MAKO – Modular Aquatic Knowledge Obtaining (Unit)

Pioneer Class: MATE ROV 2024 World Championship

Embry-Riddle Aeronautical University

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Team Members:

Mark Thompson ('26) | Nicolas Chamberlain ('26) | John "Jack" McSwiggin ('26)

Garrett Lynn ('26) | Justin Yocum ('26) | Emily Coello ('26)

Garrison Ottolini ('25) | Sirio Jansen-Sanchez ('26) | Robert Thibodeau ('26)

Over the past year, our team of students has worked hard to design and build an ROV to perform the tasks set forth by the MATE competition. We decided that we wanted to make a submersible that is easy to control, easy to work on, and difficult to break. Through countless hours of research and work, we are confident that we have achieved this goal. We look forward to our first MATE competition, and we cannot wait to prove what we can do.

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WHO WE ARE

Mark Thompson

Position: CEO

Major: *Aerospace Engineering*

Favorite Movie: *Cheetah Girls*

Justin Yocum

Position: *Safety Officer*

Major: *Aerospace Engineering*

Favorite Movie: *The Little Mermaid*

Sirio Jansen-Sanchez

Position: *Software Lead*

Major: *Electrical Engineering*

Favorite Movie: *Kung Pow Enter the Fist*

Emily Coello

Position: *Marketing Lead*

Major: *Mechanical Engineering*

Favorite Movie: *Coraline*

Garret Lynn

Position: *Team Member*

Major: *Mechanical Engineer*

Favorite Movie: *Beverly Hills Chihuahuas 2*

Garrison Ottolini

Position*: Team Member*

Major*: Mechanical Engineering*

Favorite Movie: *Barbie Fairytopia*

John “Jack” McSwiggin

Position: Pilot

Major: *Aerospace Engineering*

Favorite Movie: *Superbabies: Baby Geniuses 2*

Robert Thibodeau

Position: *Team Member*

Major: *Aerospace Engineering*

Favorite Movie: *Samurai Cop*

Nicolas Chamberlain

Position: *Team Member*

Major: *Aerospace Engineering*

Favorite Movie: *The Incredible Bulk*

MEET OUR SUBMARINE

Design

The MAKO Unit is designed to be as versatile and robust as possible while keeping the price low. The submersible is built with an aluminum exoskeleton which can withstand most impacts. All of MAKO's systems are contained within the exoskeleton to ensure that the submersible does not sustain catastrophic damage in the event of a collision. The exoskeleton also makes transportation easier, as it provides a multitude of handholds.

This exoskeleton provides nearly endless mounting locations for equipment such as thrusters, cameras, and lights. This means that we can tailor the submersible to the customer's specific needs. The modular design of the MAKO Unit ensures that we can provide a custom submersible at a reasonable price. This modularity ensures that each MAKO Unit is best suited for the customer's specific needs.

Design Process

Design Goals

We wanted our ROV to be simple, modular, cost-effective, expandable, easily maintained, and robust.

Frame

When the initial design process was started for MAKO we broke up into smaller groups and each brainstormed a basic frame design for the ROV. Then these designs were pitted against each other, and as a company we decided on a rectangular frame design with rigidly mounted internal thrusters. This design later evolved into an octagonal shape when viewed from the side to allow for more room to mount sensors or tools while being able to retract them into the frame for transport. With the frame design in mind, we then picked the material for the frame, considering our design goals, we decided to go with aluminum extrusion. We made this choice because it satisfied all our previously detailed requirements and the slot system on the extrusion would allow us to mount new components with ease. We considered using carbon fiber tubes for the frame, to save weight, however, because carbon fiber tubes would make modularity, adaptability, and manufacturing more difficult, we went with aluminum extrusion.

Electronics

For housing the electronics of our ROV we decided to use the 203mm cylindrical enclosures from Blue Robotics. We picked a cylindrical enclosure because we determined that it would provide the best possible ratio between usable space and minimizing stress concentrations due to corners in the enclosure. The 203mm diameter was decided on because it would allow us to put all 8 ESCs in a row across the diameter of the tube while providing ample room for cooling and cable management. For mounting the electronics enclosure to the frame, we wanted something that was flexible, to make working on the electronics easier, but also prevent the translation of vibrations from the motors into the electronics themselves. The final design we settled on was strapping our enclosure down to a cradle located centrally in the sub. Since the electronics enclosure was the largest single volume on the ROV, we made sure to mount it centrally, and above the center of gravity of the ROV, for added pitch and roll stability. For mounting the electronics within the enclosure, we initially considered using DIN rails since it is a common approach to modularity. However, we stepped back and considered our design goals, and decided instead to use aluminum side rails. To affix the electronics, individual, template-based trays were used, to allow for ease of expansion and modularity.

Software

For software we wanted something lightweight, simple, and straightforward, while allowing for expansion. We picked BlueOS for this application, as it would install easily on a Raspberry Pi, and would interface with the Pixhawk we had on hand for this ROV. Furthermore, BlueOS provided an avenue of expansion using equipment and sensors we already had. However, after a few pool tests we realized that BlueOS did not provide the in-depth debugging features that we needed, and would not support our intended control system. The new solution we chose was ROS2, a stark departure from simple and straightforward, but would be extremely modular and provide the low-level debugging abilities we were looking for.

Mechanical

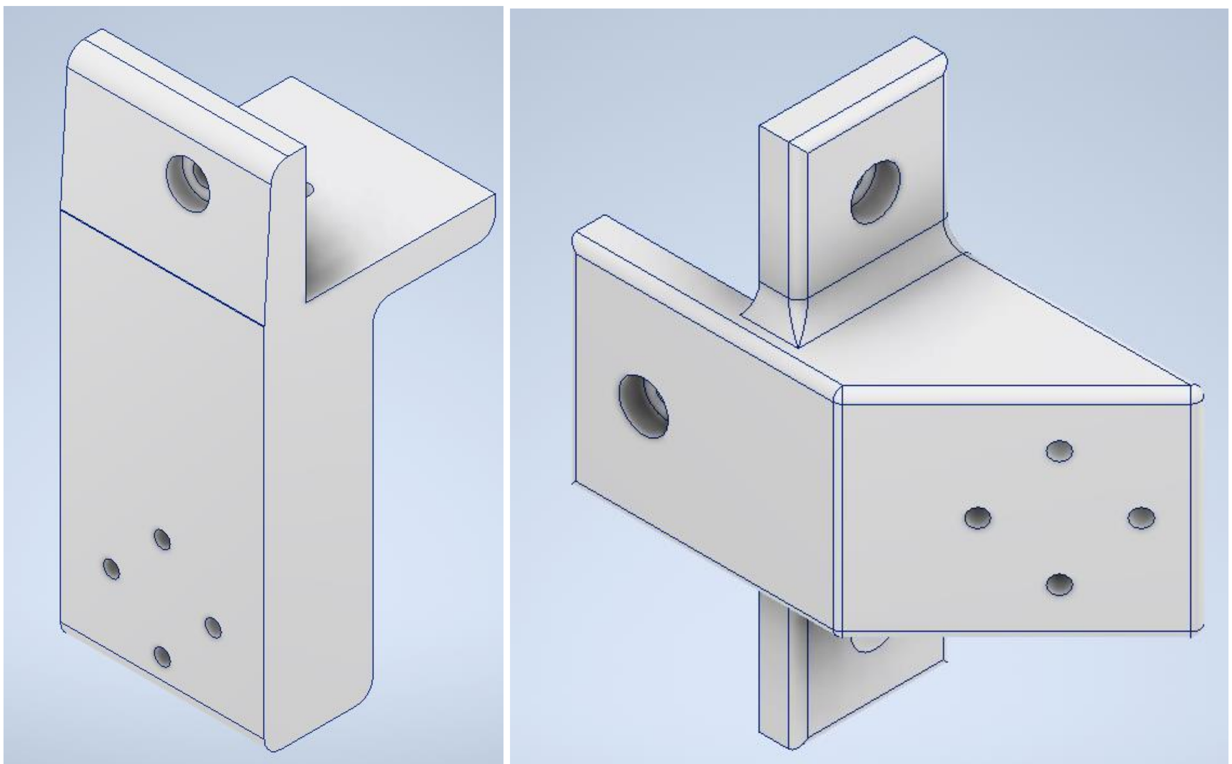
Dimensions

The MAKO Unit has an overall width of 24 inches, a length of 21.5 inches, and a height of 18 inches.

Propulsion

From MAKO's inception, we decided to use eight thrusters to maximize thrust and maneuverability while meeting competition requirements. To achieve all six axes of motion, MAKO's thrusters are arranged with four mounted vertically on the bottom of the frame, and a horizontal thruster on each vertical beam of the frame, angled at 45° to allow for both lateral and longitudinal translation. These thrusters are all located within the boundaries of MAKO's frame to avoid motor damage in the event of a collision. Additionally, having four vertical and four horizontal thrusters means that if one thruster is damaged, its opposing thruster can be disabled, allowing for symmetric thrust.

As for the thrusters themselves, off-the-shelf Blue Robotics T200s were used. Being the standard for small submersibles, we knew Blue Robotics would provide effective and reliable propulsion for MAKO at an affordable price. Combined with pre-existing performance data and easily integrable electronics, these thrusters were a far better solution than anything we could have designed in-house. Furthermore, T200s were used instead of T500s due to their lower cost, simpler power requirements, and T500s being overpowered for our needs.



CAD design of vertical (left) and horizontal (right) thruster mounts

Tools

Arm

We knew that our sub was going to need an arm in order to adequately perform the tasks required by the competition. We were originally looking into buying a robotic arm, but once we realized how expensive it would be to do so, we decided to make our own.

The main structure of our arm is made up of 3D-printed parts. Our gripper can grab objects up to 2 inches wide. Our arm also has a reach of 11 inches and has a rotation of 180 degrees.

Our arm has two joints, each controlled with a dedicated servo. The first joint is used to swing the arm assembly out of the frame of the submersible while in use. This joint is also used to turn the arm, without the need to yaw the rest of the submersible. The second joint is used to rotate the gripper assembly. This is used to adjust the orientation of the gripper to ensure that it is in the ideal position to grab an object.

Lights
Our sub also has two, forward-facing LED lights made by Blue Robotics. These lights feature high-efficiency Cree XLamp emitters which output 1500 lumens each at only 15W of power draw. These lights are used to create a better image for our sub's camera if it is operating in a low-light environment.

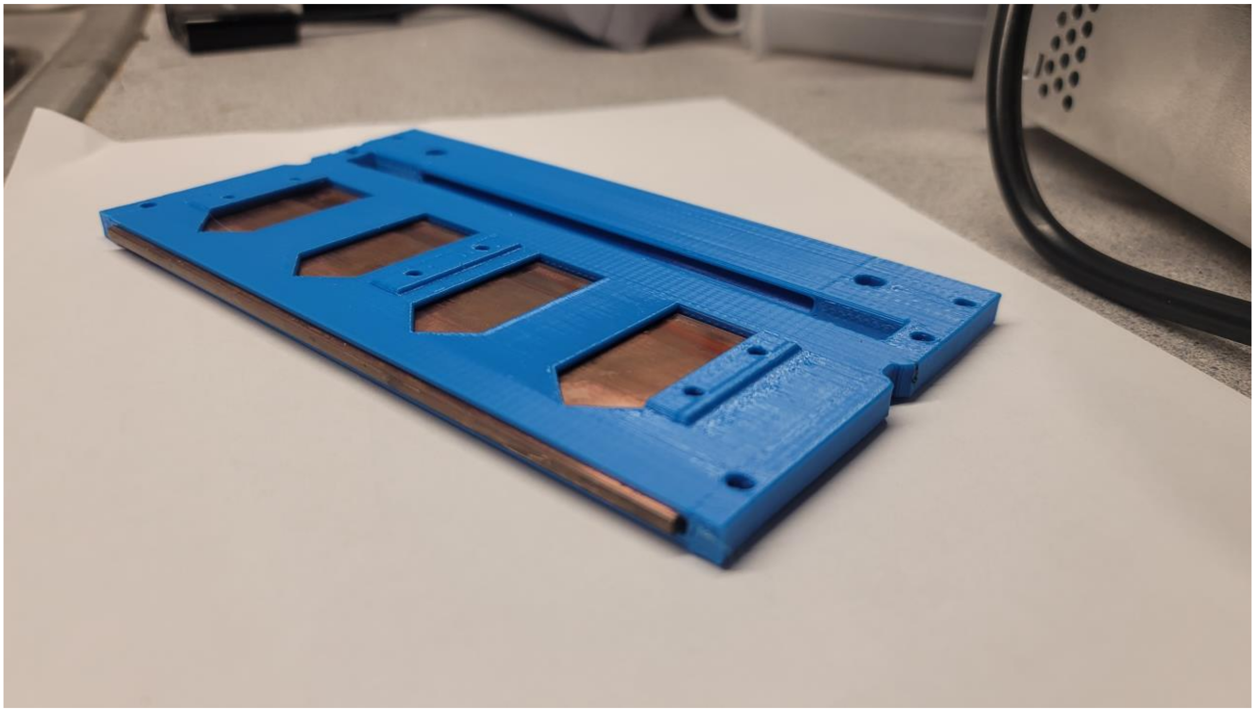
Camera
Our submersible has an ExploreHD 3.0 camera made by DeepWater Exploration. We decided to use a waterproof camera instead of mounting a standard camera within our electronics housing because of the curved nature of our acrylic tube. This would have created a distorted image, making it hard for the pilot to control the submersible effectively.

3D Printing

MAKO utilizes FDM 3D printed parts extensively in the electronics enclosure and frame to take advantage of the ability to rapidly prototype key elements of the newly built ROV. All prototype frame components were printed with an impact-modified PLA from Overture 3D, and the electronics compartment utilizes PETG from Overture 3D. For the final revision of MAKO, all PLA parts will be replaced with polycarbonate from Gizmodorks printed with our own special technique that allows for a significant increase in tensile strength and modulus.

Electronics Enclosure

In the electronics enclosure, 3D printing allowed for the tight integration of the electronics and their cooling and cable management. For instance, the ESC tray benefits from 3D printing with internal wire routing and an embedded copper cooling system. Furthermore, 3D printing allowed for an entire rework of MAKO's electrical enclosure within hours, even while accounting for manufacturing time.



3D printed ESC tray with an embedded copper plate on the bottom and signal wire pass-through on top. Bus bars, one per side, attach to the plate where the two larger holes are up top.

Frame

MAKO's frame utilizes 3D-printed brackets for the aluminum extrusion and for the mounting of the thrusters. We utilized additive manufacturing extensively not only for its ability to rapidly prototype the design but also as a means to keep the weight down. Since the mechanical loading on the sub would not be significant and the fact that loadings were relatively easy to predict; thick, and heavy off-the-shelf aluminum gusset plates could be avoided and lightweight plastic connectors could be used instead. We did ISO 527 standard tensile testing to determine whether our FDM 3D printed parts would be strong enough with the given cross section. Furthermore, the plastic connections effectively provide skid plates for the frame, allowing the pilot to be unconcerned about scraping the aluminum frame of the sub on the pool floor.

Electronics

MAKO's electronics consist of an onshore 48VDC Meanwell power supply which is fed by a 240VAC step-up transformer. The DC voltage is sent down our 22m long, 8.36mm^2 stranded copper power tether into single pin Cobalt connectors which provide a waterproof seal for MAKO's main electronics enclosure. Inside MAKO, the voltage is then stepped down to 24VDC for the Blue Robotics Basic ESCs and T200 thrusters, and once again to 12VDC for the remaining control systems like the LattePanda Sigma and Fathom-X ethernet converter.

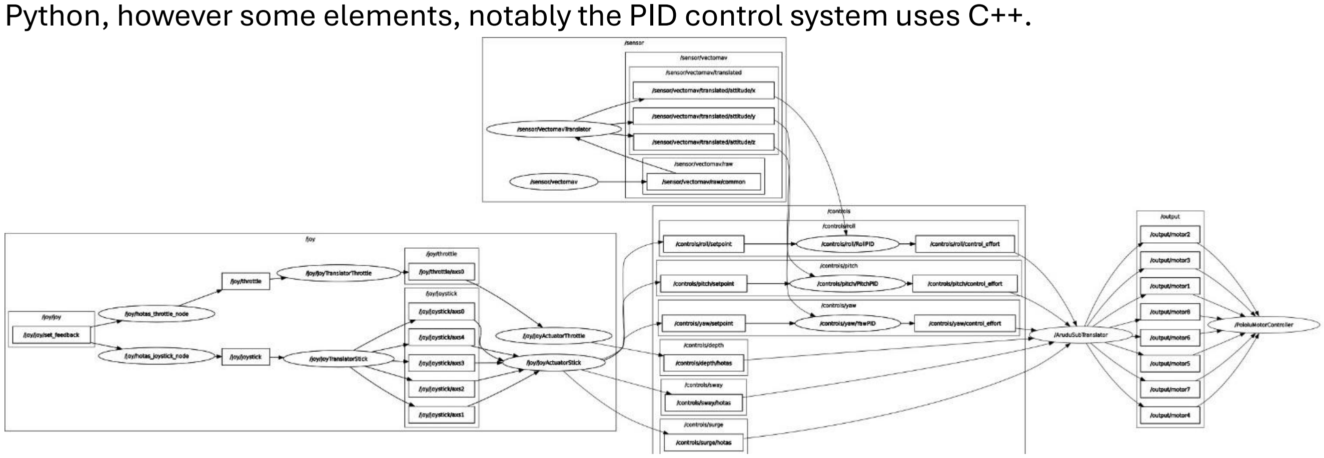
Communication to the onboard computers is done via a Fathom Tether which is plugged into a Subconn 3 pin wet-mate connector. We chose to use a wet-mate connector to allow for MAKO to be fully autonomous if the need arises. Power to the ESCs and therefore thrusters is switched by a 120A SPST relay that is controlled by an externally accessible emergency stop to provide the utmost safety to any diver that may be in the water with MAKO.

The control system of MAKO consists of a Logitech G X56 HOTAS, and Dell Latitude Rugged laptop, which is connected to MAKO using a NETGEAR router which receives and distributes data from the Fathom-X interface from Blue Robotics.

We chose to use a significant quantity of Blue Robotics products for their reliability and widespread use, which would allow users who are already familiar with the Blue Robotics ecosystem to use MAKO with ease. We used the LattePanda Sigma because of its immense computing power for its size and its onboard Arduino interface that allows for the expansion into autonomy and the addition of more sensors. The decision to use the HOTAS for the piloting of the sub was focused on the fine control it can provide, we knew that it would be far more precise than anything we could manufacture in-house. Both the Blue Trail Engineering Cobalt connectors, and Subconn connectors were used because they are reliable, and provide an absolutely watertight seal to pass high current power and delicate signals through.

Software

MAKO utilizes Robotic Operating System 2 (ROS2), which consists of a network of individual nodes that send and receive information from each other through topics, combining to create a robotics system. The ROS2 network for MAKO is primarily written in Python, however some elements, notably the PID control system uses C++.



MAKO's ROS2 network

The ROS network begins with the joystick inputs, these are read using the native Linux joystick drivers, each device in our dual interface setup has its own “raw topic”. A separate node subscribes to its respective message and a configuration file determines which buttons and axes are then utilized by the rest of the network. Up to this point these are ratiometric values between -1 and +1 inclusive. These inputs then go to two possible locations, our PIDs or the motor controller directly. The rotational axes are fed into their respective PID controllers, which take the ratiometric value as a setpoint and output a desired PWM modulation between -400 and +400 inclusive. Each PID’s plant is fed by its respective axis from our VectorNav VN100 IMU, which has its output split up to its individual axis by a translator node. These values are then fed to our motor controller. For our lateral axis the values are simply scaled by the same factor of 400 and fed to the motor controller. The motor controller then computes the sum of the intent on all axes and determines what PWM value to send each respective motor. The motor controller also handles the clamping of our PWM values to ensure that we don’t exceed our power supply limit and adds additional safety features such as communication persistence with our PWM generator and motor (dis)arming functionality. In the near future, MAKO’s robotic arm control will be implemented similarly through additional axes that are not currently being utilized. Some inverse kinematics may also be implemented to ensure no unintended collisions with the frame occur.

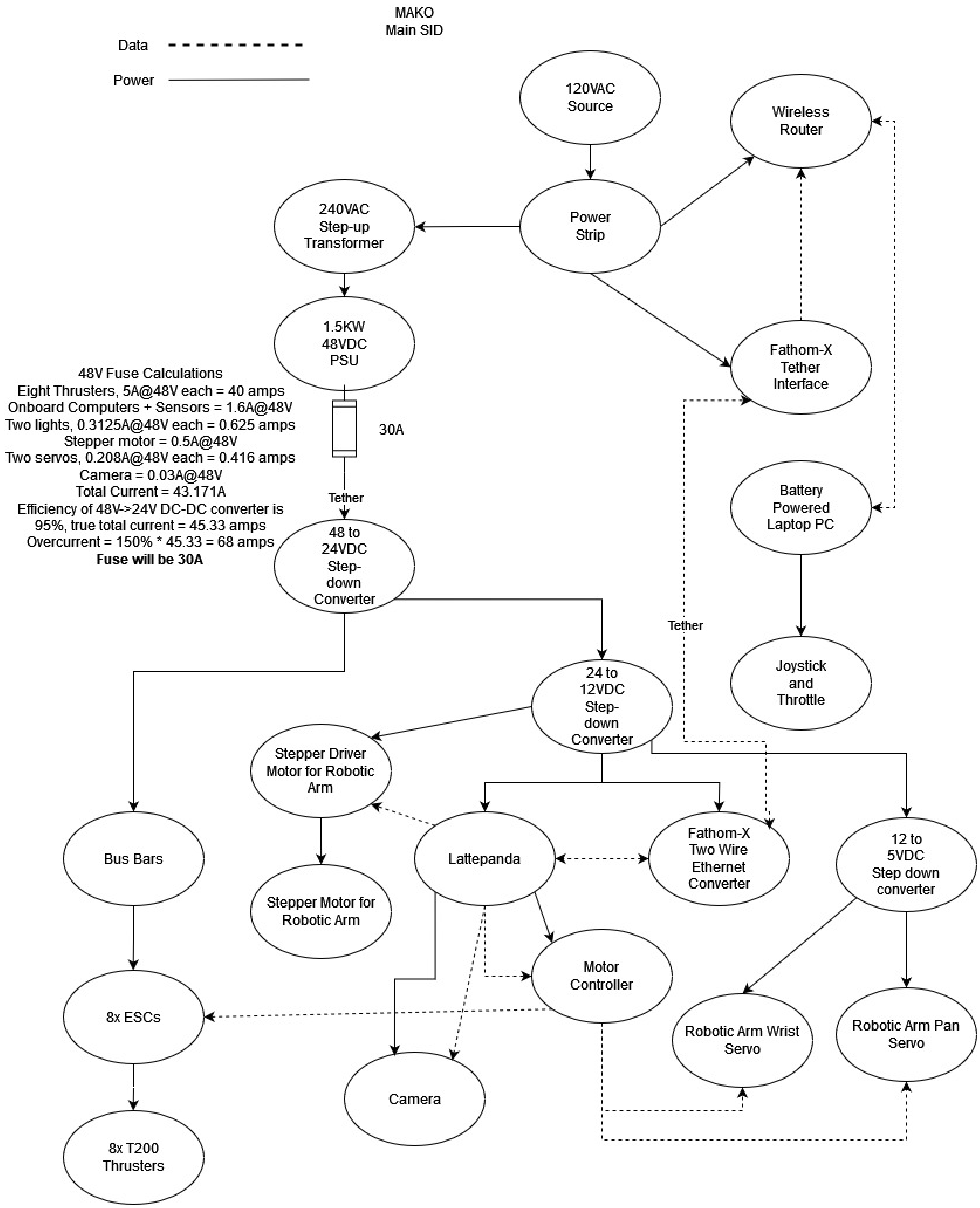
Buoyancy System

MAKO itself is neutrally buoyant as designed, we did not have to do any significant changes to the ROV’s frame to make it neutrally buoyant. If we needed to fine tune the buoyancy of MAKO the plan was to utilize the vertical and horizontal thruster mounts as air bladders, since they are relatively large volumes that can be hollow due to the additive manufacturing process. When the tether was initially designed buoyancy was not considered, however, after the first tethered pool test pool noodles were added to the tether to ensure that only the necessary tether would be submerged. The power cabling of the tether may be changed out before the competition, in that case, the tether will be made neutrally buoyant using 3D-printed hollow rings placed at regular intervals along the tether.

Tether

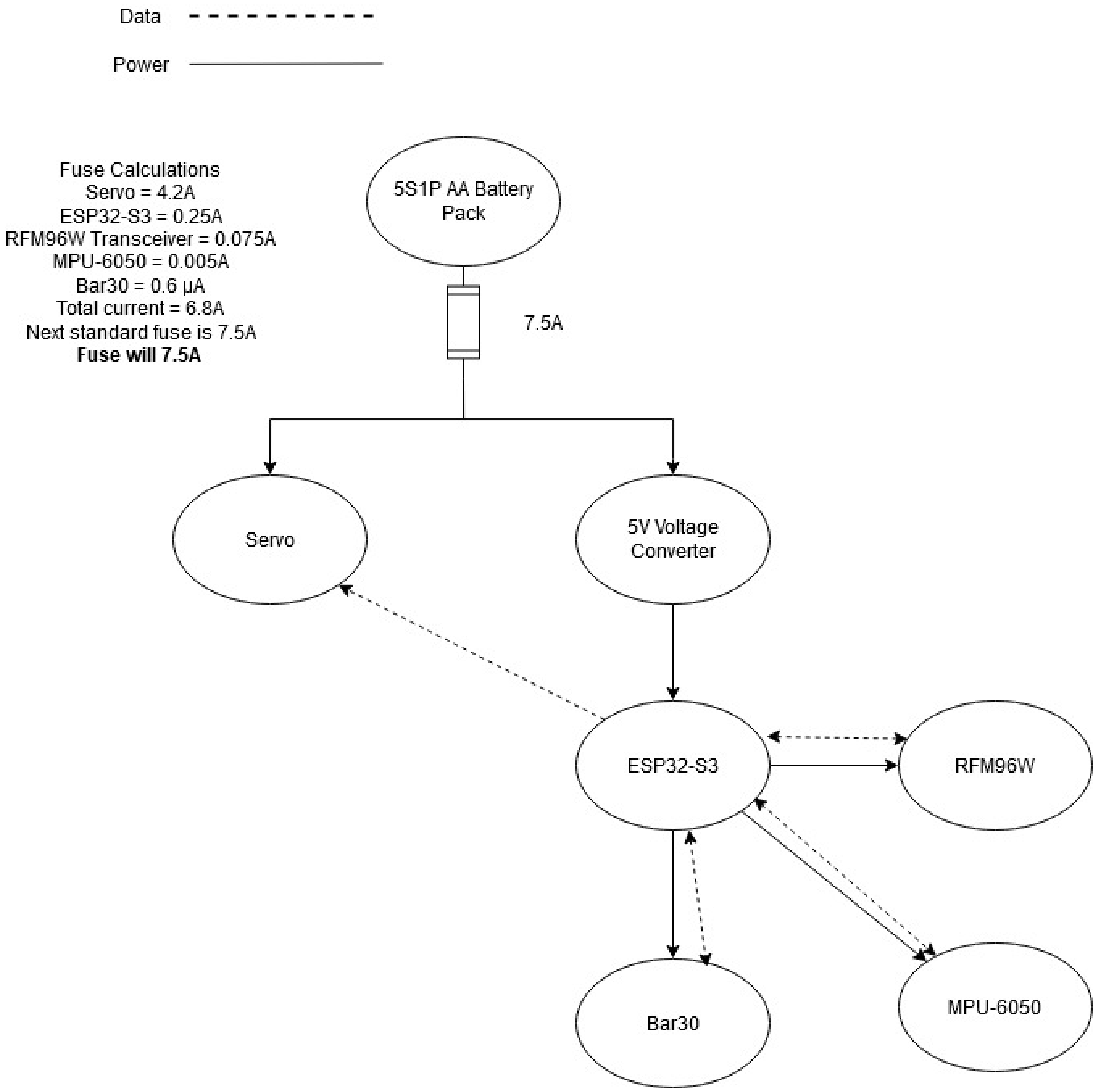
The tether itself consists of three cables, two 22m long, 8.36mm^2 stranded copper power wires, and one Fathom Tether from blue robotics which has a length well beyond the 22m of the power wires. The tether is wound around a Fathom Spool from Blue Robotics. For tether management, the spool is unwound till two full revolutions of the tether remain on the spool for strain relief, then the spool is locked in place to prevent more rotation. The excess unwound tether is then placed into the water to prevent a tripping hazard from being created due to the large coil of cable that it would create. Starting from the ROV side 3ft sections of pool noodle are added at regular intervals. The startng distance from the ROV depends on the intended depth for the day's mission. The newly floated tether is left in the water to prevent a tripping hazard.

SYSTEM INTEGRATION DIAGRAM



MAKO’S SID

NON-ROV SID – VERTICAL PROFILER



Vertical Profiler SID

ACCOUNTING

FUNDING			
Source			Amount
ERAU EECS Department			$2,000
ERAU COE			$15,000
Alumni Donation			$4,000
Outside Donations			$10,000
Competition Fee			($350)
		Total Funding	$30,650
ROV			
Section	Acquisition	Component Examples	Cost
Frame	Purchased	Aluminum Extrusion, Electronics Tube, Fasteners	$880.63
Computer/ Electronics	Purchased/Reused	LattePanda Sigma, Polulu Maestro, Sensors	$2,440
Tools/Mechanisms	Purchased	Robotic Arm, Camera, Headlights	$731.76
Propulsion	Purchased	BlueRobotics T200 Thrusters	$1,600
Onshore Equipment	Purchased/Reused	Power Supply, Fathom Interface, Dell Laptop, Logitech HOTAS	$4,274.36
Connection	Purchased	Tether, Data Cable, Penetrators	$622.99
		Total Cost of ROV	$10,549.46
TRAVEL BUDGET			
Category			Set Budget
Lodging			$3,000
Gas			$400
Airfare			$1,400
		Total Travel Budget	$4,800
EXPENSES			
Total Funding	$31,000		
Total Expenditures	$15,699.46		
Surplus	$15,300.54		

Funding and Budget for WaveCo's MAKO

SAFETY

At WaveCo, our top priority is safety. In our lab, we make certain that everybody follows a simple set of rules. First, and most important, is common sense. If something feels like it has the potential to be unsafe, we don't do it. Second, when working with power tools, safety glasses are required, and long hair must be tied back. Third, when working with any materials that create airborne particles, everybody in the lab must wear a mask.

For most of our testing, we used lithium batteries instead of onshore power because our power supply had not yet been delivered. The batteries were supplied by our organization's other team. We took special care when working with these batteries due to their combustible nature. When the batteries were not in use, they were kept in a battery bag which helps to prevent the spread of fire if they were to combust. These battery bags were then kept in their own pelican case. We also made sure that there was somebody present whenever the batteries were being charged.

For pool testing, we had several safety precautions in place. We would not put the sub into the water without having at least one person with it in the water. We did this for several reasons. For starters, it made it a lot easier to get the sub in and out of the water. Second, and more importantly, our sub is fitted with an emergency stop which is attached to the sub itself. If the diver feels that the sub is behaving in a way that is dangerous, they can pull the e-stop, immediately cutting power to the thrusters.

For our customers, our submersible comes equipped with multiple safety features. For starters, each of the thrusters has a guard on both the front and the back, which eliminates the possibility of somebody's finger getting caught. MAKO also comes with an onshore emergency stop switch which cuts power to the sub if something happens that could result in injury to a diver or damage to the sub. The sub also comes equipped with a switch to arm and disarm the thrusters. This means that there is no chance of the thrusters spinning before the pilot is ready.

TIMELINE

Preliminary Design (Aug. – Sept. 2023) :

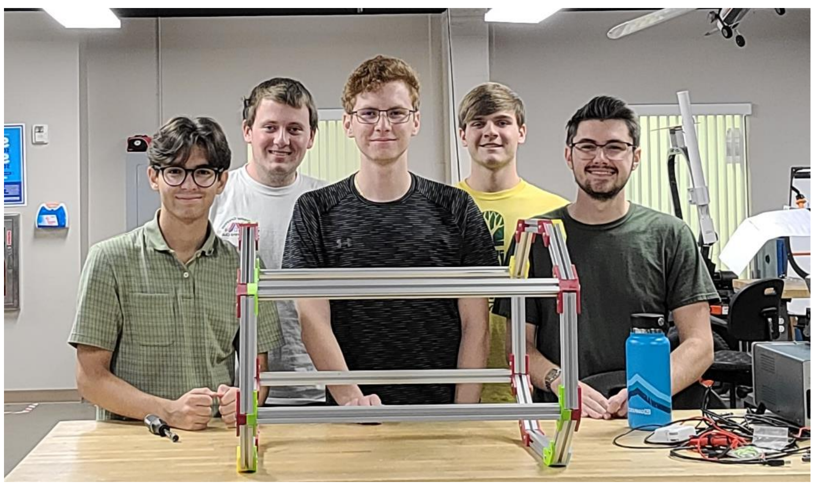
Various frame and motor layouts were discussed. We quickly settled on MAKO's final octagonal shape but continued to work on motor and tube placement.

Finalizing Design Choices (Oct. 2023) :

With MAKO's basic structure finalized, we began working on the internal layout of the electronics tube and performing CAD work for our 3D-printed mounting joints.

Build Days (Oct. 2023 – Jan. 2024) :

In mid-October, we assembled MAKO's frame for the first time. Over the following months, we built the central tube's mounting platform, attached motors, and assembled the e-tray.



WaveCo in one of our university's robotics labs after assembling MAKO's base frame

Software Workdays (Jan. – Apr. 2024) :

Initially, we intended to use ArduSub for our control needs. After initially succeeding, we began encountering issues when we added a camera, forcing us to transition to ROS. This required a full redesign of Mako's software setup in March and April.

First Water Test (Feb. 2024) :

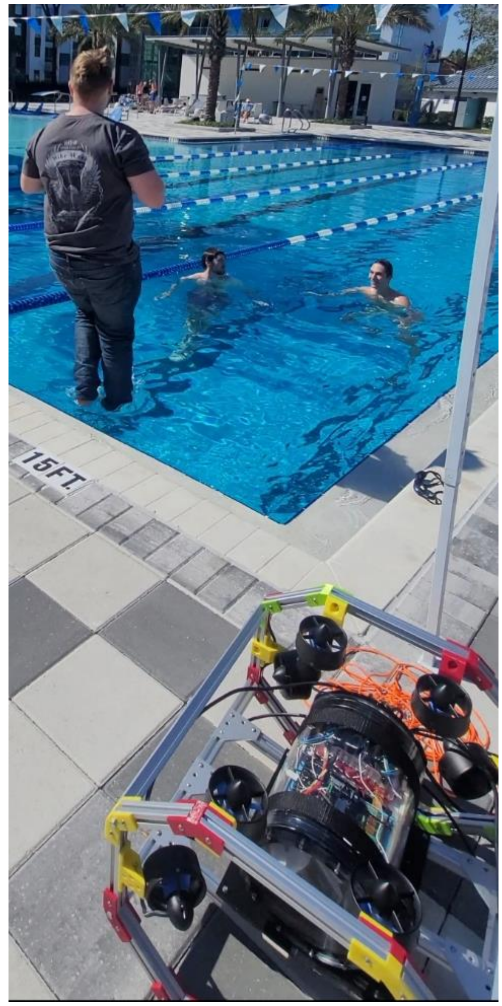
Right on time for Parent Weekend, we got MAKO in the pool and controlled it. Without stabilization or depth hold, maneuvering was difficult, but doable. The test was cut short after we detected a slight leak, however.

Redesigns (Mar. – Apr. 2024) :

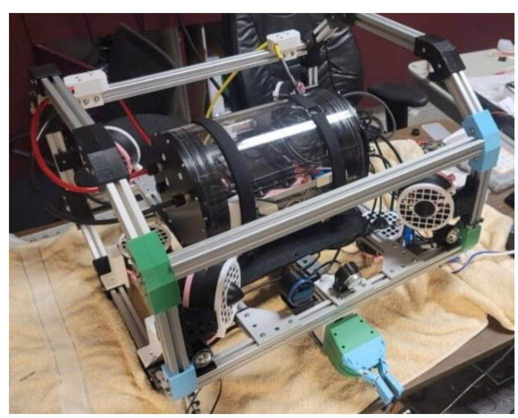
Notable changes included: moving the vertical thrusters from the top of the frame to the bottom, replacing a Raspberry Pi 4 with a LattePanda Sigma, and replacing a Pixhawk with a Pololu Maestro servo controller and VectorNav VN-100 IMU/AHRS.

Functional Sub (May 2024) :

Final preparations were made, both hardware and software-wise, in our end-of-year "Sprint Week." Our ROS code was completed and we powered MAKO through a ground tether, rather than a battery.



First Pool Test



Final Sub Design