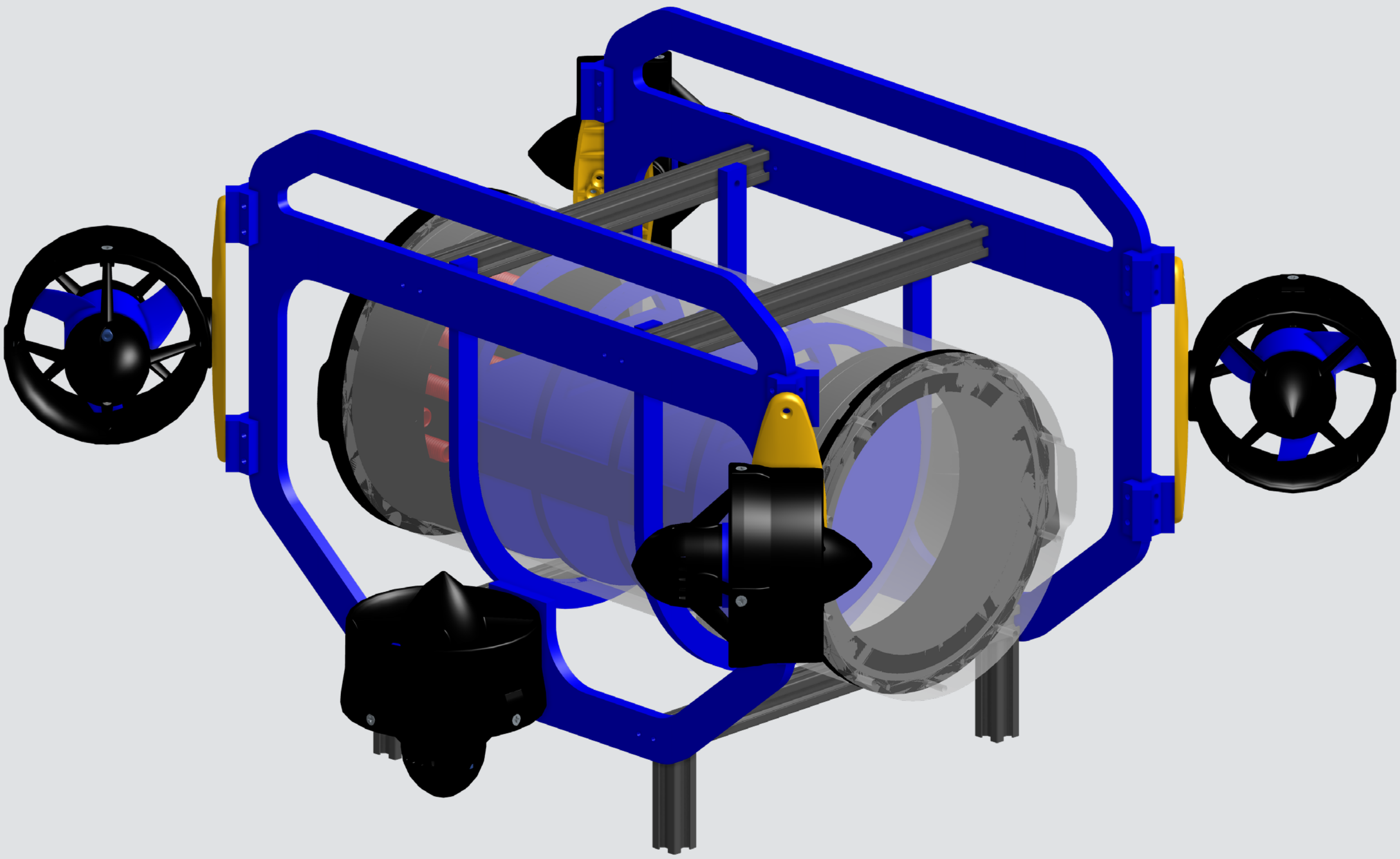
East Tennessee State University

ETSU BUCCANEERS



2023 TECHNICAL REPORT

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ABSTRACT

The ETSU Buccaneers are a leading collegiate business enterprise devoted to revolutionizing aquatic solutions through the layout, production, and operation of superior underwater Remotely Operated Vehicle (ROV) systems. Kraken is geared up with a complete tool set, permitting it to complete a wide range of underwater missions. Its purposes consist of exploration, marine studies, infrastructure utilization, and environmental restoration for the upkeep of aquatic ecosystems. This report affords an in-depth account of Kraken, the company's flagship ROV, including the layout and improvement process, highlighting its capacity to conquer challenges set forth by the MATE organization.

Developing Kraken required meticulous planning, prototyping, and rigorous testing to make certain the highest requirements of success and safety were fulfilled. Key features consist of a modular layout for adaptability, cost-effective manipulators, a custom control system, a versatile frame, and a vectored thruster configuration.

Kraken represents a tremendous milestone in underwater robotics, supplying versatile capabilities and robust construction through simple, yet successful, systems. This report delves into Kraken's design, development, and operational skills, showcasing its capability to revolutionize underwater exploration and intervention.

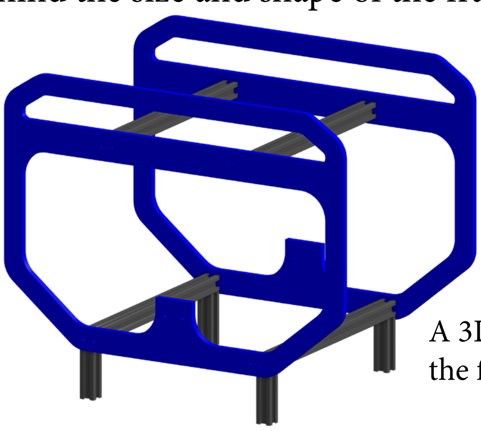
The ETSU Buccaneers are committed to pushing the boundaries of underwater robotics in concord with aquatic ecosystems. With its unprecedented talents, Kraken is poised to redefine underwater operations and make contributions significantly to the sector of aquatic robotics.

DESIGN RATIONALE

MECHANICAL SYSTEMS

FRAME

The vehicle consists of skids that are 35.6 cm x 25.4 cm centimeters and are 0.635 cm thick. These skids were created using high-density polyethylene (HDPE), which is known for its robustness, light weight, and resistance to corrosion. The construction process of Kraken involved computer-aided design (CAD), followed by the creation of a prototype, using a laser cutter and spare acrylic sheets. After reviewing the prototype and making alterations, the final design was milled by a CNC machine. The two skids are connected by four 1.5 cm x 1.5 cm x 24 cm beams of extruded aluminum, which provides additional strength and support to the vehicle. To prevent the ROV from scraping the seafloor, four 5 cm risers were installed on the bottom. Kraken's small frame allows for easier acceleration and movement through the water, which was an important factor for the design rationale behind the size and shape of the frame.

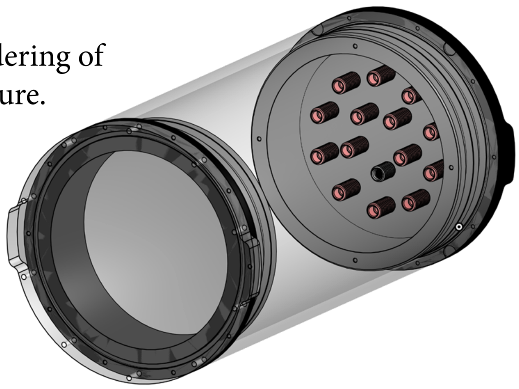


A 3D rendering of the frame.

WATERTIGHT ENCLOSURE

Housing all of Kraken's vital electronics is a 6-in (15.24 cm) watertight enclosure from Blue Robotics. The various wires run through 15 Blue Robotics WetLink penetrators and into the capsule, where power and signal wires are distributed to their respective places. The watertight enclosure is depth-rated to 65-meters. The acrylic body of the capsule is 0.5 cm thick and 11.75 in (275 cm) long. The clear acrylic allows the electronics to be viewed from the exterior. The back cap, housing the penetrators, is a 15-hole end cap made out of aluminum. The front end cap is a 6-in, cast acrylic flat front face, allowing for the possibility of an internal camera within the watertight enclosure. The watertight enclosure is fastened to the ROV using two custom-designed tensioning mounts. The mounts are 3D-printed using a PLA filament. The mounts screw directly into the supporting extruded aluminum frame using slotted screw holes that allow for increased or decreased upward tension.

A 3D rendering of the enclosure.



BUOYANCY

Through thorough testing and calculations, Kraken has achieved neutral buoyancy. The HDPE of the frame has a density of 0.95 g/cm3, meaning that it is positively buoyant. Additionally, the 6-inch watertight enclosure is positively buoyant due to the large amounts of unoccupied space. To counteract the positive buoyant force, steel ball bearings are mounted inside of two 2-inch diameter PVC pipes, in order to provide an equal gravitational force. The bearings cause the ROV to have a net buoyant force, resulting in neutral buoyancy. Before mounting the bearings, the needed weight to counteract the positive buoyancy was calculated. The weight of each ball bearing was taken and then compounded until it matched the needed weight in order to achieve neutral buoyancy. Each canister is placed at the right and left side of the ROV, below the center of buoyancy.

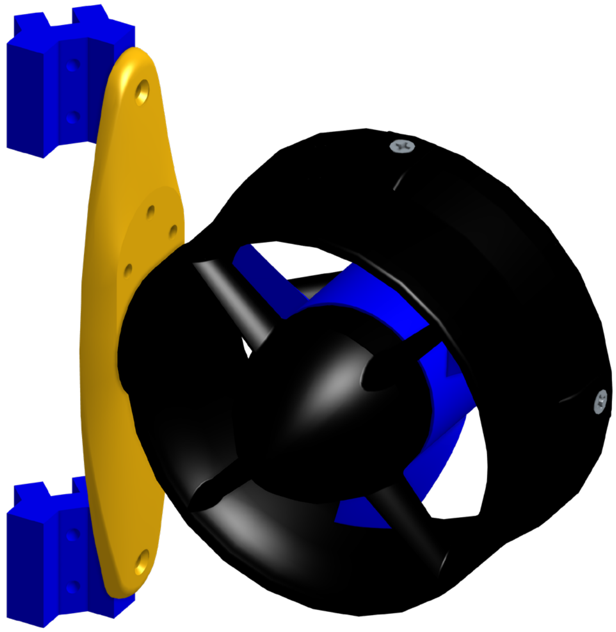
MANIPULATORS

Two manipulators are mounted to extruded aluminum beams located on the front of Kraken's frame. The right manipulator is an Actobotics gripper, mounted horizontally. It is capable of grasping items up to 10.6 centimeters wide. The left manipulator is an Actobotics parallel gripper, able to hold items up to 7.1 centimeters wide. This manipulator can also be used as a hook when opened due to its vertical configuration. Both of the Actobotics grippers were chosen for their simplicity, light weight, and affordability. A Savox waterproof servo is mounted to each gripper, with their signal wires being connected to the Arduino Mega board, enabling them to open and close through a controller at the surface. Dual manipulators were selected to be mounted in these configurations to increase the range of objects that Kraken can hold.

The manipulators found on Kraken.
Source: Robotshop.com

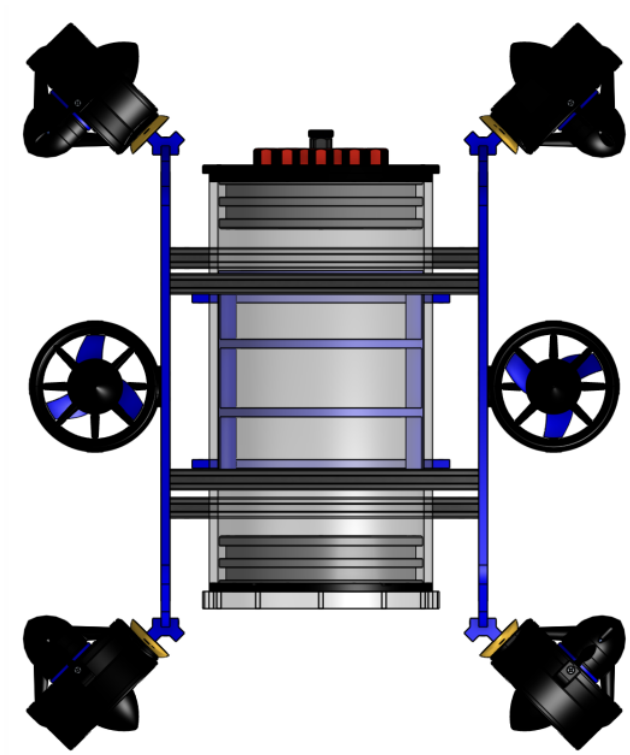
THRUSTERS

When searching for capable thrusters, explicit criteria for the selection were articulated. The thrust capability, particularly for the vertical thrusters, was given the highest priority. The thrusters had to be compatible with the control system and ideally equipped with their own Electronic Speed Controllers (ESCs). To fulfill these requirements, Blue Robotics' T200 thrusters were used. Initially, the ESCs were planned to be used with a Raspberry Pi Model 3, but limited compatibility was discovered between the two without an additional servo bonnet. Subsequently, it was discovered that blue robotics ESCs were better suited for an Arduino Mega running C++, rather than a Raspberry Pi with a servo bonnet running Python.



3D Rendering of thruster with mounts.

3D rendering of vectored thruster configuration.



Four thrusters are positioned at 45° angles on each corner, known as a vectored orientation. This configuration allows each thruster to simultaneously contribute to ROV's propulsion in any horizontal direction. It also prevents any internal components from obstructing the thrusters' flow. The remaining two thrusters are located on the sides near the center of gravity to propel the vehicle towards the surface or seafloor. Having two vertical thrusters is a considerable benefit when needing to retrieve heavy objects from the seafloor.

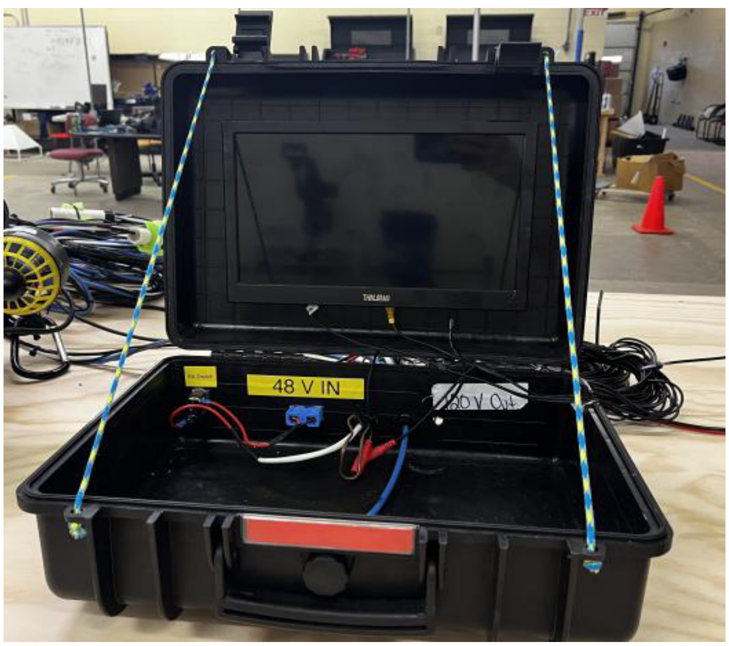
ELECTRICAL SYSTEMS

TOPSIDE CONTROL SYSTEM

Kraken's electronics are located onboard the ROV, resulting in a topside control system with minimal components. Mounted on the inside of the topside system's lid is a monitor. This monitor broadcasts footage from the cameras onboard Kraken. Through the strain relief and abrasion protection mounted on the back side of the control box, camera wires, power wires, and communication wires enter the box, in order to receive power and communication from the surface to the ROV.

TETHER

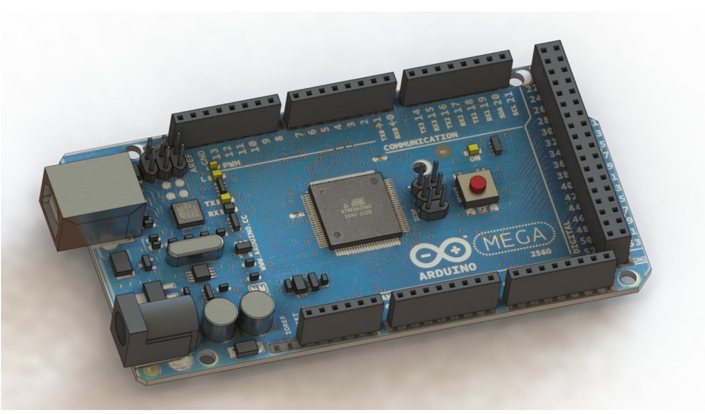
Kraken employs an exceedingly simple tether, composed of a mere handful of components. The tether consists of a 16 gauge, two-wire speaker cable shielded by a white jacket that serves as Kraken's power cable. An Ethernet cable is utilized for communicating with the controller and the USB host shield aboard the ROV. The tether is 15 meters long, allowing Kraken to reach distant areas. Strain relief is implemented at both ends of the tether through two tether thimbles, ensuring its durability and longevity.



Top left: Photo of topside control system
Top right: Photo of topside strain relief
Bottom right: Photo of bottomside strain relief
Credit: Gavin Bentley

ARDUINO MEGA

Kraken is controlled by an Arduino Mega. Through research, it was determined the Arduino Mega was easily compatible with the Blue Robotics ESCs used to control the thrusters. Additionally, the Mega contains 54 signal pins, allowing for effortless connection to the ESCs. A USB host shield easily connects to the Arduino, enabling a controller to be connected to control the thrusters and manipulators. The Arduino receives power from the 12 volt power distribution, and is plugged in through a 12-volt barrel connector. The Arduino also contains a USB-B uplink port which enables code to be changed at any point without reopening the watertight enclosure, as the uplink cable uses its own outward penetrator. Another reason Kraken is outfitted with an Arduino Mega is that the company members were previously familiar with C++, the programming language that is utilized in the Arduino system.



A 3D rendering of an Arduino Mega microcontroller.
Credit: Augustine Aelevanthara (GrabCAD)

CAMERAS

Kraken is equipped with one Blue Robotics Low-Light Analog Camera and one Chuanganzhou backup camera. The analog camera is located above the front of the six-inch watertight enclosure, in a separate two-inch diameter enclosure. This camera provides a wide-angle view of the manipulators, allowing the pilot to conduct in tasks. The second camera is positioned facing the front of Kraken, allowing the pilot an improved vision for navigation.

Photo of analog camera in enclosure.
Credit: Gavin Bentley

POWER

To operate, Kraken relies on a 48-volt power supply from the surface. The system includes two power converters that facilitate the distribution of different voltages across the ROV. There is a 48-volt to 12-volt converter housed within the Blue Robotics watertight enclosure that serves as the main power for all of the ROV. The power runs directly from the converter into a power distribution hub. The 12-volt power distributor provides power to the ESCs, the T200 Thrusters, and a Blue Robotics Camera. Meanwhile, the 5-volt converters provide power to the Arduino Mega and the USB-to-Ethernet converter. Located on one of the power distribution outputs is a 12-volt to 5-volt converter. The 5-volt converter provides power to the two servos that serve purpose for the manipulators.

CODING

Kraken's movement is controlled by an Xbox 360 controller. The left joystick of the the controller tells the ROV which direction to go and how fast. This is referred to as lateral movement. The right joystick controls rotational and vertical movement.

The code tracks three sets of thrust coeff-cients: lateral, rotational, and vertical. The lateral thrust coefficients are derived from the left joystick, while the rotational and vertical coefficients are each derived from the left joystick. The Arduino checks the controller input roughly 60 times per second. Each time it is checked is referred to as a tick.

Every tick, the lateral and rotational coefficients are added together and the a corresponding PWM (pulse with modulation) signal is generated. This signal is then transmitted to the ESC that controls the desired thruster.

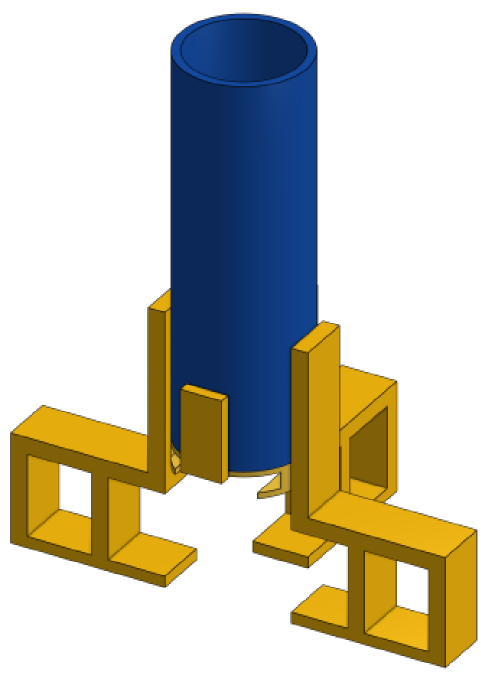
```
//we use the left stick to indicate which way we want to go and how fast
int16_t c = (int16_t)(Control::GetHat(LeftHatX) * MOVE_SPEED);
int16_t s = (int16_t)(Control::GetHat(LeftHatY) * MOVE_SPEED);

//the diagonal pairs are 0,3 and 1,2
//members of these pairs will always have the same multiplier but opposite sign
int16_t diag03 = -c + s;
int16_t diag12 = c + s;
input[0] += diag03;
input[1] += diag12;
input[2] -= diag12;
input[3] -= diag03;

//we use the horizontal axis of the right stick to indicate which direction to turn and how
fast
int16_t r = (int16_t)(Control::GetHat(RightHatX) * TURN_SPEED);
input[0] += r;
input[1] -= r;
input[2] -= r;
input[3] += r;

//we use the vertical axis of the right stick to dive and surface
input[4] = input[5] = (int16_t)(Control::GetHat(RightHatY) * VERT_SPEED);
```

Screenshot of code for ROV movement.
Credit: Nick Sells

SUPPLEMENTAL TOOLS

FRY RELEASE DEVICE

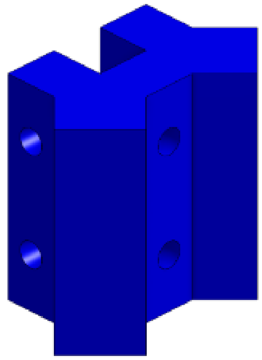
To assist in reintroducing endangered native Northern Redbelly Dace Fry into their habitat, Kraken uses a custom-designed fry release device. The device was designed using CAD, then 3D-printed using polylactic acid (PLA) filament. Kraken carries the device down by gripping a loop of rope that serves as a carrying handle attached to the top of the device. The device is set in the designated safe release area. After allowing the fry to acclimate, Kraken pulls the tray beneath the fry holding area, releasing the fry.



A 3D rendering of the fry release device.

BUILD VS. BUY. VS. REUSE

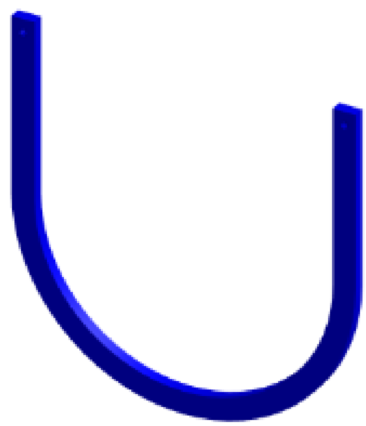
This year, Kraken boasts numerous 3D print ed components. Rather than purchasing pre-manufactured parts, CAD software was utilized to design original parts. More specif ically, Onshape was used to design 45-degre mounts for the vectored thruster scheme, a cradle for securing the watertight housing in the center of the ROV, and an electronics housing plate to house all of the electronics within the watertight housing.



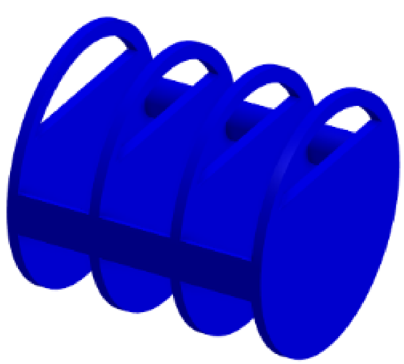
45-degree mount for vectored thruster configuration.

To manufacture these custom-designed mounts, assistance was enlisted from STREAMWORKS and their Ultimaker S5 3D printers. Using cost-effective PLA material, the components were printed in blue and gold to align with the university's color theme.

Cradle design to fasten watertight enclosure to frame.



Reusing components from the previous ROV helped Kraken's development stay affordable. The thrusters, ESCs, watertight enclosure, and beams of extruded aluminum remained as part of Kraken's design. The benefits of reusing these components include lowering company costs and reducing waste as these components are the most expensiv the ROV.



Electronics housing plate within watertight enclosure

SAFETY

COMPANY SAFETY MEASURES

During Kraken's operation, the company adheres to a strict set of protocols to ensure the safe handling of the vehicle. To illustrate, whenever Kraken was to be deployed, the team would execute a "Pre-Flight Checklist." This checklist consisted of various steps such as a fuse check, thruster test, a thorough enclosure test, tether check, visuals check, and basic ROV operation safety protocols.

While constructing the ROV, all company members are required to wear safety glasses as part of their Personal Protective Equipment (PPE). Additionally, it was mandatory to wear closed-toed shoes and remove any jewelry, particularly when using power tools. Team members with long hair were required to tie it back to prevent it from getting caught in any machinery.

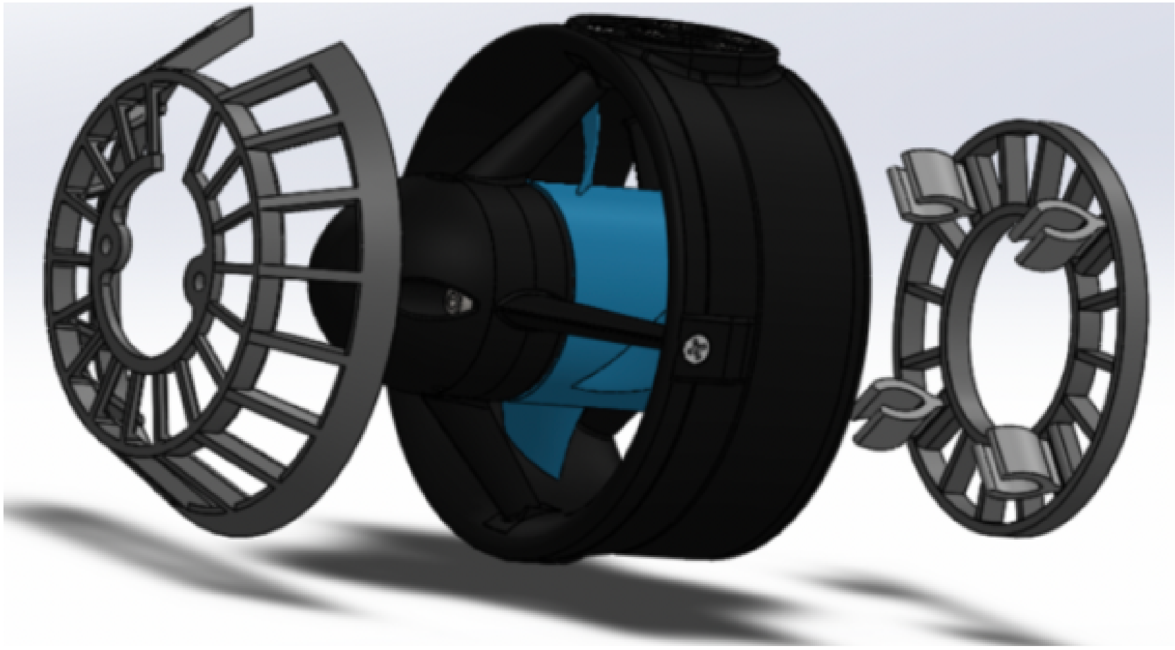
Preflight Prep

1. Connect to power
2. Notify team members power has been connected
3. Flip on power
4. Pilot call out "Power on"
5. Team member place ROV in water
6. Team member calls out "hands-off"
7. Initiate Motor test
8. Pilot drive Forward
9. Pilot Turn Right
10. Pilot Turn Left
11. Pilot Lift Down
12. Pilot Lift Up
13. Pilot Drive Back
14. Pilot call out "Motor Test Complete"
15. Visual systems Check
16. CEO asks teammates if systems are ready to go
17. When all confirmed, CEO says "mission launch"

The pre-flight checklist the poolside team goes through before entering the water

ROV SAFETY FEATURES

Kraken was designed to be effective at completing its desired tasks, all while maintaining a safe operation. One way the operation is ensured to be safe is by the company's following of a preflight checklist. Another way is to make the ROV itself safe through its design. All of Kraken's thrusters are properly shrouded to fit within the MECH-006 requirement. The mesh is smaller than 12.5 mm to fit the requirement listed as "this IP code equates to a mesh size >12.5 mm" on the 45th page of the 2023 Explorer Class Competition Manual. Kraken was also designed without sharp edges to also fit the MECH-006 requirements to pass safety.



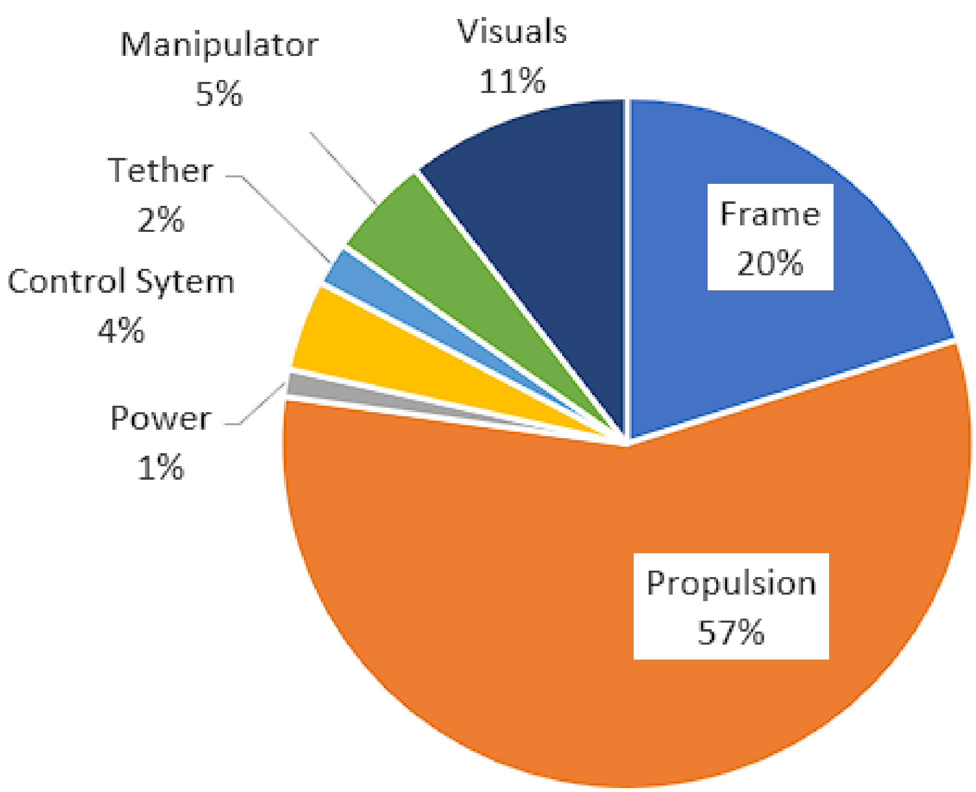
Exploded view of thruster with propeller guards

Kraken has various electrical safety measures in place to ensure secure operation. One of the most crucial safety features integrated into our ROV is a properly sized inline fuse to meet the ELEC-001E requirement for a "properly sized Littelfuse." To maintain a clean electrical design, Kraken's wires are appropriately waterproofed and heat shrinked to guarantee a safe and stable connection, satisfying the ELEC-022E requirement for "workmanship."

Kraken is also outfitted with proper strain relief on both the surface side and the submersed side of the ROV. The ROV utilizes two Blue Robotics tether thimbles attached through their own respective carabiners attaching to the frame and the control box. At the surface, appropriate wire abrasion protection was implemented into the control station, to ensure wires were not cut or exposed through repetitive contact.

FINANCES

The Buccaneers' budget this season was a planned $4000 for the ROV and an approximated $8,000 for travel / international competition expenses. The company was supported by several sponsors who were dedicated to the work accomplished by the Bucs. The overhead was fairly lower than last year considering that the majority of the expensive components were reused, and that the company did not have to worry about purchasing many tools as STREAM-WORKS allowed us to use the tools present at the ETSU Valleybrook campus where they are located. After the construction of the vehicle was completed, company members sat down and listed out every part of the vehicle to determine its true final cost. The shown image below is the ROV Cost Breakdown which shows the cost of every subsystem of Kraken.



Expenses by component type

COMPANY BUDGET

In order to understand the Bucs' financial position throughout the academic year, a running budget was maintained throughout the season. In the budget sheet, all of the incomes were listed in the uppermost section of the spreadsheet. As donations were received, the sheet was updated with the necessary information. Below the incomes, all expenses were listed including all of the components of the ROV and various aspects of travel in order to compete at the world championships. In the totaling section of the file, all incomes are compounded, all expenses are totaled, and the amount needed for fundraising is listed.

School Name:				East Tennessee State University	
Income:					
Source:					Amount:
Tennessee Valley Authority (TVA)					$2,400.00
TVA Credit Union					$500.00
STREAMWORKS Education					$2,000.00
Honda Kingsport					$400.00
Expenses:					
Category	**Sub-Category**	**Type**	**Description / Examples**	**Projected Cost**	**Budgeted Value**
Hardware:					
	Frame	Purchased & Re-used	HDPE Sheets & Extruded Aluminum	$100.00	$55.00
	Enclosure	Purchased	Acryllic, Caps, & Penetrators	$500.00	$446.00
Electronics:					
	Propulsion	Re-Used	Thrusters & ESCs	$1,500.00	$1,416.00
	Power	Re-Used	Power Converters	$100.00	$31.98
	Control System	Purchased	Arduino & Host Shield	$100.00	$105.19
	Tether	Re-Used	Camera wires, ethernet, and power wires	$50.00	$50.00
	Manipulator	Re-Used	Two Claws	$120.00	$120.00
Sensors:					
	Visual	Purchased	Camera	$200.00	$260.00
Travel:	Flight:			$5,000.00	$3,978.31
	Hotel:			$3,000.00	$2,985.00
	Food:			$1,500.00	$1,480.00
				Total Incomes:	$5,300.00
				Total Expenses:	$10,927.48
				Total Expenses - Re-use / Donations:	$9,309.50
				Total Fundraising Needed:	$4,009.50

Budget and cost accounting of 2022-2023 season

CHALLENGES

This year, many challenges were faced and overcome during the construction of Kraken. The decision of what material to build the frame from was an issue. Company members with opposing ideas strongly adhered to their respective viewpoints. A cost-benefit analysis was conducted on various frame materials. Tensile strengths, costs, densities, and modularity were researched and compared. A compromise was achieved and both HDPE and extruded aluminum were used.

Another major struggle was found in attempting to find company sponsors. The company reached out to a multitude of local businesses and corporations. However, very few agreed to contribute funds. Part of this was found to be that because these businesses already supported the university in a particular way, the business was not in the position to support the company as well. The ETSU Research Corporation lent a hand to the Buccaneers providing much support to the company financially and providing necessary professional guidance in navigating university protocol.

The Buccaneers could not have done this without the support of the ETSU Research Corporation. To David Golden, Betsy Cunningham, and the whole of the ETSU Research Corporation, the Bucs say thank you.

TROUBLESHOOTING

Many challenges have arisen during the construction, prototyping, and testing of Kraken. Kraken has undergone many hours of in-water operation, to smooth out any potential issues. Several issues have stemmed from the watertight enclosure and its potted cable penetrators. There were multiple instances where the epoxy of the penetrators aged and cracked, allowing water to enter the enclosure at an alarming rate. This problem was solved by the conversion to Blue Robotics WetLink penetrators. These penetrators were an expensive addition, but necessary to have a more reliable ROV.

Another obstacle the company faced was the Arduino in the enclosure intermittently disconnecting. This would cause Kraken's thrusters to continue running on the last input sent, meaning that the pilot would lose control of the ROV and Kraken would spin uncontrollably. The disconnections would be found to be caused by an insufficient amount of voltage reaching the Arduino. The company was able to fix the power issue through the use of another power cord for the Arduino.

REFERENCES

Moore, Steven W., et al. Underwater Robotics: Science, Design & Fabrication. Marine Advanced Technology Education (MATE) Center, 2010.

Blue Robotics. 2023. Basic ESC R3 Example Code for Arduino. [online] Available at: <https://bluerobotics.com/learn/basicesc-r3-example-code-for-arduino/>.

M.A.T.E. 2023 Explorer Manual. [ebook] Marine Advanced Technology Education. Available at: <2023_EXPLORER_Manual_FINAL_1_17_2023_withcover.pdf (hubspotusercontent-na1.net)>

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