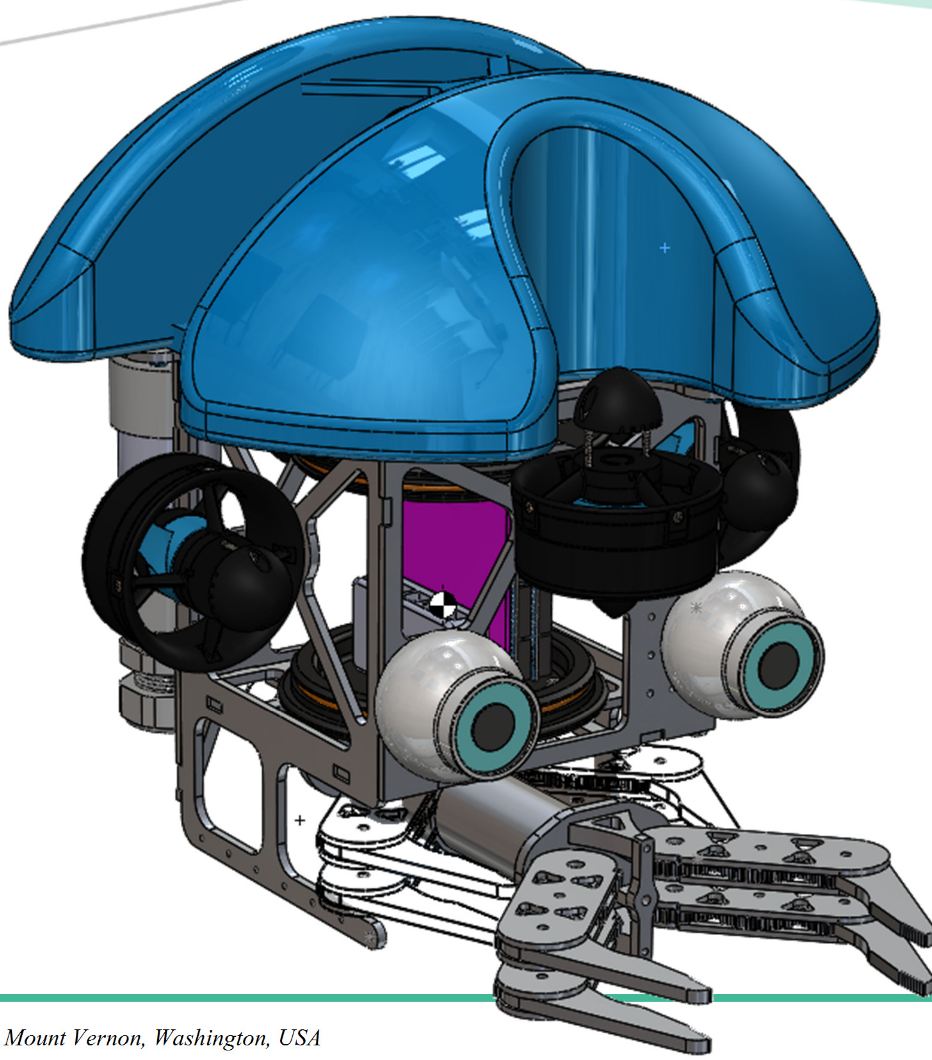


From Sea-Tech 4H club in Mount Vernon, Washington, USA

Approx. 3,900 km (2,400 mi) from the International Competition

TEAM CADMUS

ALORA HOUGHTON – CEO

SATONE HARATANI – CFO

COOPER RISTOW – ENVIRONMENT & SAFETY OFFICER

ISAIAH HOUGHTON – DESIGN SPECIALIST

LAZLO COCHEBA – FABRICATION DIRECTOR

VARICK ANDREWS – TECHNICAL DIRECTOR

KAYLIE HOUGHTON – MARKETING DIRECTOR

Technical Report 2016

TABLE OF CONTENTS

ABSTRACT

Team Cadmus, composed of seven members, was founded for the 2016 MATE competition season as a part of the Sea-Tech 4-H club located in Mount Vernon, WA. Our company's goal was to build a small, maneuverable and intuitive ROV that will perform research on both Europa's sub-zero oceans, and Earth's endangered reefs located in the Gulf of Mexico. To achieve these tasks, our company has designed and fabricated specialized tooling. These include a pressure sensor for measuring depth, a thermocouple for measuring temperature, as well as our most versatile tool, the Sea-Tech Legacy Claw. All systems are controlled by either Radio Control (RC) or an onboard Arduino microprocessor. ROV Cadmus is designed to be compact and lightweight to improve maneuverability and lower transport fees which will save NASA $20,000 per kilogram for the mission to Europa.

BIOGRAPHIES

Figure 1 - Alora Houghton

ALORA HOUGHTON

Company Role: CEO

Poolside Role: Tether Operator

Alora is a homeschooled junior who has had a fascination with mechanical processes since a young age. Before becoming involved in the MATE competition, Alora first experienced the world of engineering through her local FIRST Robotics club where she participated as a fabricator and a pilot. As a result, she has had the most enjoyment throughout the fabrication and marketing processes of such events, and continues to pursue and develop these interests as the year's CEO. This year, Alora has enjoyed maintaining the team's schedule and learning about the importance of management. In addition to being involved in MATE, Alora enjoys participating in her speech and debate organization, and is an avid musician. This is Alora's second year in the MATE competition and Sea-Tech 4-H club.

Figure 2 - Satone Haratani

SATONE HARATANI

Company Role: CFO

Poolside Role: Mission Specialist

Satone is a freshman in Anacortes High school, who has had interests in engineering and science from a young age. Prior to joining Sea-Tech 4-H, she had very little experience with robotics; however, her experience in the club has taught her much about Robotics and Engineering. This year, she has focused on reports, such as the marketing display and spec sheet, and mission strategies for our competitions. Among Satone's other interest are photography and playing various instruments. She is also an accomplished sailor, having navigated the Pacific Ocean from Japan to Alaska and down to Washington State with her family. This is Satone's second year in the MATE competition and Sea-Tech 4-H club.

Figure 3 - Cooper Ristow

COOPER RISTOW

Company Role: Environmental Health and Safety Officer

Poolside Role: Pilot

Cooper is a homeschooled 8th grader who has held a lifelong interest in planning, building, constructing electrical and mechanical systems. Observing the annual Sea-Tech display since a young age, he set his sights on being part of the team, developing his skills and gaining knowledge for when the time came. He is in his element during the entire mission season, enjoying brainstorming with his peers, experimenting, and researching new technology. In addition to working with his team, Cooper is an active Boy Scout, an avid archer, and trap shooter. He also enjoys building and flying his RC aircraft. This is Cooper's second year in the MATE competition and Sea-Tech 4-H club.

ISAIAH HOUGHTON


Figure 4 - Isaiah Houghton

Company Role: Design Specialist

Poolside Role: Data Analyst

Isaiah is a homeschooled junior who has expressed and explored an interest in the engineering field, due to his affinity for working with and building mechanical systems. He originally started his competitive robotics career in the FIRST robotics competition, which began his interest in building machines to overcome challenges in creative ways. This year, his greatest challenge was learning to use CAD software to design components for ROV Cadmus, as well as learning to collaborate with his fellow teammates in order to accomplish design and fabrication projects. In addition to robotics, Isaiah has interests in writing, music, and competitive speech and debate. This is Isaiah's third year in the MATE competition, and second year in the Sea-Tech 4-H club.

LAZLO COCHEBA


Figure 5 - Lazlo Cocheba

Company Role: Manufacturing Director

Poolside Role: Manipulator Operator

Lazlo is an active homeschooled 8th grader who has grown up with a strong interest in engineering. He has spent many hours learning alongside his older brother and father, becoming involved in the robotics and engineering atmosphere long before he was old enough to join the Sea-Tech 4-H club. He competed for the first time in the MATE competition in 2014 as part of the Sea-Tech 4H club Scout Class. He has also participated in Jr. FIRST Lego League, FIRST Lego League, and FIRST Tech challenge. Aside from robotics, Lazlo enjoys fishing, both freshwater and saltwater. He also enjoys beekeeping, cooking, baking, and raising various livestock. This is Lazlo's second year in the MATE competition and Sea-Tech 4-H club.

VARICK ANDREWS

Figure 6 - Varick Andrews

Company Role: Technical Director

Poolside Role: Mission Commander

Varick is a junior at Mount Vernon High School, who has an avid interest in engineering and robotics. Ever since he was introduced to robotics, it has been a constant adventure through every single challenge and triumph, and an enjoyable and educational experience throughout it all. Going into the season, Varick helped drive the team forward in the design and fabrication stage of his company's ROV. He developed new skills in fabrication, team cooperation, and troubleshooting. This is Varick's third year in both the MATE competition and the Sea-Tech 4-H club.

KAYLIE HOUGHTON

Figure 7 - Kaylie Houghton

Company Role: Marketing Director

Poolside Role: Alternate Tether Operator

Before joining the Sea-Tech 4H club and MATE, Kaylie was engaged in FIRST Robotics at her local high school, stationed as pilot during competition. She is a homeschooled sophomore who enjoys the building and troubleshooting of her team's ROV. This year, she was especially involved in the marketing aspect such as bringing in donations, informing supporters and managing the team Facebook page. Kaylie's interests in addition to robotics include writing, photography and graphic design. She actively participates in a speech and debate club and is an accomplished musician. This is Kaylie's second year in the MATE competition and Sea-Tech 4-H club.

MISSIONS

MISSION THEME

Astrophysicists and scientists are in need of a machine that can traverse to and penetrate the ice covered surface of one of Jupiter's largest moons, Europa, in order to perform critical analyses while exploring the moon's sub-surface ocean depths. The purpose of this mission will be to investigate whether or not the moon has the fundamental qualities to support simple life forms in its icy oceans. During this mission, ROV Cadmus must analyze the temperature of venting fluids from a crevice in the ocean floor, determine both the depths of the ocean and the icy crust which blankets it, and connect an Environmental Sample Processor (ESP) to a power and communications hub. It must do all this while avoiding terrain potentially hazardous to the vehicle.

Along with exploring the moon Europa, ROV Cadmus must perform tasks in the Gulf of Mexico. These would include retrieving small cubical satellites (CubeSats) from the ocean floor, identifying them by serial number, and carrying them to a collection basket for transport to a surface vessel for analysis. ROV Cadmus must also be able to collect oil samples from key locations on the ocean floor and return them to the surface for chemical analysis. Next it must survey two colonies of *Paramuricea Biscaya,* a coral found in the Gulf of Mexico, assess their separate conditions and return a sample of each to the surface for testing. Finally, ROV Cadmus must cap off an unproductive oil well to help produce an artificial reef by installing a flange to the wellhead, and placing a cap over the flange with proper fasteners.

SYSTEM DESIGN

FRAME

The frame of ROV Cadmus is 27.3cm (10.6in) high, 18.73cm (7.4in) wide and 18.7cm (7.4in) long. It's designed to be compact, allowing our ROV to fit well within the 48 cm (19 in) envelope, as well as to be compatible with our sensors and mission tools. The frame was manufactured using 5052 aluminum alloy for its strength and weldability. It was designed using CAD (Computer Aided Design), and was water-jetted by Janicki Industries. The five separate frame pieces were Tungsten Inert Gas (TIG) welded together and powder-coated black to protect the aluminum from corrosion. Our company chose to powder-coat our frame rather than anodizing it because of its similar protective qualities and the fact that we could do this ourselves.

Figure 8 - Powder-coating our Frame

BUOYANCY AND BALLAST

The float of ROV Cadmus is 14.0cm (5.5 in) tall, 37.2cm (14.6in.) wide, and 37.3cm (14.7in.) long. It is constructed of four sheets of 10 pound per cubic foot (pcf) polyurethane foam that were cut and laminated together using polyurethane glue. The final dome shape was sanded by hand. We used automotive body-filler to smooth the surface before applying waterproof paint. The dome shape was chosen to ensure a confident fit within the 48cm

Figure 9 - Finished Sanding the Float

envelope, and also to improve maneuverability for the protection of the delicate coral colonies during observation.

The ballast of ROV Cadmus consists of lead shot placed in ¾ inch PVC pipes that are secured onto the ROV at the bottom and sides of the frame. We also drilled out tall holes in the float and filled them with lead shot, securing them with a polyurethane potting compound. ROV Cadmus' has a strong righting moment to aid the control and stability of the machine underwater.

Figure 10 - PVC Filled with Lead Shots for Ballast

CLAW

Part of this year's challenge was to create the smallest and lightest ROV possible in accordance with competition standards. To that end, our company decided to use an electric claw to eliminate the need for pneumatic lines in the tether.

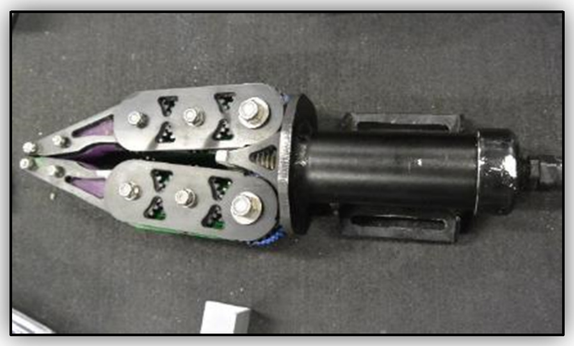


Figure 11 - Sea-Tech Legacy Claw

The claw is manufactured from both aluminum and plastic and is controlled using a Double Pull Double Throw (DPDT) switch on the pool side. The claw is attached to the bottom of ROV Cadmus using a combination of bolts and 'External Fixators', which are more commonly used by orthopedic surgeons to support broken bones during the healing process. The fixator assembly consist of small stainless steel clamping mechanisms which are designed to hold on to carbon fiber truss rods. The fixators provide infinite adjustability, which allows the claw to slide from a stowed position (inside the 48cm envelope) to a deployed position. We repurposed our claw from a previous club ROV, making it low cost and dependable for undersea operation. The claw is used in nearly every task and we consider it to be the most important mission tool on ROV Cadmus.

CAMERAS

ROV Cadmus' optic systems are composed of two forward facing Internet Protocol (IP) cameras. The cameras are attached with aluminum mounts which are fastened to the frame with external fixators similar to the ones on the claw. This allows for the quick and easy repositioning of the cameras as needed. Two forward facing 12V LED light banks were installed to illuminate ROV Cadmus' surroundings which will ensure a safer and more efficient operation. These systems are specifically used in missions such as the identification of CubeSats and coral reef observation.

Figure 12 - Cameras Mounted by Fixators

THRUSTERS

ROV Cadmus' propulsion system consists of five BlueRobotics T100 thrusters with an external brushless electronic speed control (ESC). These thrusters make a perfect choice for a small, lightweight ROV while still having more than enough power to complete the missions.

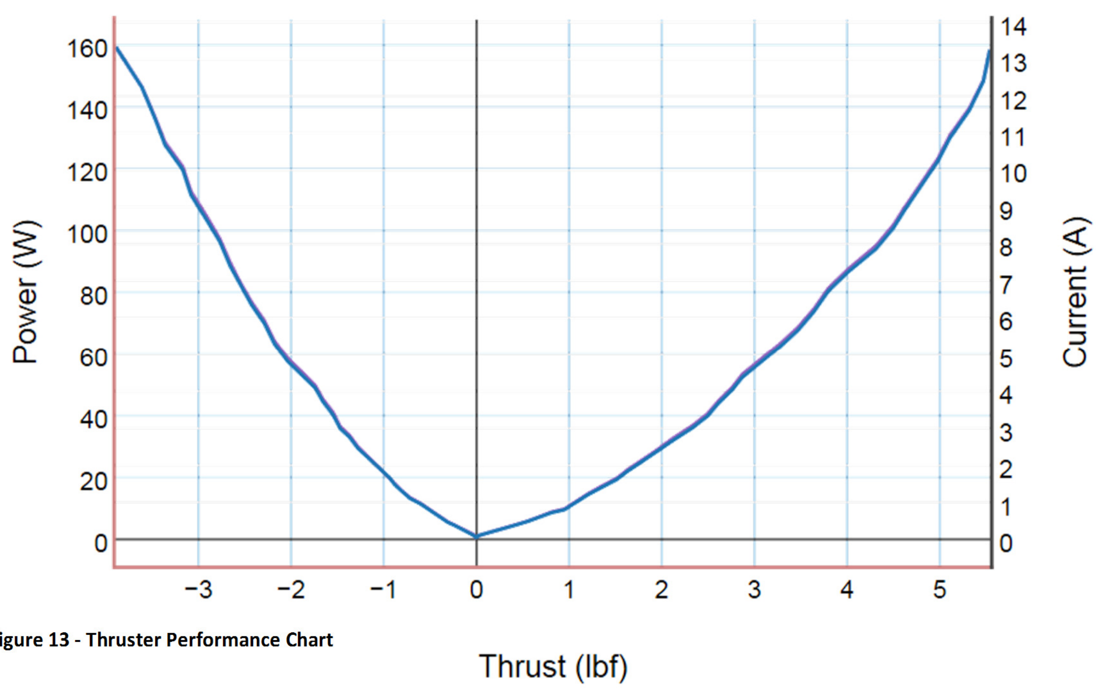


Figure 13 - Thruster Performance Chart

Each thruster is able to produce a maximum forward thrust of 2.36 kgf (5.2 lb) while only being 9.4cm (3.7 in) in diameter and 11.3cm (4.5 in.) long, with a dry weight of just under half a kilogram. The current draw is 12.5 amps at max thrust; however, each thruster's power is limited using our programmable RC transmitter.

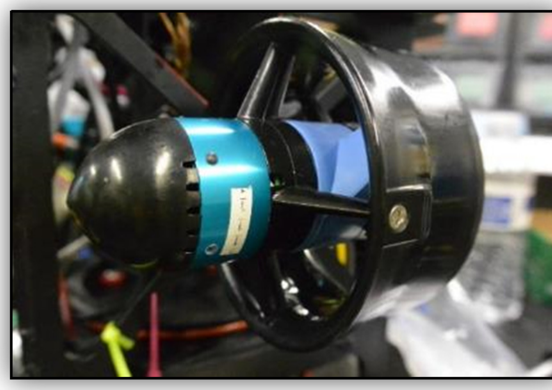


Figure 14 - BlueRobotics Thrusters

There are two thrusters on either side of the vehicle, providing us with horizontal thrust and yaw, two on the fore and aft to provide vertical thrust, and one thruster fastened within our float providing us with lateral propulsion.

CONTROLS AND TETHER

ROV Cadmus utilizes a combination of systems for vehicle control: First is thruster control which is done through an RC transmitter. Next, an Ethernet cable is used for the transmission of data for both the cameras and the sensors to the pool side, and finally a DPDT switch is used to articulate the claw.

Thruster Control

The thruster control system is one of an RC system used primarily for model airplanes. On the pool side there is an RC transmitter and a receiver on the bottom side. Normally, RC could not be used in underwater applications as the controls signal would have a hard time passing through water. ROV Cadmus uses a modified coax antenna to pass all the way down the tether and into the control box. This allows for the signal to be sent by wire all the way through the water and into the electronics canister where it provides input to the RC receiver. The receiver then decodes the signal and sends out a PWM signal to the brushless DC motor controllers.

Figure 15 - RC Controller

Ethernet/LAN

The Local Area Network (LAN) is used primarily for the relaying of data from the ROV to the two poolside laptops. The system is comprised of a router inside the control box and a switch in the electronics canister. The switch allows for the connection of multiple Ethernet devices. Only one Cat5 Ethernet cable is necessary to run down the tether rather than one for each device. In the LAN, the router functions as a hub for information and is in charge of routing all data packets in the network to their specific destinations.

Monitors

The poolside screens consist of two laptops, with one laptop running a Closed Circuit TV (CCTV) camera software, and the other is running a GUI (Graphical User Interface).

Sensors and GUI


Figure 16 - Moisture Sensor inside Canister

The sensor system is composed of three separate sensors that report to an on-board Arduino Uno microcontroller.

For our sensor array, we utilize a type K thermocouple for analyzing the ventilated fluid in our outer space mission, an analog fluid pressure sensor to generate an accurate measurement of both the depth of the ocean, and the depth of the ice n Europa’s crust, and a moisture sensor to warn us when we have a water breach in our electronics canister. The temperature sensor is attached to an Adafruit thermocouple amp break-out board that interprets the resistance value and gives the temperature to the Arduino.

The Arduino is connected over the LAN to a laptop on the poolside. The sensor laptop runs the Python GUI that was written by our company specifically for interpreting and providing data for the Data Analyst in an easy-to-read format.

Control Box

The tether connections from ROV Cadmus to the box consist of three connections: Main thruster power, camera and claw power, and an Ethernet connection for the camera and sensor data. Our poolside Control Box is built from a plastic firearm case that has been modified to support our application. It houses A/C and D/C power. The A/C section powers the two poolside laptops as well as the router that is housed inside. The box contains red LED indicator lights, as an easy way to tell that the ROV is powered on.

Figure 17 - ROV Cadmus' Control Box

The D/C powers ROV Cadmus' thrusters as well as a poolside voltage and amperage meter. For power in, we have a strain relief leading to a length of wire which will then lead to a 25 amp fuse located 30.5cm from the Anderson power pole connector. The A/C power consists of a factory made extension cord in order to conform to MATE safety regulations.

Canister/Housing

All of the onboard electronics are housed in an aluminum canister which is 12.7cm (5 in) by 15.2 cm (6 in). This is sealed with ultra-high molecular weight UHMWPE end caps and electrically insulated from within using adhesive EVA sheet. The SID is shown in Figure 19.

Tether

The tether assembly is 16m (53ft) long and contains one main tether and two auxiliary power wires for our thrusters. The main tether is neutrally buoyant and covered in a polyurethane jacket with a braided Kevlar strain relief. It is .55" in diameter and consists of 12 conductors that power on-board systems, electrical components, and the Ethernet cable. The entire assembly is protected inside a black nylon sheath.

Figure 18 - ROV Cadmus' Tether Assembly

System Integration Diagram

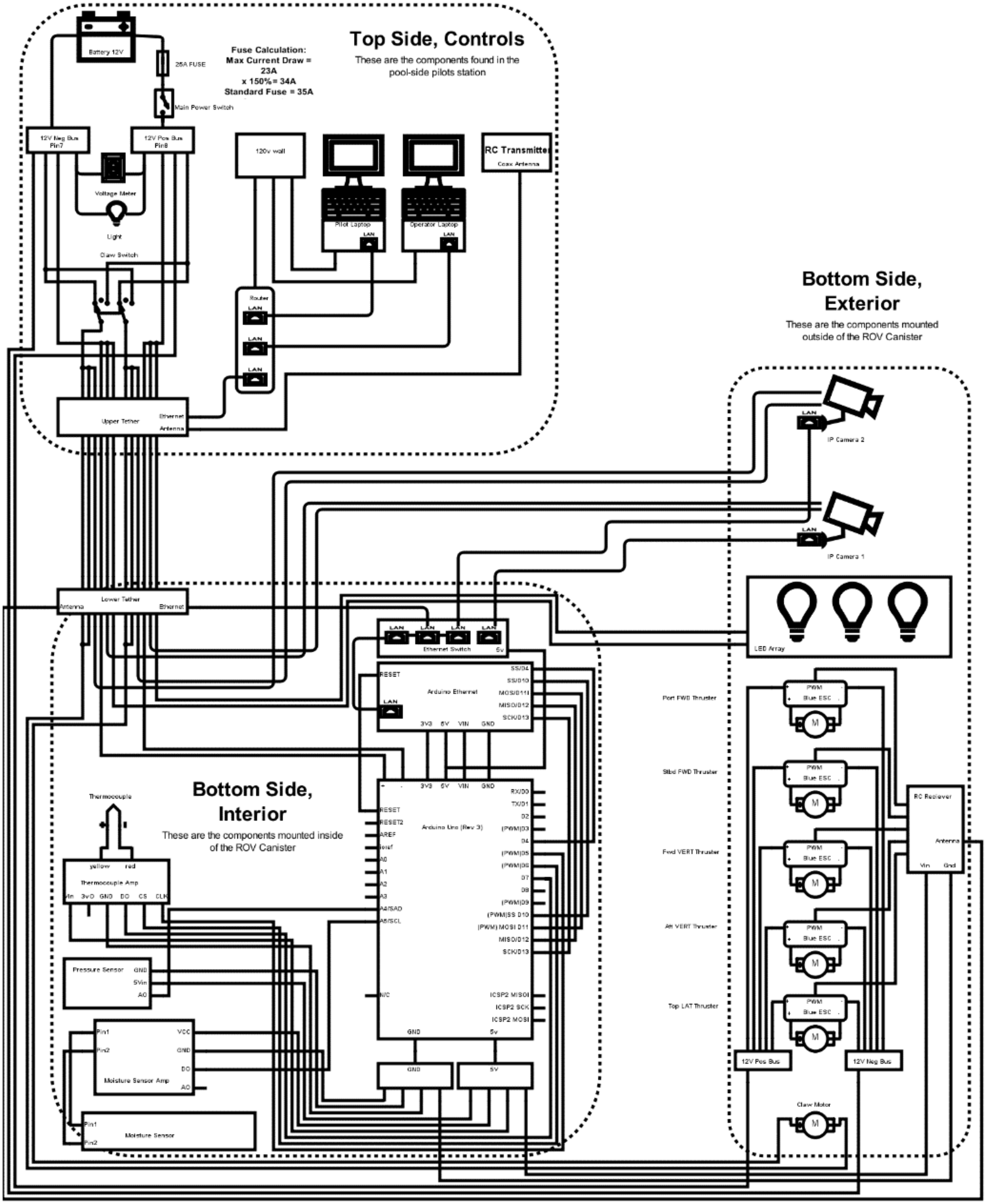


Figure 19 - System Integration Diagram (SID)

SAFETY

ROV Cadmus employs the following safety features to prevent and/or control dangerous situations.

EMERGENCY STOP BUTTON

Our company has positioned an easy-to-use illuminated rocker switch, which serves as our emergency power shut-off, in an accessible location on the top surface of the control station.

SHROUDS

Each thruster has an integrated shroud to prevent injury and any unwanted objects from coming in contact with the blades.

LABELING

There are warning labels attached to all potentially dangerous parts of the ROV to prevent injuries.

Figure 20 - Caution Labels on Claw

IN-LINE FUSE

The in-line fuse is located outside of the control station. The fuse provides a safeguard against all electrical or circuit overloads.

SHARP EDGES

Any sharp edges present on ROV Cadmus are filed down or covered to prevent injury to operators.

PRECAUTIONS

To maintain a safe working environment for the ROV operators, our company has enforced precautions such as the use of a safety checklist (See pg. 23) on the pool deck, the required use of safety glasses during the operation of machinery, and the prohibition of loose hair and clothing.

TROUBLESHOOTING

We established a troubleshooting flow that was utilized through a multitude of our design and engineering processes.

EXAMPLE 1: Electronics Canister

Knowing that we would need an excellent seal on ROV Cadmus in order to prevent water intrusion, we thought up the solution of providing two double O-ring seals on either endcap as well as using Teflon tape to seal off all of the pass-throughs created by cords passing through the uppermost endcap. We left the ROV in the water for twenty minutes before pulling it up once again to check the canister. An inch of water was found at the bottom of the canister. Since our solution was proven inadequate, we created a new solution, which was to use silicone to seal all wires exiting the endcap. This new solution highly effective. We celebrated and moved on to the next challenge.

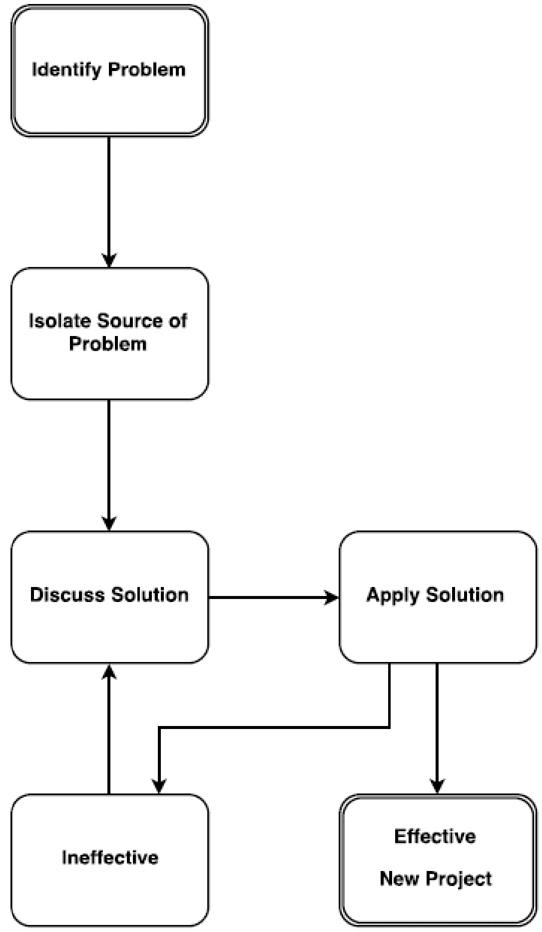


Figure 21 - Troubleshooting Flow

EXAMPLE 2: Sway Thruster Mounts

When we were fabricating a mount to be used for our sway thruster, we realized that we didn't have an optimal place to put our upper sway thruster so it did not interfere with the cables exiting ROV Cadmus' upper endcap. We then identified the source of this problem: the frame itself. The ROV was originally designed with a mount on the top of the frame for the sway thruster, but this was the precise reason it was interfering with the outbound cables. We thought up the solution of simply cutting this mount out of the frame and fastening it to our float, raising the thruster and allowing the wires to pass through with no obstructions. This procedure being successful, we moved on to a new project.

TEAM COOPERATION

PROJECT MANAGEMENT

This year, our company strived to develop a project management system that would both increase morale and efficiency. To do this, our company created a simple task list that enabled us to visually keep track of specific design and fabrication milestones for each component, the exact dates for when these components were to be completed, and also the names of each specialist in charge of completing that task. If the specialist did not complete the task by the set date, the company CEO would write down the status of the project in an additional column, and allow one more week for completion before passing the task onto an available member. Once the task was successfully completed, the CEO re-checked the status column as ‘Complete’. In addition to maintaining and updating a Task List, the CEO also provided periodic emails reminding the company of upcoming tasks due within that particular week. The task list and daily communications proved to be a very efficient and motivating way to ensure a productive mission season.

CHALLENGES

Technical

Our company had quite a few problems regarding the Arduino control of the thrusters. In the beginning of the season, our company wanted to control the ROV and process the sensor data using only the Arduino microprocessor. As a result, countless hours were spent developing such a system. Unfortunately, starting so late in the build time and having to develop a previously untried system in the club, there were bound to be technical problems. In the end, rather than having the Arduino running all electronic systems in the ROV, our company gave it the task of solely running the sensors and IP cameras. The thrusters were converted to an RC control system that we integrated as a backup, and the claw was run through a simple on-off DPDT switch.

The thrusters were a new technology that had really interested our company due to the very high power output for their relatively small size and weight. However, we found that there were some limitations to the integrated ‘BlueESC’. Prior to the Regional Competition, our company lost 2 of 5 thrusters due to firmware issues. During the first dive of the regional competition, the ROV lost yet another thruster due to firmware problems, and had to abort the mission. For a while, our company was troubled over what needed to be done to ensure a working machine for the second competition run since all but two horizontal thrusters were not responding. Thankfully, our company hit upon the idea to use aluminum adhesive tape to form very crude shrouds that directed a portion of the horizontal thrust downward, enabling our company to ascend to the surface, and thus complete missions with no penalty.

Non-Technical

Starting out in the season, our company had problems collaborating with one another and making decisions on time. In the end, our company didn’t get as much training as we would’ve liked, and didn’t perform as well as we could have at the regional competition.

LESSONS LEARNED

Technical

A key concept that we learned in building and testing ROV Cadmus is to thoroughly troubleshoot all potential hazards or anomalies in a system, particularly with a new or experimental system prior to implementation. In our eagerness to utilize a new Arduino control system, we didn’t take into account the time needed to learn a new programming language, troubleshoot the USB controller and Ethernet communication. Next year we will start earlier and build upon this year’s knowledge.

We also made a few errors regarding the design of the ROV. Our company’s original designs depicted a neutrally buoyant machine without the use of additional ballast, but due to miscalculations on the size of the float early in the year, it was necessary to attach extra weight. These problems could have undoubtedly been avoided with further research and planning on our part.

Non-Technical

A lesson that we learned in designing and managing ROV Cadmus, was the necessity of rigid planning and collaboration. This was a problem that most definitely could have been remedied with a more strict enforcement of deadlines for projects, as well as back-up plans for systems that were too far along in the schedule to be continued.

FUTURE IMPROVEMENTS

In the future, our company would improve our time management skills during the fabrication and testing of our product. We would make better use of our time by making more solid decisions early on to decrease the excessive amounts of work at the end of the season. We would also be more thorough with our research and implementation of new systems. These improvements will have enabled the team to have more practice with pool missions and presentation skills before competition.

TEAMWORK

Throughout the entire mission season, our company built, maintained, and applied a very strong sense of teamwork and sportsmanship. To complete the tasks at hand, our company strived to not only divide the work, but to also share the load as the time constraints became more demanding for individual members. At the beginning of the year, the company divided the upcoming tasks by giving each member specific roles which correlated with their individual strengths and interests.


Figure 22 - Returning from Size Measurements

The CEO coordinated with the team on a weekly basis and reminded them of meetings and scheduled tasks, while the CFO was in charge of managing the budget and creating an organized parts list. The company's Marketing Director was also very involved during these processes and oversaw the creation of our marketing presentations, maintaining daily communication with our sponsors and supporters through social media. All three of these members made up our primary communication and marketing team.

Our company also nominated four different specialists to oversee the design and fabrication process. Our company's Design Specialist was charged with the responsibility of managing the design process by modeling potential ROV components, collaborating with other members and overseeing the company's design proposals. The Technical Specialist was the leading supervisor regarding the application and fabrication of the new onboard control systems along with our Safety Officer, who not only kept everyone accountable to our personal safety regulations, but also oversaw and developed the float and poolside controls with the help of our Manufacturing Specialist. Aside from helping with development of the poolside controls, the Manufacturing Specialist assisted throughout the fabrication process of the entire ROV, primarily the frame, thruster attachment, and camera alignment.

REFLECTIONS

"Coming from a previous team who's ROV was running for its second year, I really enjoyed standing alongside my team as we designed and fabricated an ROV from the ground up. Even through all of the troubleshooting problems and long hours, I've come to realize that at the end of it all, the only memories that you hold onto are the ones of triumph and fun you've had along the way, and that's something that has really stood out to me with this team."

~Alora Houghton (CEO)

"Being involved in team Cadmus as my second year in Sea-Tech 4-H and competing in MATE, I have learned briefly about new technology our club has not effectively used before, such as using Arduino. This year, I felt that my fellow teammates and mentors had higher expectations for me than last year, and it has been more challenging to make myself time to complete tasks due to complications with other classes and clubs than last year, but through the complications, I have taught myself to effectively make time to work and complete assigned tasks for my team, which has helped me to become more organized and a better member for my team."

~Satone Haratani (CFO)

"During the fabrication process and even still through to competition, my team went through a multitude of trials that tested each one of our personal skills. Looking back on it, I've learned to appreciate all of the complications we faced because it challenged us to be creative and resourceful while under pressure. It helped us to come together as a team and combine our knowledge to find a solution to the problem. All those challenges that seemed to only cause us stress and anxiety actually built us into a stronger company that works together to overcome certain situations and become the best we can be."

~Kaylie Houghton (Marketing Director)

INSPIRATION

At the beginning of the year, our company collaborated to find a theme inspired by this year's mission regarding the exploration and observation of Jupiter's moon, Europa. Since one of our club's traditions were to elaborate on themes taken from Greek mythology, we settled on the theme of Cadmus to be the marketable symbol of our product and company.

Our symbol interweaves much of the fascinating story from which we've based our theme upon. The defeated serpent circling the planet Jupiter and its fourth largest moon, "Europa", and the Greek symbol for Jupiter displayed in the center.

Figure 23 - Team Logo

According to legend, Princess Europa was abducted by Jupiter (Zeus) while he was disguised as a white bull. Cadmus was one of her three brothers that his father, King Agenor of Tyre, sent to retrieve his daughter. Before long, the two other brothers abandoned the search, leaving Cadmus to ask the Oracle of Delphi for his sister's whereabouts. There, the Oracle advised him to found a new city where "the bull stops to rest". Later that spring, a serpent like dragon (which is where we get our symbol) fought with Cadmus and was slain after a fierce battle. Cadmus planted the dragon's teeth on the battlefield, which spawned the five "Spartoi" warriors, whom helped Cadmus built the city of Thebes. Unfortunately, the Bull

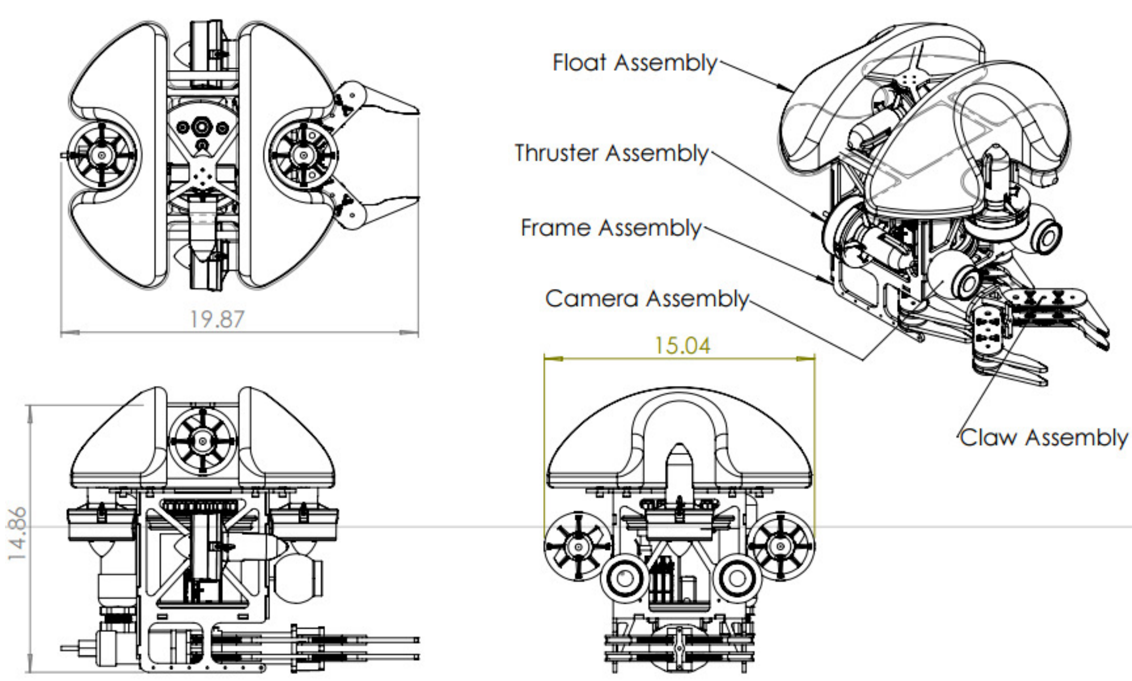
(Zeus) never arrived, and Cadmus never saved Europa; and that is why Europa still orbits around Jupiter to this day.

Team Cadmus plans to return to Europa and rescue her from the clutches of Jupiter by exposing the mysteries hidden deep beneath the surface of her icy shell. Through observation and exploration, Europa will be restored to her former glory

CONCLUSION

At the end of the season, we had an amazing experience, learned many new skills and refined old ones such as critical thinking, team cooperation and collaboration, technical skills, public presentation skills, and many more. Though we did have quite a few problems and bumps on the road, in the end, we all had so much fun, both as friends and as a company. Never would we have had an experience like this anywhere else. The things we learned throughout this season are things we can use in both our careers and throughout our entire lives.

ROV CADMUS TOP LEVEL DRAWING



SAFETY CHECKLIST

The following is an example of a Safety Checklist for ROV Cadmus. We use many such checklists to ensure proper preparation and operation of the vehicle.

SAFETY CHECKLIST - ROV LAUNCH	
PERSONAL	
	SAFETY GLASSES
	CLOSED-SOLE SHOES
	NO LOOSE CLOTHING
	NO LOOSE HAIR
MISSION SET UP	
	ROV IS RESTING SAFELY AT POOL DECK
	TETHER IS NEATLY UNRAVELED
	CONTROL AREA IS DRY, CLEAR OF DEBRIS
	CONTROL BOX, LAPTOPS PROPERLY DEPLOYED
	VERIFY ALL CORDS PROPERLY INSTALLED
	VERIFY 12V POLARITY
	VERIFY POWER AT ROV CANISTER
	VERIFY LAPTOPS ARE FUNCTIONAL
	PERSONNEL AT THEIR STATIONS
	CALL ALL-CLEAR
	TURN ON POWER
	BENCH TEST THRUSTERS
	BENCH TEST CAMERAS
	BENCH TEST SENSORS
	LAUNCH ROV

EXPENSE OVERVIEW

Cadmus Budget Sheet

Item	Purchase Date	Description	Part Number	Notes	Quantity	Unit Cost	Purchased
CLAW							
1	N/A	IG32 planetary Gear Motor	TD-070-053	Repurposed	1	$23.80	$23.80
2	N/A	QTC worm Module	KSUW1-R1	Repurposed	1	$45.71	$45.71
3	N/A	QTC Worm Gear	KPG1-40R1	Repurposed	2	$26.53	$53.06
4	N/A	1.75" O.D. x 1/8" wall x 4" long aluminum tubing	6061-T6	Repurposed	1	$6.04	$6.04
5	N/A	2.25" O.D. x 1/4" wall x 3" long aluminum tubing	6061-T6	Repurposed	1	$8.52	$8.52
6	N/A	3" x 2" x 1/8" wall x 13" long aluminum tubing	6063-T52	Repurposed	1	$14.17	$14.17
7	N/A	Bronze Sleeve Bearing: 2" O.D. x 1.75" I.D. x 1" Long	6391K439	Repurposed	1	$5.75	$5.75
8	N/A	Silicone O-Ring: 1/4" I.D. x 3/32" cross section	9396K138	Repurposed	1	$0.15	$0.15
9	N/A	Silicone O-Ring: 1-3/4" O.D. x 1/8" cross section	9396K82	Repurposed	1	$0.46	$0.46
10	N/A	Sealing Pan Head Phillips Machine Screw: M3 x 0.5 pitch x 6mm long	93627A412	Repurposed	4	$0.69	$2.76
11	N/A	Strain Relief Cord Connector: 3/8" NPT; Black Nylon	2638	Repurposed	1	$0.96	$0.96
12	N/A	Low Profile Series Micro Connectors: 3cond male plug	MCLPIL3M	Repurposed	1	$24.61	$24.61
13	N/A	2" O.D. Delrin bar x 12"	8576K282	Repurposed	1	$13.75	$13.75
14	N/A	Water Jetted Aluminum Parts (6061-T6)	N/A	Repurposed	1	$200.00	$200.00
15	N/A	#8-32UNF x 1/2" long SS socket set screw	126-306-1	Repurposed	2	$0.09	$0.18
16	N/A	1/8 NPT, 15/16" Overall (schrader valve)	8063K33	Repurposed	1	$5.23	$5.23
CAMERA							
17	N/A	IP Cameras			2	$28.00	$56.00
18	N/A	12V LED Lights			4	$2.50	$10.00
FRAME							
19	N/A	Frame	N/A	Donated	1	$800.00	$800.00
THRUSTER							
20	3/15/2016	T100 Thruster w/Blue ESC Speed Controller	T100-THRUSTER-R1/BLUESC-R1	Donated	5	$179.10	$895.50
FRAME							
21	N/A	1 1/2" 10 pfc polyurathane foam	N/A	Donated	1	$50.00	$50.00
TETHER							
22	N/A	C-3400, Neutrally Buoyant cable (53 ft)	N/A	Repurposed	1	$1,100.00	$1,100.00
23	N/A	Nylon Black Cable Sheath (100 ft)	N/A		1	$16.16	$16.16
SYSTEMS							
24	3/29/2016	Proto-Screwshield (Wingshield) R3 Kit for Arduino	ID: 196		1	$14.95	$14.95
25	3/29/2016	3-pin SM Plug + Receptacle Cable Set	ID: 1663		10	$1.35	$13.50
26	3/29/2016	4-pin JST SM Plug + Receptable Cable Set	ID: 578		10	$1.35	$13.50
27	3/29/2016	Thermocouple Type K Glass Braid Insulated	ID: 270		2	$9.95	$19.90
28	3/29/2016	2-pin JST SM Plug + Receptable Cable Set	ID: 2880		10	$0.68	$6.80
29	3/29/2016	Thermocouple Amplifier MAX31855 Breakout Boarrd	ID: 269		1	$14.95	$14.95
30	3/26/2016	URBEST® 400V 10A 8 Positions Pre-Installed Terminal Barrier	TB2508		1	$7.59	$7.59
31	N/A	Spektrum DX6i		Repurposed	1	$129.99	$129.99
SENSORS							
32	3/29/2016	Thermocouple Type K Glass Braid Insulated	ID: 270		2	$9.95	$19.90
33	3/29/2016	Thermocouple Amplifier MAX31855 breakout board	ID: 269		1	$14.95	$14.95
34	N/A	Module Soil Moisture Sensor	3-01-0313-A		1	$4.89	$4.89
MISC.							
35	N/A	Misc Hardware - bolts, nuts, washers, etc.	N/A		1	$100.00	$100.00
TRAVEL							
	5/26/2016	Airfare	N/A	Travel	7	$450.00	$3,150.00
	5/26/2016	Hotel room, 5 days	N/A	Travel	3	$625.00	$1,875.00
	5/26/2016	Automobile	N/A	Travel	1	$600.00	$600.00
						Total:	**$9,318.73**
						Repurposed:	**$1,635.14**
						Donated:	**$1,745.50**
						Travel:	**$5,625.00**

ACKNOWLEDGEMENTS

We would like to thank…

- MATE for giving students like us the opportunity to experience engineering fields in such an incredible way
- Janicki Industries for their financial aid and water jetting services
- Alex Hanson for the time spent teaching us new programming systems
- Our club leader, Lee McNeil, for opening up his home to our teams during the construction of our ROV and the many hours of support
- Our Mentors, Marty Houghton and Jay Cocheba, for going above and beyond to provide our team with constant support and an unforgettable experience
- Our friends and families for their patience and understanding during the craziness of the mission season

WWW.FACEBOOK.COM/TEAM-CADMUS

CREDITS		Figure 11	Satone Haratani
Figure 1	Priya Kumar	Figure 12	Satone Haratani
Figure 2	Kaylie Houghton	Figure 13	http://docs.bluerobotics.com/thrusters/
Figure 3	Satone Haratani	Figure 14	Satone Haratani
Figure 4	Satone Haratani	Figure 15	Satone Haratani
Figure 5	Satone Haratani	Figure 16	Satone Haratani
Figure 6	Priya Kumar	Figure 17	Satone Haratani
Figure 7	Priya Kumar	Figure 18	Satone Haratani
Figure 8	Satone Haratani	Figure 19	Varick Andrews
Figure 9	Cooper Ristow	Figure 20	Satone Haratani
Figure 10	Satone Haratani	Figure 21	Isaiah Houghton
Figure 11	Satone Haratani	Figure 22	Shylan Houghton
Figure 12	Satone Haratani	Figure 23	Kaylie Houghton