 → May 10, 2024		Fabricate plates for topside	
Add topside strain relief		Not Started	Josiah Myhre	May 11, 2024 → May 12, 2024	High		Fully Assemble Top
Task		Not Started					

Figure 5: Screenshot of the tasks needed to create the Topside in Notion

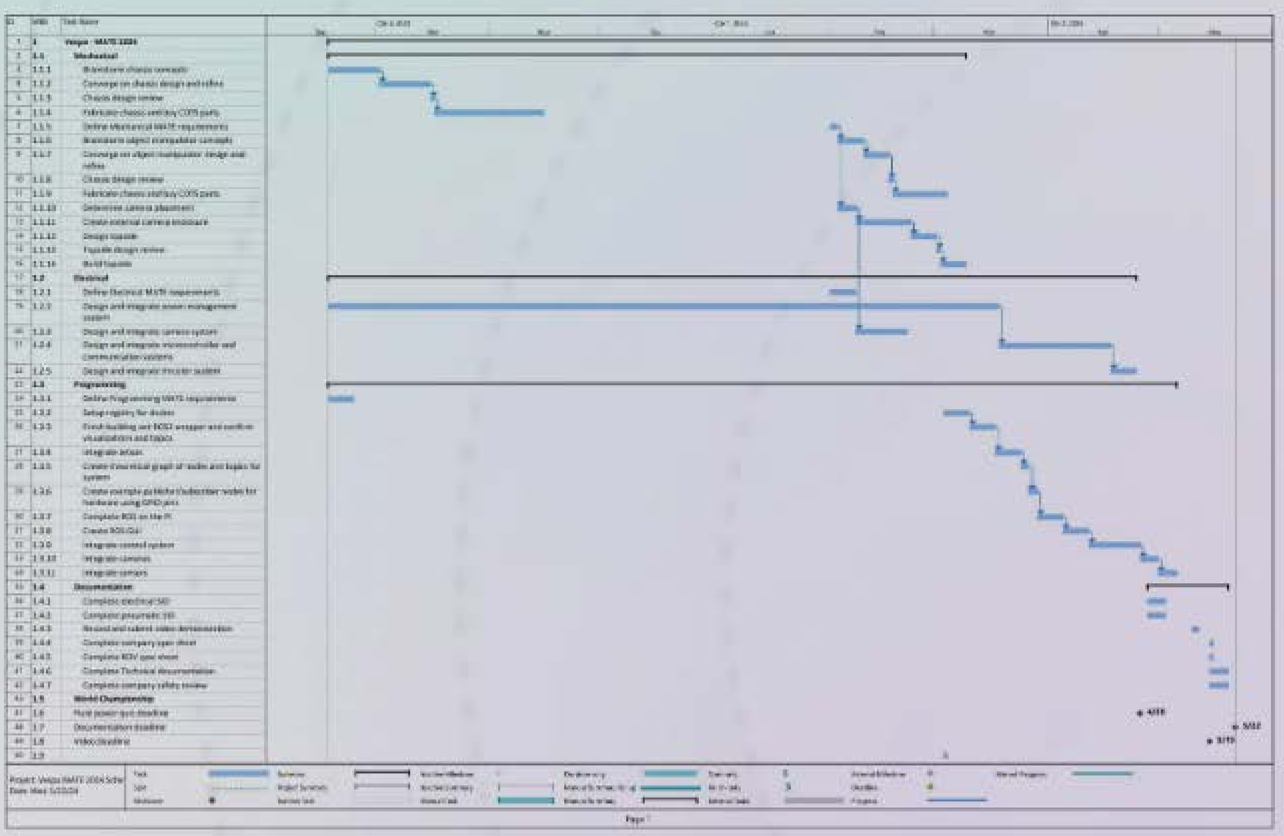


Figure 6: VESPA MATE 2024 Gantt Chart

Acknowledgments:

Hydromeda extends our deepest gratitude to the following individuals and organizations for their support and contributions to our VESPA ROV project:

Veolia: For their generous sponsorship and support, enabling us to acquire essential materials and resources.

Dr. Yonas Tadesse: For his expert guidance, mentorship, and unwavering support throughout the project, providing us with the knowledge and inspiration to succeed.

ECS Student Council: For their financial support and encouragement, helping us bring our project to fruition.

UTD Makerspace: For providing us with access to the facilities and tools needed to operate and bring our ideas to life.

SolidWorks: For their software donation, which allowed us to create precise and detailed designs for our ROV.

Dynamic Manufacturing Solutions: For their assistance with manufacturing and fabrication, ensuring our components were built to the highest standards.

University of Texas at Dallas Erik Jonsson School of Engineering and Computer Science: For offering a supportive environment and resources that have been crucial to our project's success.

MATE: For organizing the ROV competition and providing us with the opportunity to apply our skills and showcase our work.

VEOLIA

ECS STUDENT COUNCIL

SOLIDWORKS

THE UNIVERSITY OF TEXAS AT DALLAS
Erik Jonsson School of Engineering and Computer Science

MATE ROV COMPETITION 2024

MECHANICAL DESIGN

Mechanical Design Rationale

Vespa is a rugged, compact, and reliable ROV, prioritizing maximum simplicity and adaptability for the end-user. Its layout facilitates the interchangeability of tooling, cameras, weight, and buoyancy components. The vehicle has a 5-DOF propulsion system and features a rigid chassis consisting of HDPE panels connected by T-slot aluminum extrusions. At the core of the chassis is the watertight enclosure which houses a watercooled aluminum tray securing electronics. Vespa's mission tooling includes a pneumatic claw, servo-powered rotating claw, servo-powered spool tool, and static hook which offers versatile functionality in meeting task requirements.

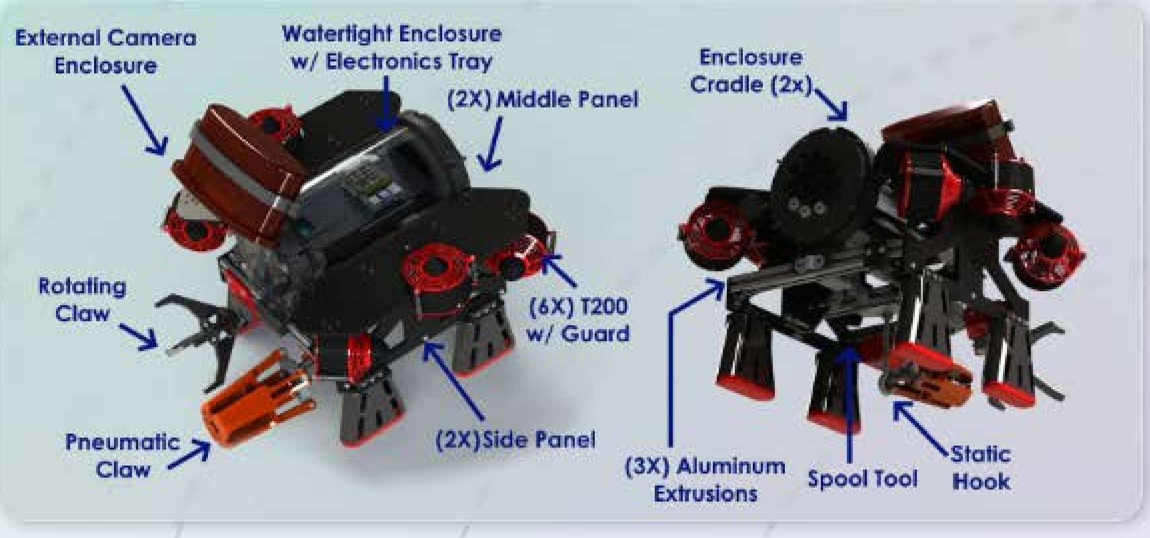


Figure 7: VESPA with annotations

The design process began with identifying ROV requirements for MATE, followed by dividing these requirements into subsystems. We utilized incremental and iterative development in our design methodology which allowed us to identify risks early and implement changes without disrupting development.

For the conceptual ideation of the chassis, we employed a focused approach by selecting an initial concept that met our predefined requirements. This concept was then iteratively refined as shown in Figure 8, with Finite Element Analysis (FEA) employed to optimize and justify geometry selection. Our approach, though not divergent in nature, was deliberate and systematic, ensuring that each iteration improved upon the design's structural integrity and performance metrics. Similar analytical approaches were utilized across the ROV's different subsystems to justify design decisions.

Figure 8: Design iteration of chassis

To optimize the geometry of the HDPE panels, we utilized FEA, particularly topology optimization using the SolidWorks Simulation package. The design optimization study balanced stiffness vs weight. The weight reduction showed us where to make optimal cuts that reduced drag and improved mounting accessibility such that stiffness was not compromised. Under the load of the electronics enclosure weight and the T200 thrusters at max thrust, the topology optimization allowed us to converge on geometry that improved functionality while maintaining the required rigidity of the chassis; figures 9 and 10 show the results of the topology optimization and the static studies validating the optimized geometry.

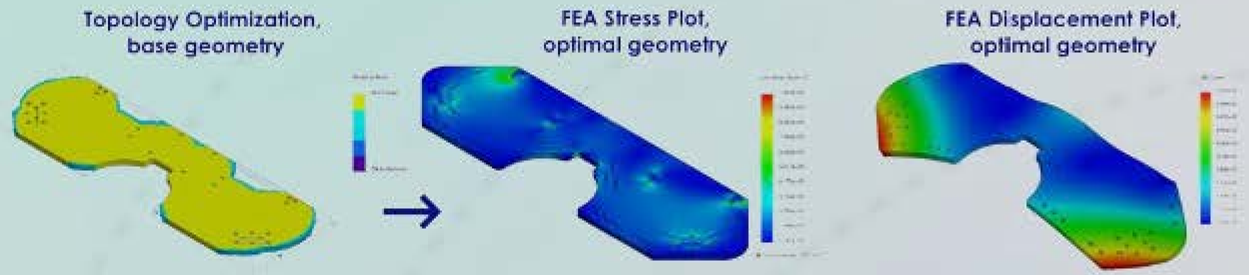


Figure 9: Topology optimization and static FEA of optimal HDPE side panel

Figure 10: Topology optimization and static FEA of optimal HDPE middle panel

Chassis

The VESPA's frame consists of HDPE panels held together by 3D-printed cradles and 1" aluminum extrusions. The main composition of the frame being HDPE panels is mainly to give a bigger size to the ROV, while not adding too much weight and still providing rigidity. The cradle is to hold a 6" series acrylic enclosure that houses the main electronics that power the ROV. Initially the cradle was just meant for holding the acrylic enclosure as well as being apart of the whole structure. As testing went on, the holes that mounted the cradle onto the extrusion shared the same hole as the strain relief. Before, the strain relief was located more towards the right of the ROV, which caused drag onto the ROV when moving in any direction. To reduce that drag, the strain relief was moved close to the center of mass from left-to-right. Although, the aluminum extrusions are what keeps the whole thing together as the cradles and the panels are all connected to the extrusions. The extrusions are also mounted onto the bottom to allow mounting for tooling and other attachments that are needed for the ROV's mission tasks.

Thrusters

Our Hydromeda ROV uses six Blue Robotics T200 thrusters placed in a way that allows control over five degrees of freedom. These degrees of freedom include three translational degrees (forward/backward, left/right, vertical) and two rotational degrees (roll, yaw). Each thruster can fire both forward and backward.

Four thrusters are placed on the corners of the frame lined up along the horizontal plane. These thrusters control left/right, forward/backward, and yaw motion. Two thrusters are placed in a vertical orientation on the left and right sides of the ROV, allowing for rolling and vertical motion. This decision made our robot cost-effective, maintained full functionality, and implementation of a control system was simple.

We used T200 thrusters because of their ease of use and reliability. Blue Robotics is a sponsor of MATE, and the T200 thrusters are used in their own ROVs. Each thruster uses 204W at 12V when at peak strength, where they each produce a force of around 35 N. The T200s use a brushless motor, which is more durable, efficient, and powerful than a brushed motor. We placed thruster guards on the front and back of each thruster to avoid any injury due to accidental contact.

A trade-off we had to take was the lack of ability to pitch the ROV. We realized that this wasn't a critical requirement, and avoiding the ability to pitch the ROV greatly simplified how joystick input would be mapped to the thrusters. Another trade-off was that a brushed motor would have been cheaper.

Main Enclosure

We selected BlueRobotics' 6" Watertight Enclosure with 15-hole aluminum endcap and acrylic clear endcap as Vespa's electronics enclosure because of its robust design, with a pressure rating of 65 meters, and its cost-effectiveness, as it eliminates the time required to design and iterate a custom enclosure. The Watertight Enclosure has the added benefit of compatibility with BlueRobotics' relatively low-cost WetLink Penetrators, which do not require potting and are easy to install; this made the WetLink Penetrators the clear choice for passing cable into the enclosure.

The main enclosure houses the main electronics that power and control the ROV. The two trays that hold the electronics are attached to the aluminum endcap to ensure that cables aren't being strained or tugged when taking the aluminum endcap off. Initially, the two trays and mounts for electronics were all 3D-printed, but at some point we encountered issues with components producing too much heat. In order to reduce the amount of heat stored into the electronics tray, the top tray was replaced with a laser-cut sheet metal out of 6061-aluminum. The aluminum tray essentially acts as a large heat-sync for components directly touching the aluminum as it disperses heat into the air of the enclosure as well as to the water as it is attached to the aluminum endcap.

Figure 11: Electronics Enclosure

Mission Tooling

Pneumatic Gripper

The pneumatic gripper serves as the primary means of interacting with the various PVC props present throughout this year's tasks. The use of a four-jaw gripper removed the need for the gripper to rotate in order to interact with PVC in all orientations. A list of requirements was created, identifying the sizes and orientations of all PVC sizes and orientations that would need to be interacted with. From there, all props were modeled, and the jaws of the gripper were shaped and tested over four iterations until the unique design that is now used proved capable of meeting all PVC-related requirements. The use of 3D printing for the creation of the jaws meant that we were free to design them to meet our needs precisely.

Figure 12: Pneumatic Gripper

Spool Tool

The spool tool was created specifically to interact with the SMART cable repeater and power connector that are featured prominently in task 2. The spool tool features a unique 3D-printed coil grooved spool actuated by a servo. The groove on the spool ensures that the fishing line can spool and unspool without tangling. Stainless steel beads on the line keep the line under slight tension at all times, allowing it to unspool in a clean arc beneath the ROV consistently. A guard above the spool ensures that the line doesn't jump out of its groove, and prevents the stainless beads from entering the spool. The ability to lower the line up to 30 centimeters below the ROV, makes the acquisition of screw hooks while keeping the ROV clear of obstacles much easier.

Figure 13: Spool Tool

Rotating Claw

The rotating claw consists of a 3D-printed four-prong claw actuated by a servo. The claw was designed to have as large of an area of acquisition as possible without interfering with the pneumatic gripper. The claw portion of the tool was designed in a way that minimizes drag while maneuvering the ROV, utilizing only as much material as necessary for structural integrity. The mount for the rotating claw was designed so that it can interact with the valve on the irrigation system when the ROV is resting on the seafloor, taking vertical positioning of the ROV during operation out of the equation for the operator.

Figure 14: Rotating Claw

Static Hook

The static hook is a simple, yet effective tool. Designed for interacting with U-bolts, as well as the rope loops on coral props, it was identified as a necessary tool very early on in the design process. It consists of a 3D-printed mount and a bolt hook. The hook was designed to stop 12 millimeters short of the bottom of the ROV's legs so as not to touch the seafloor before they do, yet still be as low as was determined to be acceptable. The hook size was selected to be as large as possible while still being able to interact with #6 screw hooks. The rationale for this was that the static hook could serve as an alternative to the spooling tool if the spooling tool were to fail for some reason. This logic was validated when testing the static hook on #6 screw hooks proved possible, though less efficient.

Figure 15: Static Hook

Camera System

To view the tooling and surroundings, three cameras were used on the ROV, two Blue Robotics Low-Light HD USB Cameras, and one Logitech C920 webcam. The decision to use three cameras was driven by the fact that the ROV needed at least 3 points of view to successfully complete all tasks for the competition. The ROV needs to see directly in front of itself, be able to observe the claw and gripper, and have visibility of the static hook on its underside. Having a camera for each of these points of view ensures that the operator is able to successfully achieve the tasks, given that they have visibility of the object manipulators as well as the objects that need to be manipulated.

The two Blue Robotics Low-Light cameras were used because of their compact size, which helps with their placement inside the ROV main enclosure where space is at a premium. Placing these cameras inside of the enclosure also solves the problem of waterproofing them, simplifying their implementation and removing the need to design their own enclosures.

The Logitech C920 camera was given its own enclosure due to its size, as well as the fact that it needs visibility of the rotating claw and pneumatic grippers from a higher angle. To achieve the desired top-down view, the camera needed to be mounted above the ROV so that it could be angled down.

External Camera Enclosure

The team approached the external camera enclosure with the idea of wanting a repeatable manufacturing process that could create multiple camera enclosures without much repeated monetary cost. The team also wanted the camera to be easily extractable so that it could be swapped and replaced if need be.

Since the enclosure is external to the main enclosure, the team had to research manufacturing and post-processing methods that would result in it being watertight and waterproof. The first option we opted for was printing the enclosure using ABS and sealing the walls using acetone vapor. After the application of acetone onto the print, the enclosure developed cracks ranging from only surface-level imperfections to cavities permeating from the outside in. Realizing the difficulty and uncertainty of using this method, the team pivoted to using silicone molding and resin casting.

The benefit to silicone molding and resin casting is that there are no pores in the casted part for water to enter and having the silicone mold allows us to recreate the part again. Additionally, since resin is a similar density to water, there is also the benefit of the resin being positively buoyant or not affecting the buoyancy of VESPA, since before it was negatively buoyant. The design consists of the resin casted enclosure and an acrylic faceplate. The sealing method between the two parts would involve an o-ring.

While pressure testing the external camera enclosure, we discovered that the enclosure would start to collapse when held to a vacuum pressure of 15 inHg as shown in figure 16. This discovery prompted a design study to justify the structural integrity of the next camera enclosure iteration.

Figure 16: Deformed prototype of camera enclosure

The camera enclosure design study focused on the trade-off between thickness and max displacement when at pressure. We started the study by incrementally increasing the thickness while recording the static simulation's max displacement at each increment. With this approach, we were not satisfied with the large size that was required for our desired max displacement of 0.7mm, so we decided to alter the long-edge feature type from flat to radius (See figure 17). With this change, we found that max displacement significantly dropped because the curved surface was able to better distribute the compressive load. After many iterations, it was shown that a thickness of 10.25mm with a radial curve on its long edge was the optimal geometry as it reduced the max displacement by half of the original design made with a flat long edge. The optimized design had a max deformation of 0.66 mm, while the old design had a deformation of 1.2 mm.

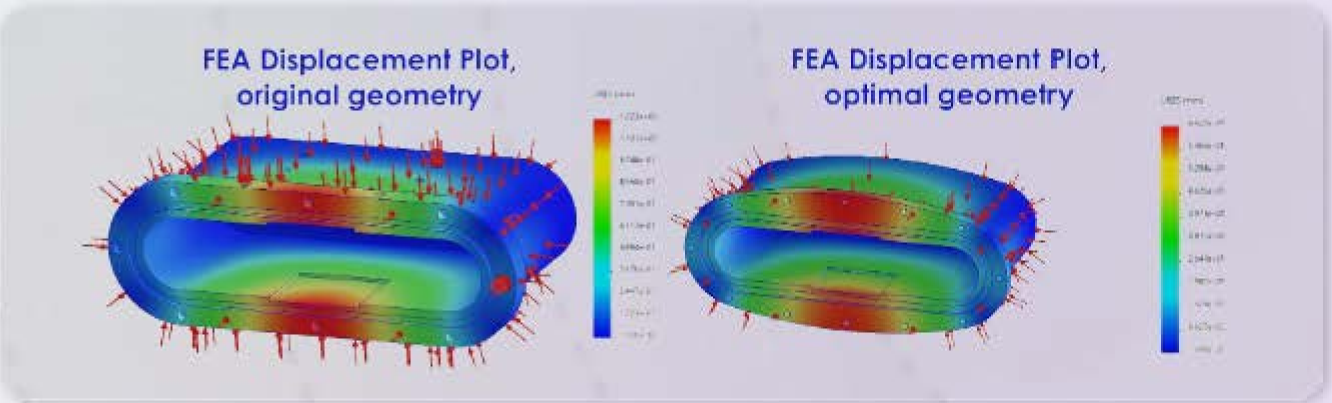


Figure 17: Design Optimization Displacement Plots

Buoyancy & Ballasts

To achieve a neutrally buoyant ROV and help driver control, a combination of buoyancy and ballasts were needed. Knowing that ballasts needed to be added to the ROV, and wanting to create a more integrated design with the ROV, it was decided that ballasts could be attached inside the legs of the ROV. Because it was not known what the ballasts specifically had to do yet, and what the optimal position was, each leg of the ROV was designed with 3 cutouts where ballasts could be inserted. This would allow for modularity of the ballasts as well as four different main positionings of ballasts being the front left, front right, back left, and back right of the ROV. This would also allow for easy updating of the ROV's buoyancy, and balance, and increase possible mounting areas for other potential tooling. 1" diameter weathering steel rods were cut into 1.5.

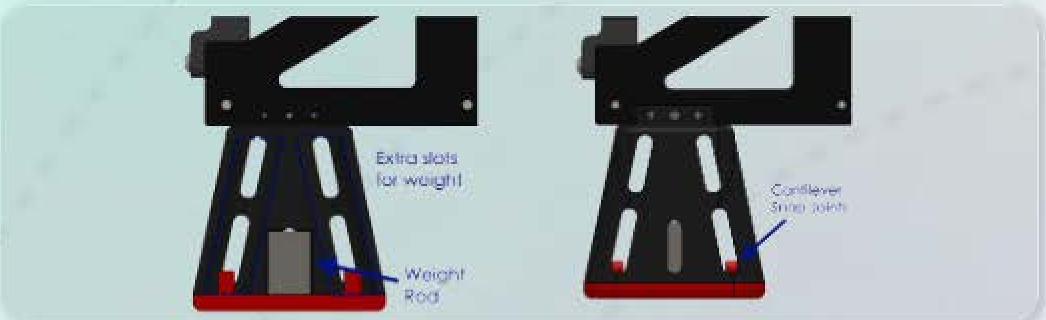


Figure 18: ROV Stilts / Ballast Holder

To add buoyancy and decrease the drag created by the tether, pipe insulation foam was attached. The buoyancy of the tether has the added benefit of reducing the risk of collision with the ROV.

Topside

The topside station houses all the surface electronics in order to connect the computer to VESPA. The box is a customized pelican case with connectors on the sides for the tether, pneumatics, and HDMI for monitors. The station is separated between the top and bottom: the top has all the components that require ease of access and visuals while the bottom are components that don't need constant access. The top and bottom are sectioned with 16-gauge steel sheet metal that was laser-cutted.

Float

VESPA's vertical profiling float serves to complete two profiles following the deployment by the main ROV in task 4.1. The float is controlled by a servo motor-driven buoyancy engine which utilizes water displacement to determine the float's height. As the motor draws the plunger, the syringe can either intake or eject water to control the displacement of the float. It is made of a 550 mL syringe with a custom-fitted plunger on a central motorized lead screw connected to an Arduino Uno unit, and powered by 8 AA batteries. The motor and engine are enclosed by a 723.9mm acrylic tube with a 114.3mm diameter. It features custom resin-cast endcaps and 3D-printed parts to ensure water tightness and cost-effectiveness.

Following the release from VESPA, the float communicates with the base station and begins its descent. During each descent, the float will utilize wireless transceiver modules to communicate data collected from pressure sensors to the base.

Figure 19: Non-ROV Device

ELECTRICAL DESIGN

Electrical Design Rationale

Developing the electrical systems for VESPA requires lots of thought and communication with all members to ensure that software and hardware components seamlessly integrate. Ease of use, repairability, and reliability play an immense role in how the ROV is wired and which components are built or sourced for VESPA. While paying close attention to MATE ROV rules, the electrical team followed the iterative approach, first by working with the other teams to build a robust, functional prototype that allowed Hydromeda to quickly gain an understanding of the ROV's features and faults. After a solid foundation was built with VESPA, the Electrical Team prioritized the requirements for an easily repairable and robust setup that caters to efficient mechanical design.

To develop the electrical system, the Electrical Team discussed how components could be implemented after the other teams had outlined the ROV's requirements for various tooling and hardware. The team designs a basic SID to map the connections and devices cohesively so that all members are on the same page. Then, suggestions and improvements are made to the layout that enhance the repairability and reliability of the ROV. For example, after mapping a basic layout for the ESCs (Electronic Speed Controllers) and wiring them with basic connections, extended quick connector cables and proper protection of the signal cables were developed to ensure the ROV's serviceability and modularity in case of failure.

The ROV and Topside SID diagrams can be found in Appendix A1. The SID shows all the connections and power between different components in the ROV system.

Power Management

When we created our specialized PCB, we had to take into account the size constraints of the space we were working within as well as the large currents being supplied to the thrusters. Through the use of Kicad, we were able to create a PCB that fit our needs and accomplished the task as needed. In Figure 20 we can see a 3D representation of our build.

For the design of the onboard power converter and distribution setup, efficiency and space were top priorities. The power converter needed to be as dense as possible to leave room for the other components in the tube while consuming as little of the power budget as possible to allow maximum power through to the thrusters. When considering whether to design the 48V to 12V converter in-house or buy an off-the-shelf converter, it was decided that, due to time and budget constraints on development, an off-the-shelf converter would work best and an in-house converter could be left for future consideration. The off-the-shelf converter needed to balance the large power consumption of the thrusters and in-tube electronics nearing 1.5kW. For this reason, the "QBDS128A0B : Barracuda DC-DC Converter" from OmniOn was chosen. The 1/4-brick design is extremely small for a 1.5kW converter, and in testing, the converter never overheated in the tube which was an early concern due to the small size.

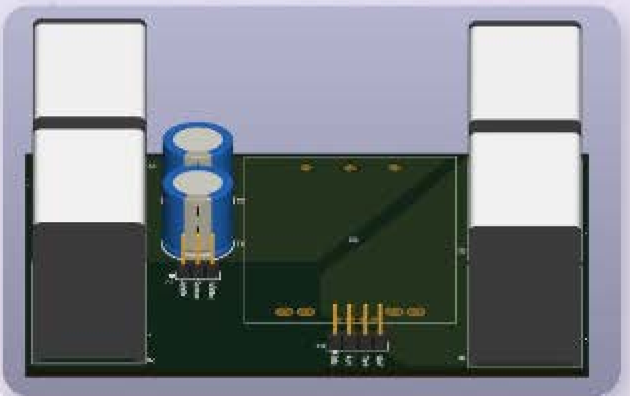


Figure 20: Render of 48V-12V Converter PCB without the DC-DC Converter Module

SOFTWARE DESIGN

Software Design Rationale

As a new team, we chose to use an off-the-shelf solution to control VESPA. We chose to use the Navigator flight controller from BlueRobotics, an Ardupilot-based flight controller expansion board for a Raspberry Pi computer. Several factors went into making this decision, including the open-source nature of Ardupilot and the expandability of the board for future development. We chose to use BlueRobotics's BlueOS platform for controlling the ROV with the Navigator and a laptop at the control center. We were attracted to the modularity and extensibility of the software, which allowed us to implement thruster limiting for our specific power consumption requirements.

Topside

In terms of hardware, we used a Jetson Orin NX on the topside, with a joystick, mouse, and keyboard connected through USB ports, and a monitor connected with an HDMI to DVI cable.

For our topside computer, we chose to use Cockpit, a user interface extension for BlueOS. Some factors that went into this decision included the easy modification of different data display windows, the ability to inspect MAVLink messages, and the simple video feed implementation for our onboard cameras. To access Cockpit, a laptop/portable computer is used at the control center with the hardware controls. It connects to VESPA over ethernet via a router built into the topside console and is thus able to receive and transmit data.

Control Systems

Thruster Control

Controlling the thrusters was simple via ArduSub, an ROV-oriented version of Ardupilot. BlueOS translates input from an Xbox/PS4 controller to MAVLink messages encoding thruster values. Using the thruster layout on VESPA, joystick input corresponding to translational and vertical motion is "translated" into commands for all six thrusters, creating the desired motion.

Manipulator Control

Controlling the manipulators on VESPA was an important goal for the team, given that this is how it interacts with the game environment. To control the spool tool, we chose PWM control of the servo, with the servo programmed for limited rotation. We chose limited rotation to avoid putting strain on the tooling. Similarly, we chose PWM control for the rotating claw. In this case, we chose continuous rotation, given that the design of the claw eliminated any possible strain in this configuration. PWM control of both the rotating claw and the spool tool was handled by the integrated PWM control board on the Navigator, which was itself controlled via I2C and the MAVLink protocol by ArduSub and BlueOS. We used a relay to control a solenoid, which then regulates the pneumatic input to the claw. We chose PWM to control the relay with the Navigator by treating one set of PWM pins as GPIO: we wrote the maximum value, aka HIGH, to toggle the relay and open the claw, and the minimum value, aka LOW, to toggle the relay and close the claw.

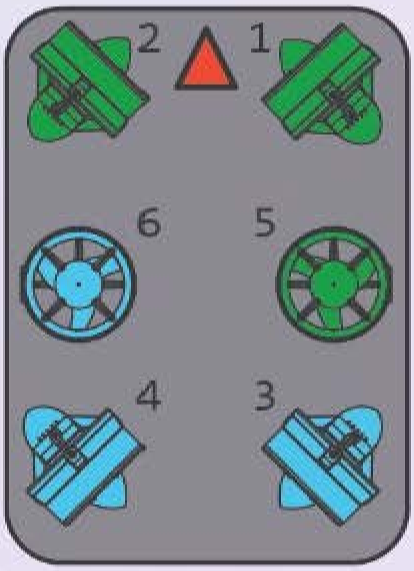


Figure 21: Six-thruster layout for an ArduSub ROV used on Hydromeda.)

CRITICAL ANALYSIS

Testing

Testing components has become second nature for members at Hydromeda. Every device, whether a simple cable to the computer, is tested to ensure that it will be ready before going underwater. Throughout the development of the VESPA, everything first undergoes a simulation with all components out, to ensure that all devices, tooling, and cabling are functioning properly. Through each simulation, we identify any issues, solve them, and note them down for testing before each launch. Once the components are tested, we move on to testing the VESPA underwater. We have created a checklist to ensure that we follow safe, proper testing procedures, ensuring that before each launch we mitigate any issues and have more time to test and debug (See Appendix A3).

With our resources, we prioritized testing and simulation to avoid having to expend costs on reprinting, recutting, and redesigning tooling. The mechanical design time prioritized making simulations on SolidWorks for sealed enclosures under water before making silicone molds and casts of the external camera enclosure to reduce the wait time and production cost, while dramatically improving the learning time and focusing on learning proper molding techniques when using new materials.

Troubleshooting

As we refined our control system through multiple launches, we noticed an issue: after certain lengths of time underwater, the ROV would shut off automatically, sometimes restarting on its own. This peculiar issue was prevalent throughout most of our launches, and we sought to find the issue. The Jetson wasn't overheating, as determined by looking at its onboard CPU temperature monitor, but it did seem like the buck converter was overheating. We rearranged components inside the ROV such that the buck converter was also contacting the aluminum heat sink, but although the buck converter was cooled down, the automatic shut-off issue was still present. After some more troubleshooting with the controls, we determined that the cause was a power draw - the buck converter we were using could not withstand the power draw caused by full acceleration. Placing software limits on acceleration mitigated this issue, but a drawback of this solution was slower sub-response time and lack of thrust to lift or move props.

Another issue we encountered while testing was that the Jetson sometimes output incorrect PWM values to the ESCs, causing an array of issues from the ESCs not arming to incorrect thruster outputs. Some investigation into custom PCA9685 boards (the PWM controller chip we use) revealed that an external clock was needed, similar to how BlueRobotics's Navigator uses the chip. Because we didn't have one on hand and internal deadlines were approaching, we instead opted to switch back to the Navigator + Raspberry Pi combination, citing its ease of use and technical support systems.

Accounting

Creating a budget and maintaining proper accounting are highly important for Hydromeda. Before the start of the season, an initial budget is created with estimates for the upcoming season and accounting is done for the duration of the project timeline to ensure proper tracking. As a new organization, Hydromeda set the budget based on research into other organizations that have competed in the MATE Pioneer challenge previously. Forecasting the budget and estimating costs was difficult given the high demand for R&D for our first ROV.

The budget was broken into 3 categories: project development, R&D, and employee travel and lodging. These categories allowed us to track what went into the final ROV, what went into researching and learning methods to help the ROV succeed, and keep a separate tab on employee needs. To track the budget, we use a custom spreadsheet that keeps track of every order over the lifecycle.

It is our mission to ensure no employee on Hydromeda has to spend money to participate. Therefore, a lot of effort is put into securing income from external sources. The income comes from fundraising, sponsorships, and the University of Texas at Dallas.

2023-2024 Hydromeda Income Summary		
Income Name	Description	Amount
Fundrasing	Bake Sales	$ 391.00
Donations	Comets Giving Day	$ 2,038.00
Sponsorships	Veolia Sponsorship	$ 13,000.00
School Funding	ECS Student Council Funding	$ 5,847.49
Total Income		**$ 21,276.49**

Figure 22: Income Summary

2023-2024 Hydromeda Budget Summary				
Category Name	Item Description	Budget	Actual Cost	Variance
ROV Production Cost				
Thrusters	6 T200 Thrusters and ESC, 6 Diamond Dynamics Thrusters	$1,600.00	$ 1,794.00	$(194.00)
Tether	28m High Power Cable + Ethernet and Power Cable, Wetlink Splice Kit	$ 400.00	$ 880.00	$(480.00)
Electronics	RPI, Navigator, Buck Converters, PDP, USB Hub, Cameras	$1,000.00	$ 1,107.00	$(107.00)
Chassis	HDPE Sheet, Manufacturing, Extrusions, Brackets, Screws	$ 500.00	$ 253.00	$ 247.00
Enclosure	6" Watertight Enclosure, Variety M10 Wetlink Penetrators	$ 500.00	$ 602.00	$(102.00)
Pneumatics	Compressor, Pneumatic tubing, Solenoid, Connectors, Regulator, Relief Valve	$ 500.00	$ 355.25	$ 144.75
Tooling	Servos, Adapters, Bearings, Wiring	$ 300.00	$ 231.28	$ 68.72
Control Station	Pelican Case, Electrical components, Wiring	$ 800.00	$ 1,189.12	$(389.12)
Materials	Steel Rods, Bouyancy Foam, Filament, Steel Beads	$ 500.00	$ 326.02	$ 173.98
Total ROV Cost		**$6,100.00**	**$ 6,737.67**	**$(637.67)**
R&D Expenses				
Silicone Molding	BBDino 2-Part Super Elastic Silicone Mold, XTC-3D Brush-On Epoxy, Vacuum Chamber	$ 400.00	$ 371.32	$ 28.68
Resin Casting	TEExpert 2-Part Super Clear Resin	$ 400.00	$ 100.00	$ 300.00
3D Printing	Bambu Lab Printers, Filament	$2,000.00	$ 2,397.17	$(397.17)
Waterproofing Tests	Mineral Oil, Epoxy, O-rings, Fish Tank, Vacuum Pump,	$ 250.00	$ 217.12	$ 32.88
Soldering Stations	Soldering Iron + SMD Station, Helping Hands, Wires, Fumigator	$ 350.00	$ 365.58	$ (15.58)
Test ROV Control Systems	RPI4, Servo tester, PWM Signal Viewer, Fathom X	$1,000.00	$ 568.99	$ 431.01
Test ROV Structure	Bouyancy Foam, Servos	$ 500.00	$ 59.87	$ 440.13
Total R&D Expenses		**$4,900.00**	**$ 4,080.05**	**$ 819.95**
Team Expenses				
MATE Registration Fee	MATE Registration Fee	$ 350.00	$ 350.00	$ -
Fluid Power Quiz Fee	Fluid Power Quiz Fee	$ 25.00	$ 25.00	$ -
Lodging	5 Day AirBNB stay	$2,000.00	$ 1,055.01	$ 944.99
Travel	Gas Costs	$ 600.00	$ 600.00	$ -
Demo Props		$ 500.00	$ 436.00	$ 64.00
Snacks	Water, Chips, Pizza, Energy Drinks	$ 350.00	$ 903.40	$(553.40)
Total Team Expenses		**$3,825.00**	**$ 3,369.41**	**$ 455.59**
Non ROV Device Cost				$ -
VEO Float	Acrylic Tube, Syringe, Motor, Bearings, Rods, Electronics	$ 700.00	$ 577.90	$ 122.10
Total Non ROV Device Cost		**$ 700.00**	**$ 577.90**	**$ 122.10**

Figure 23: Budget Summary

CONCLUSION

Challenges and Lessons Learned

Throughout the development of VESPA, Hydromeda faced several challenges and learned valuable lessons. As first-time participants in the MATE ROV Competition, we encountered steep learning curves in design, testing, and project management.

One significant challenge was balancing the design's complexity with reliability. Early in the process, we realized that overly complex systems increased the risk of failure. This led us to adopt a more iterative and modular design approach, allowing for easier troubleshooting and incremental improvements.

Another major hurdle was managing the integration of various subsystems. Ensuring seamless communication between mechanical, electrical, and software components required rigorous testing and lots of adjustments. This experience highlighted the importance of thorough documentation and clear communication among team members.

Time management was also a critical lesson. Despite careful planning, unforeseen issues often cause delays. Adopting agile project management practices helped us remain flexible and responsive, ensuring that we could adapt to changes without compromising our goals.

Reflections

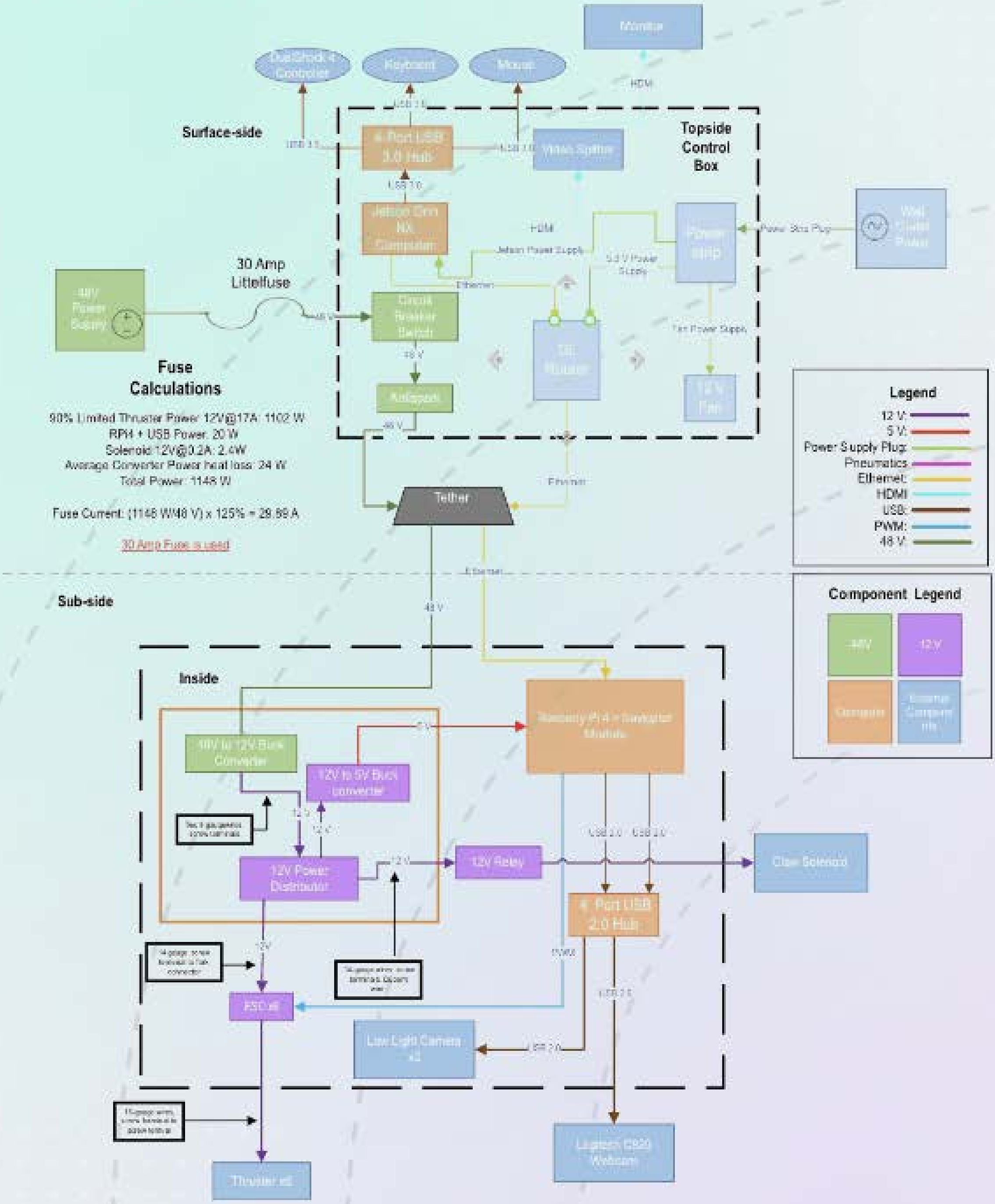
We are immensely proud of what we have achieved with VESPA. This project not only demonstrated our technical capabilities but also underscored the importance of teamwork, perseverance, and continuous learning.

The collaboration between different subgroups Business, Mechanical, Software, and Electrical—was instrumental in our success. Each member brought unique skills and perspectives, contributing to a well-rounded and innovative final product.

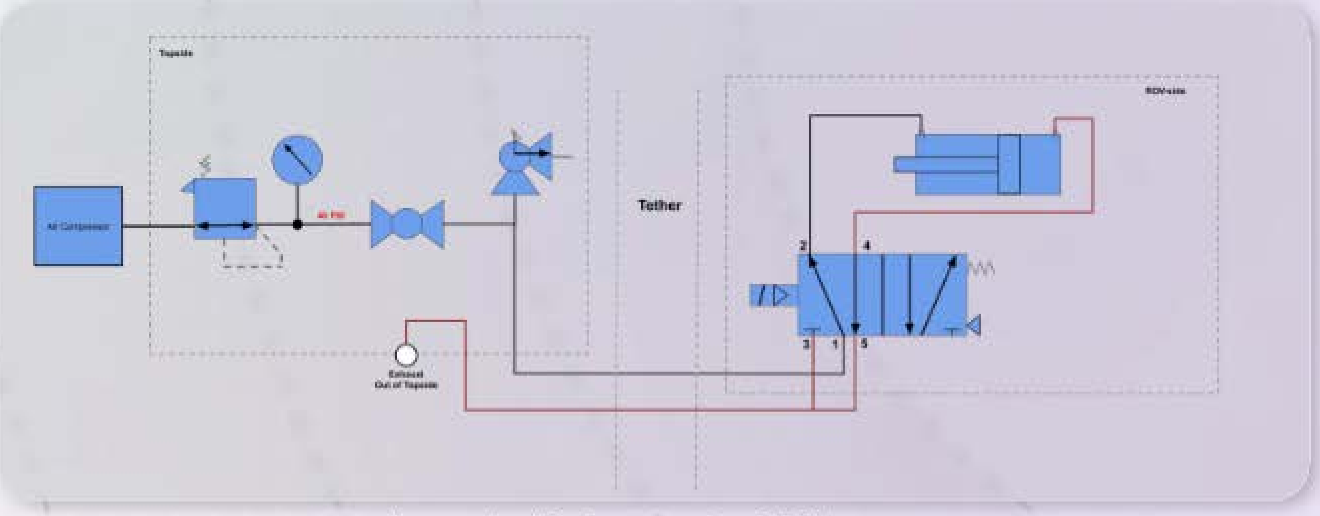
Our participation in the MATE ROV Competition has been a transformative experience. It provided us with practical skills and insights that extend beyond the classroom, preparing us for future challenges in the field of underwater robotics. We look forward to applying these lessons in future projects and competitions, continually pushing the boundaries of what we can achieve.

In conclusion, the journey of developing VESPA has been both challenging and rewarding. The support from our sponsors, mentors, and the University of Texas at Dallas has been invaluable. We are excited to continue advancing in the field of underwater robotics, driven by the passion for innovation that defines Hydromeda.

APPENDIX



Appendix A1: Electronics SID Diagram



Appendix A2: Pneumatics SID Diagram

- **Mechanical Check _______**
- **Pre-Launch ______**
  - Ensure Penetrators and OK valve are tightened
  - Check enclosure seals:
  - Ensure all endcap screws are installed to compress face seals
  - Ensure all pneumatic tubings for ROV and Topside are secured into fittings.
  - Ensure endcaps have all screws installed
  - Ensure screws are tightened
  - Ensure ROV-side and Topside tether has strain relief
  - Ensure Topside Plate is secured.
- **Launch ______**
  - Connect pneumatic line to compressor and fill compressor with 50 psi
  - Ensure all pneumatic lines are securely connected at Topside
  - Block Tether lines (Remind everyone continually to not walk over the tether at any point during the launch)
  - Watch the tether for tangling, and be ready to signal to the electrical team if an emergency shutoff is required.
  - When retrieving ROV to surface, only grab tether cables. DO NOT pull the ROV up from any of the thruster or tooling cables.
- **Post-Launch ______**
  - Relieve pressure from the line then the compressor. Disconnect line from the compressor.
  - Dry ROV.
  - After tether cables are disconnected, spool in the tether and secure the ends to the spool.
  - Carry the ROV by the horizontal panels

- **Electronics Check _______**
- **Pre-Launch ______**
  - Power Distribution Screws are tightened
  - No exposed or bare wires
  - No electrical contacts grounding to aluminum tray
  - 48V input connector is connected properly
  - 12V connectors for ESC are connected properly
  - 12V for Buck Converter and Relay are properly attached
  - Raspberry Pi and Navigator Power Input are connected
  - ESC, Solenoid, and Servo pins are properly installed and sturdy
  - Router ethernet cables are connected.
  - Topside Computer is properly connected
- **Launch ______**
  - Anderson Connector Connected
  - XT90 Connector Securely Connected
  - Power Cable Connected
  - HDMI Displays Connected
  - USB Hub is Interfacing with Topside Computer
  - All Topside devices receiving power after 120V power is connected and powered on.
  - Vent Fan Opened
- **Post-Launch ______**
  - Close Vent Fan
  - Disconnect and protect wires on spool
  - Ensure Topside components are safe
  - If any components were exposed to water, properly dry components before powering.

- **Programming Check _______**
- **Pre-Launch ______**
  - ROV Side updated to latest push
  - Topside updated to latest push
  - Ensure network connection from Topside to ROV

- **Packing List _______**
  - 2x HDMI Cables
  - 1x Dualshock Controller
  - 1x 120V Power Cable
  - 1x Surge Protector Power Strip
  - Pack of Zipties
  - iFixit Kit
  - Locking Pliers
  - Electrical tape

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