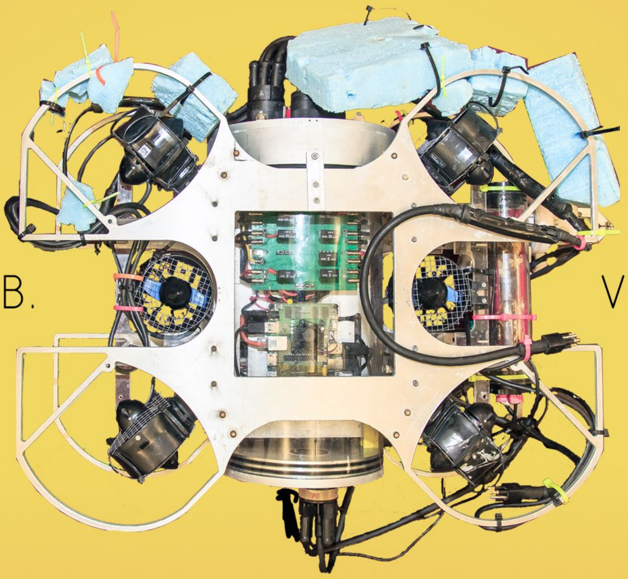
NASA Space Grant Robotics

A.S.U.B.



Ver. III

Technical Report

MATE ROV Competition 2018

Jet City: Aircrafts, Earthquakes, and Energy

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Kira Tijerino - Chief Technical Officer
Alex Bertram - Chief Finanical Officer, MATE Team Lead, Electrical and Programming Lead
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ABSTRACT

The Marine Advanced Technology Education (MATE) Center and the Applied Physics Laboratory at the University of Washington released a request for proposals (RFP) for a remotely operated vehicle (ROV) with a crew to operate in salt and fresh-water regions in the Pacific Northwest. The ROV must accomplish three main tasks: locate and retrieve an engine of a wrecked aircraft, installing or recovering a seismometer, and installing instrumentation to monitor the environment. The NASA Space Grant Robotics (NASGR) team at Arizona State University responded to the RFP by creating the Arizona State University Bot (ASUB) to satisfy the specifications mentioned in the request.

NASGR is organized into main groups and subgroups. The main groups are the Mechanical team, the Electrical team, and the Programming team; the subgroups are focused on the specific components or tasks that the ROV must complete and may include members from any of the three main teams. All teams met at least twice a week during the school year for 4 hours a week, and spent additional time outside of organized meeting times to complete manufacturing and assembly.

The hard work, dedication, and determination of NASGR over the past year has resulted in a functioning ROV that has withstood the rigorous tests the team has put it through. NASGR is confident that ASUB V-III is the perfect ROV to fulfill University of Washington's Applied Physics Laboratory's request for proposals.

Figure 1: NASGR Team Photo

Back Row, from Left: Sean Walker, Josh Miklos, Mac Bonfield, Chricitan Adane, Colton Kohnen, Cordell Michaud, Jonathan Patrick, Will Davidian, David Tome

3rd Row, from Left: Mateo Gonzalez, Paul Vohs, Matt Auer, Alex Bertram, Jacob Friedman, Jeremy Nie, Kira Tijerino, Pratik Panda

2nd Row, from Left: Rob Wagner, John Sampanes, Shubham Nipanikar, Daymon Wilkins, Austin Chau, Hanyu She, Westin Dewey, Austin Reyes

Front Row, from Left: Audrey Mendez, Annie Martin, Madison Sears, Alexandria Ardente

Not Pictured: Josh Bolinger, Garrett Doling-Bregar, Chandler Pierce, Brandon Wu, Brendan Mance, Leah Clardy, Eveline Shi, Ryan Dobrin, Hasin Shahriyar

DESIGN RATIONALE

NASGR decided to use ASUB V-II as the base for the robot, making improvements and changes to fit the proposal, leading to the final robot being the ASUB V-III. The primary constraints for ASUB were the size and weight restrictions of the Explorer Class ROV set by MATE. To optimize weight without compromising strength and costs, Aluminum 6061-T6, polycarbonate, and 3D-printed materials such as polylactic acid (PLA) and Polyethylene terephthalate glycol (PET-G) were used whenever possible.

Some of the features of ASUB V-III includes a system of six thrusters: two for vertical movements and four for translational motion. ASUB has two claws: one for grabbing and rotating objects and the other for leveling the Ocean Bottom Seismometer (OBS). A polycarbonate enclosure houses the electrical components with custom designed endcaps. A camera enclosure is angled towards the base frame of the ROV to allow the actions of the claw to be visible with a binocular view from two cameras. An additional camera within the main enclosure allows a downward facing view. For low light situations, ASUB contains a front facing light to allow for visibility in dark environments.

MECHANICAL DESIGN

FRAME

The current frame for the ROV was designed around existing components and used the frame of ASUB V-II as a base reference. Some of the challenges with this were existing hole placements that needed to be accounted for the new frame to attach to the components. One of the goals of the new design was to be lighter than the previous design. The current frame was based on an X-shape to protect the thrusters on the four corners of the ROV. The base frame incorporated mounting places for specific components such as the claw and light. The corners on the edge of the frame were added as places for wires to be attached and held away from the thrusters. They were also to be used as placement for buoyancy blocks. Polycarbonate supports connect the two frame pieces. The current frame is lighter than the previous design by twenty percent.

Project Engineers: Kira Tijerino, Mac Bonfield

Figure 2: Full Frame Assembly

ENCLOSURE

One of the critical components of ASUB V-III is the electronics enclosure. The purpose of this assembly is to keep all the electronics secure and dry on the robot. The assembly is made up of five main components: the polycarbonate tube, an electronics plate, a machined plug, a machined flange, and a flange cap. The main goal of the enclosure redesign was to leave enough room for proper cable management for all electrical components, resulting in a cleaner look and an easier time assembling and troubleshooting parts. A rail system was used to better hold the electronics plate in place and allow for easier access to the electrical components. A mix of CNC and in-house manual manufacturing were used to complete the enclosure.

Figure 4: CAD of Enclosure

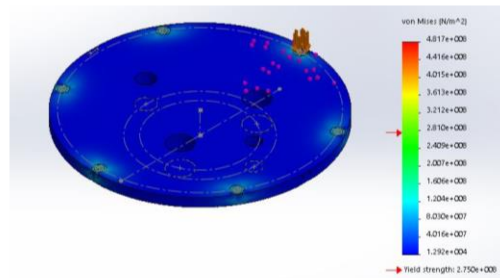

Figure 3: FEA showing the deflection of the flange cap during attachment of the bolts

Initially, the plan was to use latches to make sealing the enclosure easier, but the selected latches did not provide enough compression force to properly seal the flange. Instead, a series of bolts help compress the O-rings to ensure a watertight seal. The number of bolts required to sufficiently compress the O-rings without causing deflections was determined using Finite Element Analysis (FEA), as shown in figure 3. Redundancy measures in waterproofing were also used in the form of applying silicone sealant around where the polycarbonate tube met the flange in addition to O-rings.

Project Lead Engineer: Matt Auer

Project Engineers: Chricitan Adane, Brendan Mance

CLAW

ASUB V-III contains two claws: a primary claw for grabbing and rotating, and a secondary downward facing claw for rotation. The claw for ASUB V-II was used as the basis for the current primary claw. The previous year's claw had three major issues: the worm axle had inadequate support, the worm axle had bounding issues with the gearbox, and the claw used small square axles which rounded out and caused a large amount of play.

This year, the claw went through three revisions, fixing issues as they arose, until

Figure 5: ASUB V-II Claw

the final product was created. The final product has two degrees of freedom: the claws can open and close its manipulators, and the manipulators can rotate.

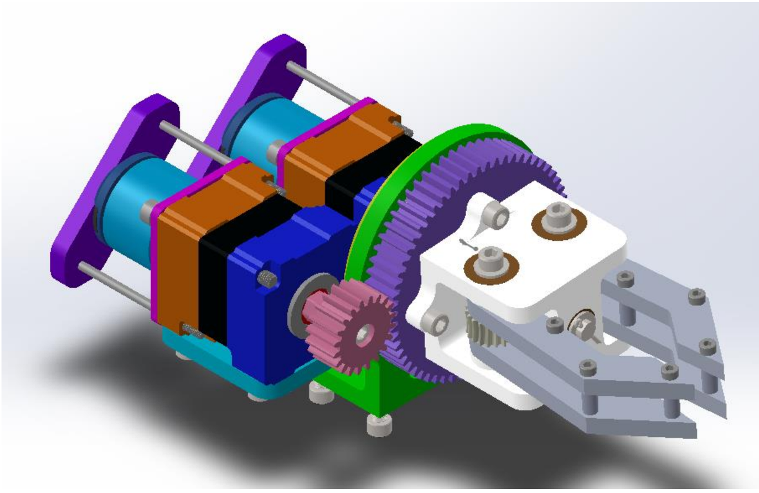

Figure 6: Final CAD for V-III Primary Claw

A critical design element of the new claw was the ability for rapid repairs should maintaince be required. This was achieved my designing each individual components in such a way that they could be easily accessed during assembly or disassembly. This way, the the majority of the claw could remain intact while a small portion was being repaired. Threaded inserts also aided in achieving this design goal.

Project Lead Engineer: Daymon Wilkins

Project Engineers: Jonathan Patrick, Audrey Mendez

The secondary claw faces downward and is designed to level the Ocean Bottom Seismometer (OBS). Because the primary claw only has two degrees-of-freedom, this necessitated the secondary manipulator to turn handles positioned below the ROV in either a clockwise or counterclockwise direction.

The claw is driven by a 12V micromotor with a max rotational speed of 100RPM and 1kg/cm of torque. The motor provides rotation of the claw through a gearbox that reduces the speed and increases the torque of the motor 2.5:1. This gives a rotational speed of 40RPM and a total of 2.5kg/cm of torque. A 3D-printed O-ring was also used to waterproof the housing, which is unique to this feature.

Project Engineer: Jonathan Patrick

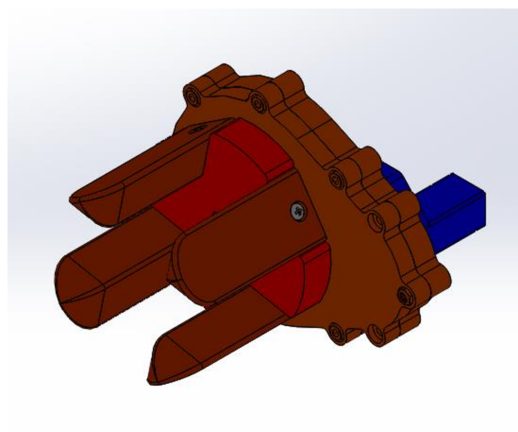

Figure 7: CAD of Secondary Claw

CAMERAS

ASUB V-III uses a 3-camera system of 3 PlayStation USB cameras. Two cameras are housed in a two-inch diameter enclosure at the front of the ROV to provide a binocular view and are slightly angled down to be able to moderate the actions of the claws. The enclosure is nine inches long and capped by two Blue Robotics endcaps. One endcap has two holes in which cable penetrators allow easy removal and waterproofing of the wires that connect to the main enclosure. In the bottom of the main enclosure, the third camera provides a downward view. This allows us to monitor whatever is below the robot. Previous designs of the camera enclosures had custom endcaps with mounts to the frame. Due to design changes with new bought endcaps, a new mounting system had to be designed. Below is a design matrix for the new mounting system of cable ties.

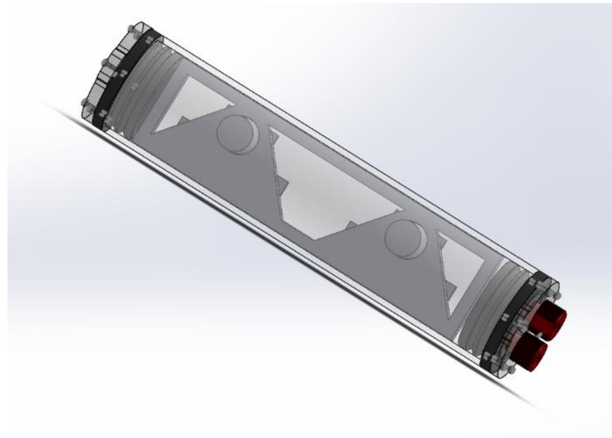

Figure 8: Isometric CAD view of camera enclosure

Project Lead Engineer: Kira Tijerino

Project Engineers: Jacob Friedman, Mac Bonfield

Failure	Probability of Failure	Detection Rating	Severity of Effect	Action for Prevention/ Mitigation of Effects
Zip ties break	3	4	8	Use sturdy zip ties, do not tighten them too much
Zip ties slide off the frame	10	1	4	Do not tighten the zip ties too little, and make sure the frame stays level
Zip ties are too tight	3	9	9	Do not tighten the zip ties too much
Zip ties cover the camera lens	10	2	5	The zip ties will wrap around the camera width wise in the center of the camera so that it doesn't pass over the lens, which will be on side of camera
Zip ties rotate	5	6	4	Do not tighten the zip ties too little, and make sure the frame cannot rotate

Table 1: DFMEA for Mounting System

LIFT BAG

The Lift bag system is considered a non-ROV device with its own power system. It's a deployable rescuing unit for the ROV to operate with three main functions: attaching to the object that needs to be retrieved or rescued, lifting the object to the shore, and remotely detaching the lift bag from the object.

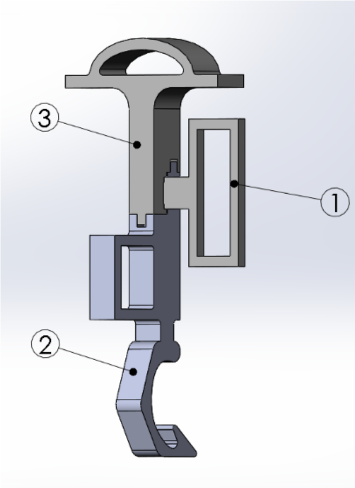

Figure 9: CAD of mechanical lift-bag system

The main goals during designing the lift-bag mechanism was to make it easy to operate, have a simple design concept and be lightweight. The major components of the design are a power system enclosure, releasing mechanism, transmission system, attaching mechanism, and an overall structure. The original design utilized a Wi-Fi signal release, however due to its complex design and lack of manufacturing capability, the backup design with the manual release was used instead for smooth operation.

The mechanical backup system for the lift-bag uses a mortise and tenon structure that has a key that is manually pulled out from the middle, which will allow the other two parts to separate via gravity. A hook for attaching the object that must be rescued, and a handle for the claw to grab and move the contraption.

All three components of the lift-bag system are 3D printed with PLA, with a coat of Teflon added to the key and keyway to reduce friction.

Project Lead Engineer: Jeremy Nie

Project Engineers: David Tome, Westin Dewey, Hanyu She, Garrett Doling-Bregar, Chandler Pierce

POWER CONNECTOR

To power the Ocean Bottom Seismometer (OBS), a wireless power connector had to be designed so 5V and 1A of power could be delivered. The connector is considered a non-ROV device that will be carried by the main claw during the mission. The connector consists of a 9V battery, a stripped wireless charging module, a switch, and a 2-piece enclosure (the enclosure itself and an endcap) printed from ABS plastic so it can be naturally water resistant. The enclosure also contains a handle so it can be easily gripped by the claw. Both pieces of the enclosure are held together with marine epoxy.

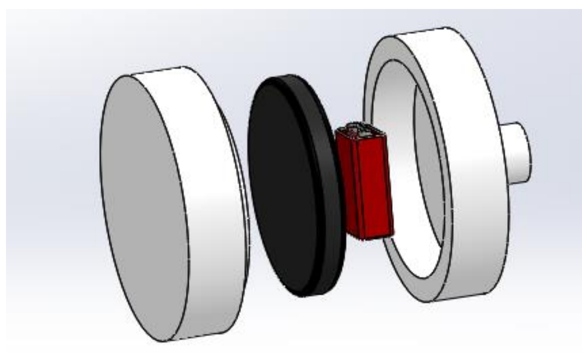

Figure 10: (From left to right) Enclosure Endcap, Wireless Charger, 9V Battery, Enclosure

Project Lead Engineer: Josh Bolinger

Project Engineers: Leah Clardy, Eveline Shi

ELECTRICAL DESIGN

OVERVIEW

ASUB's electronics are designed for reliability for the duration of the competition season. The system is run by a laptop and a 48V 30A power supply on to surface. Robot data is transferred over a Category 5e cable through the tether along with our 48V line using 10AWG stranded wire. The supply is limited by an inline 30A fuse based off our fuse calculations. The 48V is then converted using 4 320W 48V to 12V DCM converters from Vicor. This provides power to the simple power distribution board.

The Udoo x86 handles the ethernet connection provided by the surface laptop and distributes those signals to the Electronic Speed Controllers (ESC) to control our 6 Blue Robotics T100 motors as well as our Sabertooth H-bridge Controller and Blue Robotics Subsea Light.

POWER DISTRIBUTION

Power distribution is handled by four Vicor DCM converters (Figure 14). The DCM converters were used due to their small footprint, screw terminals, and integrated heatsink. Previously we have used Vicor converters on our ROVs, but they never came with screw terminals, resulting in breaking of the power converters and a bigger footprint resulting from the need to solder thick gauges to the converters.

Figure 11: Vicor DCM

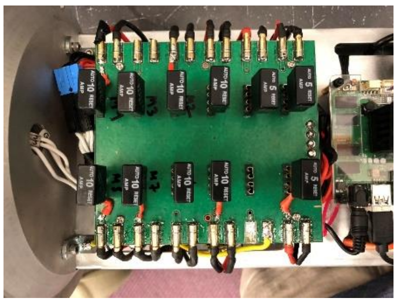

Figure 12: Power Board

The Vicor DCM converters are wired in parallel to maximize power while maintaining a constant voltage level. These converters are then routed to a small power distribution board (Figure 15) to handle the fusing required to safely operate the ROV. The distribution board is stacked on top of the Vicor DCM converters to reduce the footprint even more in comparison to previous years.

Project Lead Engineer: Ryan Dobrin

Project Engineers: Alex Bertram, Hasin Shahriyar

MOTORS

Figure 13: TIOO Motors

ASUB utilizes six T100 thrusters (Figure 16) for full movement in all transitional axes. Four thrusters are positioned at the corners of ASUB at 45-degree angles to provide superior rotation and translational control. Only two thrusters are used for height control. The thrusters are controlled using Blue Robotics Basic ESCs. The main requirements of the ESCs were to source up to 10 A while maintaining a small footprint due to limited space in the ROV enclosure.

Two M100 Motors (Figure 17) are used to control the rotation and the grabbing piece of the claw. This can be done due to the planetary stages used in the claw to reduce the turning speed of the motors and increase the torque.

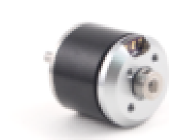

Figure 14: M100 Motor

UDOO X86

The Udoo x86 Board (Figure 18) is the backbone of our system, handling all sensor and motor control operations. What makes this board special is that it has an integrated Arduino 101, making it a fair bit easier for integration and footprint minimization.

The Udoo board runs a full x86 system, allowing ASUB to run a Linux machine and use a stable version of Robot Operating System (ROS) while still being able to provide Digital In/Out for the system.

Figure 15: Udoo x86

PROGRAMMING DESIGN

ROBOT OPERATING SYSTEM (ROS) FRAMEWORK

Robot Operating System (ROS) is an object-oriented framework for cross-platform, cross-language communication between encapsulated processes called nodes using a publisher/subscriber model in which nodes publish or subscribe to topics consisting of standardized messages. These features make ROS an ideal framework for organizing our robot code, as it allows for rapid prototyping and swapping of independent robot subsystems, and efficient development of high-level robot behavior by abstracting away low-level implementations of sensors and actuators. ROS is also well integrated with the computer vision library OpenCV, which facilitates the process of capturing and processing visual data efficiently, and therefore provides another benefit to our team.

INERTIAL MEASUREMENT UNIT (IMU)

The system uses an inertial measurement unit (IMU) to determine the robot's orientation, depth, and translational and angular velocities at each timestep. These data are estimated using a Kalman Filter on the readings from the IMU's gyroscope, accelerometer and magnetometer. These data are then published to an IMU data ROS topic, which a control node subscribes to and processes to maintain the robot's desired state using PID control.

Project Engineers: Paul Vohs, Cordell Michaud

CONTROL SYSTEM

The robot is controlled using an Xbox 360 controller. The vector created by the left joystick provides the robot's desired translational velocity in the robot's local XY-plane while the X-axis of the right joystick provides the robot's desired angular velocity. The controller's triggers provide the robot's translational velocity along the Z-axis. The velocity of each of the robot's drive motors is calculated by taking the dot product of the direction vector of each motor and the robot's overall translational velocity vector, adjusting each velocity according to the desired angular velocity, and then scaling the velocities to their proper range while maintaining the proportions between the velocities of each motor. The drive motors are arranged such that each motor occupies a corner of the robot, with its X-component facing toward the origin and its Y-component facing away from the origin. Additionally, a motor each in the front and back of the robot facing upward allows for motion along the Z-axis as well as pitching about the X-axis. The control system is therefore holonomic, and allows the robot to strafe and rotate in any direction in the robot's local XY-plane, and thus to perform dexterous tasks efficiently.

Project Engineers: Cordell Michaud, Colton Kohnen, Alex Bertram

GRAPHICAL USER INTERFACE (GUI)

The user-friendly Graphical User Interface (GUI) was created in Python to display the video feeds from the robot's two front and one bottom PlayStation Eye Cameras. Additionally, the GUI displays data transmitted from the IMU such as accelerometer, gyroscope, and magnetometer values. This was done by using ROS and allowing the GUI to subscribe to different ROS nodes that are passing all the data along. This GUI placed greater emphasis on streamlining the video output feeds given the limited bandwidth that we have. This was done through creating multiple threads for each camera feed and implementing the idea of multithreading to reduce the chance of a bottleneck, while also enabling the real-time display of robot state data from subscribed ROS topics and task-related information.

Figure 16: GUI View

Project Engineer: Pratik Panda

IMAGE RECOGNITION SOFTWARE

An image recognition software was created to identify the color and shape of a tailfin. The image recognition system stores "key points" from a set of images: points on the image that are very visible, like corners. Then it looks up those stored points and compares them to the camera's view. The more it matches, the higher the probability variable is. These probability variables can be compared with other recognizers to find the best matched image.

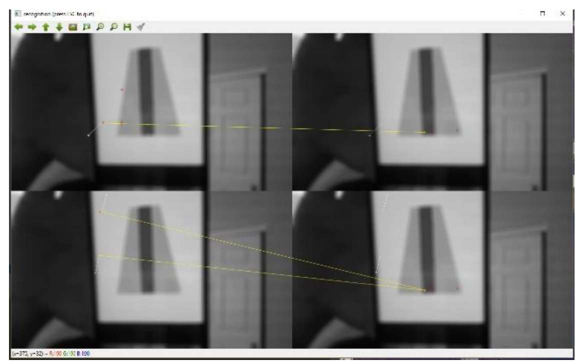

Figure 17: Image Recognition Software Interface

Project Lead Engineer: Josh Miklos

Project Engineers: John Sampanes, Paul Vohs

SAFETY

PHILOSOPHY

NASA Space Grant Robotics values the safety of all its members. We constantly strive to update and improve our safety standards as new techniques and technology become available. Maintaining safety standards wherever we operate allows us to protect our employees and reduce the occurrence of accidents and injuries. We are also conscious that we hold safety as a constant value instead of a malleable priority; we don't compromise our commitment to safety when our objectives change.

SAFETY STANDARDS

NASA Space Grant Robotics observes many practices and standards intended to improve safety. The first of these is the availability of safety equipment; we are well stocked with gloves, safety glasses, and other common personal protective devices. We also use application specific equipment, such as specialized air filters during soldering to improve the safety of our employees. We also observe many electrical and physical safety practices; for example, we use a common ground for all electrical wiring, and we work as a team to lift the ROV into and out of the water. Finally, we test the seals for any waterproof enclosures that we build before performing any function tests with them.

SAFETY FEATURES

ASUB contains many safety features; the thrusters have protective covers to prevent individuals from getting their fingers too close to the propellers while they are functioning. Machined components are checked for sharp edges, which are filed down if they are found. The frame contains several large loops that act as handles and reduce the degree of contortion that an individual must go through to pick up the ROV. The main electronics enclosure uses double O-ring seals for all its main sealing points, which reduces the risk of water leaks. Removable electronic components were connected to the main enclosure using Seaconn AWQ 4/24 waterproof electrical connectors. Finally, the entire ROV was tested for water tightness for a longer period than it is expected to be in the water during normal operations.

TESTING AND TROUBLESHOOTING

Figure 18: ASUB V-III being tested in a pool

During the validation and testing phases of the design process, ASUB underwent several subsystem and full system tests. As mentioned earlier, full system tests could not occur before individual systems were tested for machined accuracy, ease of use and assembly, and functionality. During this stage any machining inaccuracies were addressed so parts could be modified or remade if necessary. Individual programming and electronics tests also ensured components were functioning as inspected so integration could be completed. If any problems occurred, continuity tests, connection tests, and communication tests were performed to determine of the problem was on the hardware or software side of the component. Then the full robot could be tested.

The only test that could be performed without inserting the robot in the water was a simple tug test due to time constraints and assembly delays, where one team member lightly tugged one of the enclosure's endcaps to ensure a tight fit. The main electronics enclosure actually came apart during this test and the team had to resort to a more permanent watertight seal on the static endcap. Once this sealing method was complete, the entire robot was placed in the water and observed for half an hour without any power being supplied to it. If none of the issues described in the Safety Checklist were observed, the test was considered a success and testing for functionality could begin.

Functionality testing included ensuring the cameras were operational and capable of being used by the pilot for completing the required tasks, ensuring the thrusters were outputting the correct power and responding to the appropriate inputs, and that the claw could properly manipulate objects in each timespan. When issues occurred with any component, the robot was pulled from the water and the component in questions was inspected for obstruction and communication. The results of repeated testing operations resulted in the formation of the Safety Checklist, which is included in the Appendix.

LOGISTICS

COMPANY ORGANIZATION

The NASA Space Grant Robotics MATE Team is comprised of six interdisciplinary project teams, or subteams, with at least one officer or team lead managing each team. This year the project teams were claw, electronics enclosure, cameras, Wi-Fi power connector, lift bag system, and robot control. The six teams are then overseen by the lead mechanical engineer and the lead electrical and programming engineer. The lead engineers ensure that the team members underneath those disciplines receive adequate training on the relevant tools, design processes, and software required to successfully complete tasks while also acting as subject matter experts and enforcing communication between disciplines. The team leads report to the MATE team lead, who ensures that all teams are meeting the requirements put forth by the MATE Center in a timely manner, who then communicates to the CEO. The company's organization is illustrated below.

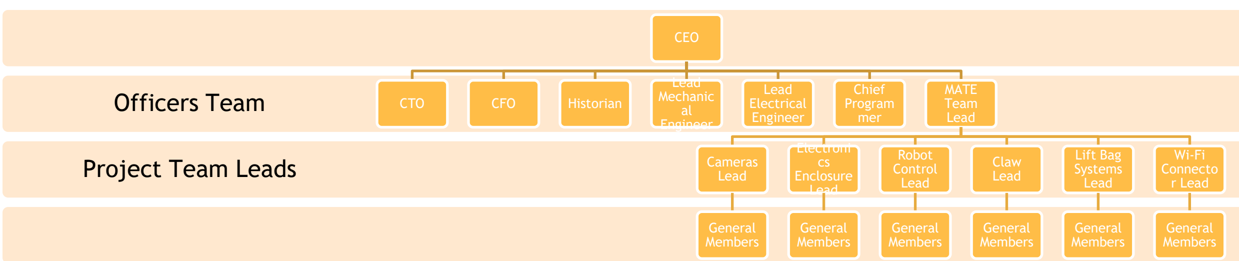

Figure 19: NASGR Organization Tree

Project Management

The NASA Space Grant Robotics MATE Team underwent six main phases: training, preliminary design, proof of concept (POC) design, final design, manufacturing, and testing. During the training period, new members completed relevant tutorials and projects related to programs they would be using and tasks they would be completing as a member of NASGR. While the new members completed their new member projects, the veteran members and officers guided new members and began identifying problem areas on the previous version of ASUB. Once new members completed their projects, they could join one of the six MATE project teams identified in the Company Organization section.

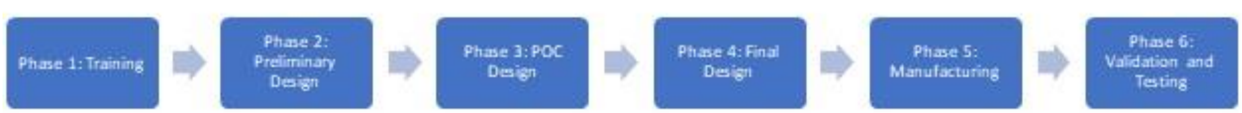

Figure 20: NASGR Phase Flow Chart

During the next three design phases, members of the project teams were asked to present their design iterations to various members of the company and address any questions and suggestions audience members had. Rough sketches were expected during the preliminary design phase, while proof-of-concept models of those sketches were required during the POC phase. The final designs were then due around the time the full MATE mission manual was released and consisted of presenting a bill of materials (BOM) that indicated manufactured versus off-the-shelf parts, a full CAD assembly, and relevant CAD drawings of major components showing any major dimensions for mechanical and electrical systems, wiring diagrams for electrical systems, and flow charts, diagrams, and simulations for programming systems. These presentations were then critiqued by the entire team and any changes had to be made a week later.

Manufacturing was started in the spring semester. During this phase some teams were still making changes to their final designs after realizing that some concepts would be difficult to manufacture in certain ways or that they miscalculated some forces or dimensions. PCB manufacturing and programming of the GUI, image recognition systems, and communications systems also took place during this phase. Once manufacturing was complete, the testing phase could begin.

To ensure the qualification video could be completed on time, certain deadlines for final designs and manufacturing were set. The company used Slack for most of its communication due to its organizational capabilities and its integration features, such as Google Calendar. Major deadlines were added to the company's calendar for teams to keep track of. Weekly stand-up meetings were held to keep track of individual member accomplishments and allow members to be aware of what was happening in other teams. All electrical and mechanical files were kept in the company Dropbox, which has version control capabilities, and all software files were kept in the company Github.

PROJECT COST AND BUDGETING

NASA Space Grant Robotics created a budget based off the amount of funding typically received from the Ira A. Fulton Schools of Engineering, which is $2000 per semester. Each team compiled a list of stock materials, tooling, fasteners, sensors, and other equipment required for their subsystem to be functional. The CFO reviewed these lists to see how they lined up with the referenced budget and made recommendations to teams. The company also applied for and received a $20000 grant from the KEEN Foundation, most of which went to cover travel to the MATE Competition for 10 employees. Funds and equipment donations were also solicited to reduce costs. The NASGR 2018 Budget is provided in the appendix. The budget only reflects purchases related to the MATE Team and does not include purchases for the Outreach and AUVSI teams.

CONCLUSIONS

CHALLENGES

As expected, with every success NASGR experienced, there were multiple challenges to accompany them, both technical and non-technical. The largest technical challenge this year was system integration. The programming side of the cameras team, for instance, had to collaborate with the mechanical side to ensure the enclosure could be properly placed on the robot for optimal control during testing. This did not happen during initial water testing and the pilot had difficulty controlling the claw because of it. The programmer in charge of designing the GUI also did not know what features the programmers in charge of robot control and image recognition wanted until later, so many features were not included in the GUI that should have been. System integration issues also occurred in the main electronics enclosure as every single component on the robot had to be connected to a power or data line on the main power distribution board and to the main computer. Once the electronics enclosure was assembled, testing had to be performed to ensure proper communication with the software environment via the tether. This is where ethernet issues were experienced initially, resulting in an entire day being dedicated to troubleshooting this issue, only for the solution to be a quick shortening of the cable attached to the Seacons.

The largest non-technical challenge was managing the largest team in NASGR history and ensuring everyone was effectively communicating. For every member of the company to contribute to ASUB's development, the project teams had to be appropriately sized and have a good mix of experienced and inexperienced team members. This was not an issue at the beginning of the year, but as time went on membership began to dwindle and this often led to one or two experienced members taking on more responsibilities than necessary, which led to delays in finalizing designs and noticing manufacturing issues. Channels within Slack were used for teams to communicate with each other, but not all members checked Slack often enough and were left out of the loop, or members were not using Slack consistently enough. For next season, these communication methods will still be used, but more emphasis will be placed on making sure individuals know what they should be doing and when they should complete their tasks by. More training will also be given to team leads to show them how to effectively communicate and delegate tasks to their teammates.

LESSONS LEARNED

Members of NASA Space Grant Robotics gained several technical skills during their time on the team. Mechanical engineers learned how to use SolidWorks to design parts and Finite Element Analysis (FEA) within SolidWorks or ANSYS for analyzing the stresses and forces experienced by parts during normal operation. Emphasis was also placed on design for manufacturing, including optimizing parts for CNC machining and 3D Printing. Several team members also gained experience using manual mills and lathes for machining aluminum parts and operating the company's 3D printer. Electrical engineers gained soldering, electrical testing, PCB design, and hardware skills along with cable management. Both electrical and programming team members gained some Arduino and ROS programming skills, which was useful for system integration purposes. Programmers learned how to use Python libraries, OpenCV, and ROS to develop robot control and image recognition platforms.

Along with technical skills, company members also gained several soft skills such as communication and project management, which helped the team leads define what tasks needed to be complete and by whom and when in terms of the design process defined in the logistics section. These skills combined allowed the more interdisciplinary teams to function and allowed individual members to learn more about areas outside of their usual domains.

REFLECTIONS

Reflections are an important part of communicating and a great source of feedback and suggestions for NASGR to implement next year. Below are a few reflections from leadership and general members.

"After being a part of NASGR for four years and gradually working my way up to the top, I can say that I have no regrets about joining this team. I have learned so much about mechanical design, machining, testing, electronics, communication, and project/team management and cannot wait to take what I've learned in NASGR and apply it to the workforce. This team has come such a long way since 2014 and I am proud to have led this year's team."

-***Annie Martin, CEO***

"I learned how integral teamwork is to complete such a huge project that is making a functioning robot. I've never worked on a team on such a large scale with units and subteams, and it showed me how teamwork shifts depending on the situation and all the different forms it can take."

- ***Audrey Mendez, Mechanical Engineer***

"I found a place where I could try my hand at implementing advanced robot behavior and control with some upperclassmen who could help guide my path. The process of getting involved was admittedly frustrating because of a high learning curve and unfamiliarity with the systems and concepts involved in the robot, but it was worth it for the knowledge I rapidly developed and implemented on a working robot. I am very excited to work on the club's robots in the future and continue to build my skills and implement more advanced robot behavior and control."

- Cordell Michaud, Programmer

FUTURE IMPROVEMENTS

From events witnessed during testing and feedback from team members, the company has identified several improvement areas, both technical and non-technical. One such improvement is standardization of all fasteners and hardware. This will save money because only a few sizes of various fasteners will need to be purchased and it removes the need to purchase specialized tooling and hardware to install parts on the robot. Another technical improvement will be improving the buoyancy system. Previously, buoyancy has been more of a last-minute effort, relying on trial-and-error during testing to make the robot neutrally buoyant. Next year, buoyancy will either have its own dedicated project team or will be incorporated into the robot control team so buoyancy can be included in the design process, which will improve robot performance overall.

On the non-technical side, closer attention will be paid to deadlines via stricter and more transparent scheduling. This past year officers and team leads were not always careful about communicating exact requirements and deadlines to project teams in a timely manner, which led to several delays in designing and increased the chances of problems occurring later. More effort will also be made to ensure that a proper Gantt chart and budget are made at the beginning of the season instead of later so that more team members can be involved in making them and be more aware of what is expected in general.

ACKNOWLEDGEMENTS

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NASGR Alumni for their help and support

The Peavler Family for use of their pool

The MATE Center and all their volunteers for providing us with this opportunity

SPONSORS

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APPENDIX

SAFETY AND LOGISTICS

Before Power	Retrieval
Ensure nothing is connected to power or in an on position	Indicate to deployment team ROV requires retrieval
Ensure enclosure is sealed	Have pilot surface ROV near deployment team
Check to makes sure cables are not a tripping hazard	Pilot indicates to deployment team the ROV is safe to remove from water
Connect Seacons	Deployment team removes ROV from water
Check strain relief is in place	Deployment team indicates to the pilot that the ROV has been retrieved
Power Up	**In the event of Leak**
Turn on control computer	Surface immediately
Plug in power supply to extension cord in OFF position	Turn off power supply
Alert surrounding team members to the intention of powering on	Assess location of leak
Put extension cord in ON position	**In the event of lost communication**
Briefly test thrusters are operating properly	Run the proper ROS scripts for sending commands via the controller
Briefly test that all components are operating properly	If the robot does not respond to the scrips, turn off the power supply and bring the robot to the surface
Check that video feeds are operating correctly	
Deployment	
Check to ensure Pilot is not touching the controls	
Check with deployment team to see if they are ready	
Instruct deployment team to launch robot into water	
Have deployment team set the ROV into the water with hands at safe locations away from moving parts	
Visually check there are no leaks	
Check water for large bubbles leaving the enclosure	
Have deployment team indicate to pilot it is okay to begin	

Table 2: Safety Checklist

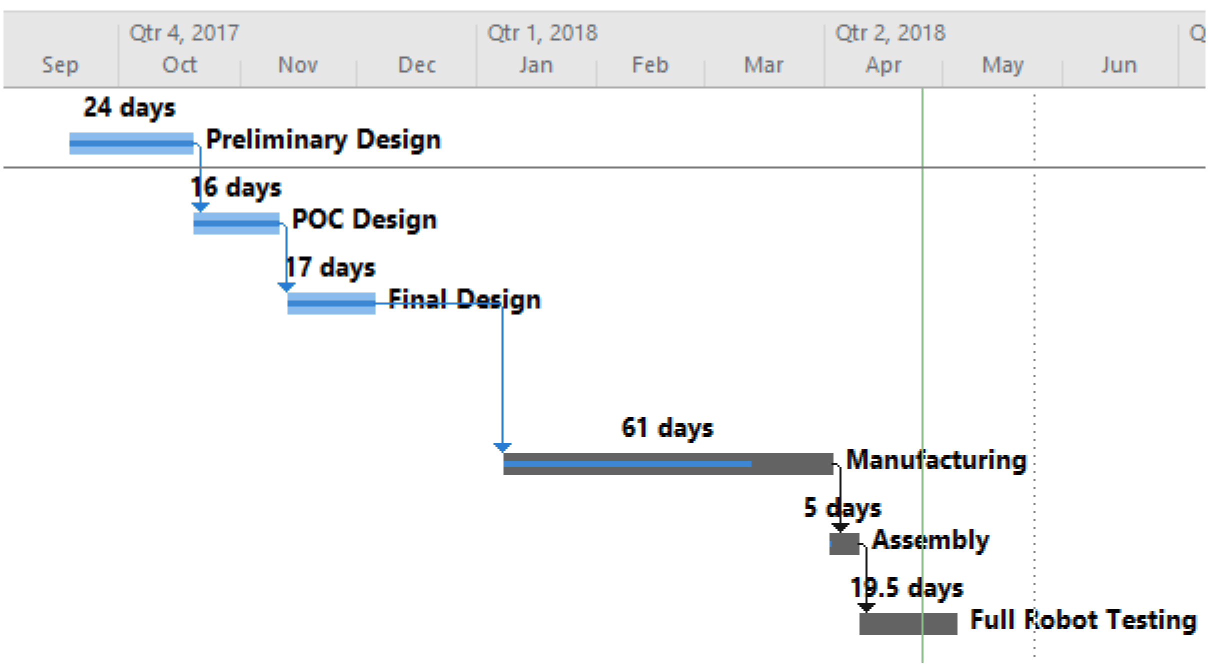


Figure 21: Gannt Chart

NASGR 2018 Budget (USD)				
Category	Item and Description	Purchase Type	Amount	Total
Sensors	Wi-Fi and Compass Modules	Purchase	$ 37.93	$ 37.93
Elecrical Equipment	Wire	Purchase	$ 26.98	
	USB Camera	Purchase	$ 39.99	
	Soldering Accessories (flux, tape, paste, mats)	Purchase	$ 186.45	
	Soldering Iron and Rework Station	Purchase	$ 296.48	$ 549.90
Electrical Components	Mti100 IMU	Purchase	$ 1,990.98	
	Power (batteries, fuses, regulators, and accessories)	Purchase	$ 52.28	
	Playstation Eye Cameras	Purchase	$ 69.90	
	Udoo Development Board and Accessories	Purchase	$ 219.10	
	Boards (Servo Driver, Adafruit FLORA, Neopixel Accessories)	Purchase	$ 113.72	
	Wireless Chargers	Purchase	$ 44.97	
	Connectors and Crimps (SBS50, holders, etc)	Purchase	$ 83.80	
	Speed Controllers	Purchase	$ 274.90	$ 2,849.65
Prototyping	Breadboards and Protoboard	Purchase	$ 31.48	$ 31.48
Tooling and Hardware	Air Compressor and Supplies, Pitch Gauge, Hex Keys, Misc. Tools	Purchase	$ 153.91	$ 153.91
Stock Material	Camera Enclosure Endcaps	Purchase	$ 53.00	
	Shafts, Rods, Aluminum and Polycarb Stock	Purchase	$ 368.72	$ 421.72
Manufacturing	CNC Machining (Milling and Waterjet)	Purchase	$ 2,880.57	
	Equipment (Taps, Arbor Press, PPE)	Purchase	$ 133.29	$ 3,013.86
Fasteners	Screws, Standoffs, Nuts, Washers, Bolts, Cable Penetrators	Purchase	$ 226.20	$ 226.20
Waterproofing	Mineral oil, O-rings, Epoxy, Scotchcast	Purchase	$ 285.64	$ 285.64
Motors and Gears	M100 Motors for Claw, Gearboxes, Gears, Servo	Purchase	$ 310.15	$ 310.15
Reused Components	Waterjetted Aluminum and Polycarbonate Parts for Frame	Reused	$ 40.00	
	Seacon Connectors	Reused	$ 1,600.00	
	Anderson Powerpole Connectors	Reused	$ 18.49	
	30 Amp Fuses	Reused	$ 7.89	
	Underwater Light	Reused	$ 113.00	$ 1,779.38
Total ROV Construction Expenses				$ 9,659.82
Lodging and Travel	Airfare and Lodging for 10 People	Purchase	$ 5,330.00	$ 5,330.00
Company Apparel	T-shirts	Purchase	$ 446.26	
	Polos	Purchase	$ 332.87	$ 779.13
Miscellaneous	Display Monitors	Purchase	$ 409.58	
	MATE Registration Fee	Purchase	$ 315.00	
	Food for Meetings	Purchase	$ 298.04	
	Shipping Costs	Purchase	$ 38.70	
	Marketing Supplies (Team Poster, stickers)	Purchase	$ 64.86	$ 1,126.18
Total Travel, Apparel, and Miscellaneous Expenses				$ 7,235.31
Cash Income	KEEN	Cash	$20,000.00	
	Ira A. Fulton Schools of Engineering	Cash	$ 4,000.00	
	FMW Fasteners	Cash	$ 500.00	
	ASU Undergraduate Student Government	Cash	$ 850.00	
	Previous Organization Balance	Cash	$ 2,329.70	$ 27,679.70
Donations and Discounts	Dassault Systemes	Donation	$ 6,000.00	
	Vicor	Donation	$ 4,000.00	
	Seacon	Discount	$ 1,600.00	
	ASU/NASA Space Grant Consortium	Donation	$ 899.00	$ 12,499.00
Total Expenses				$ 16,895.13
Total Income				$ 40,178.70
Net Balance				$ 23,283.57

Figure 22: NASGR Budget for FY 2017-18

SOFTWARE FLOW CHART

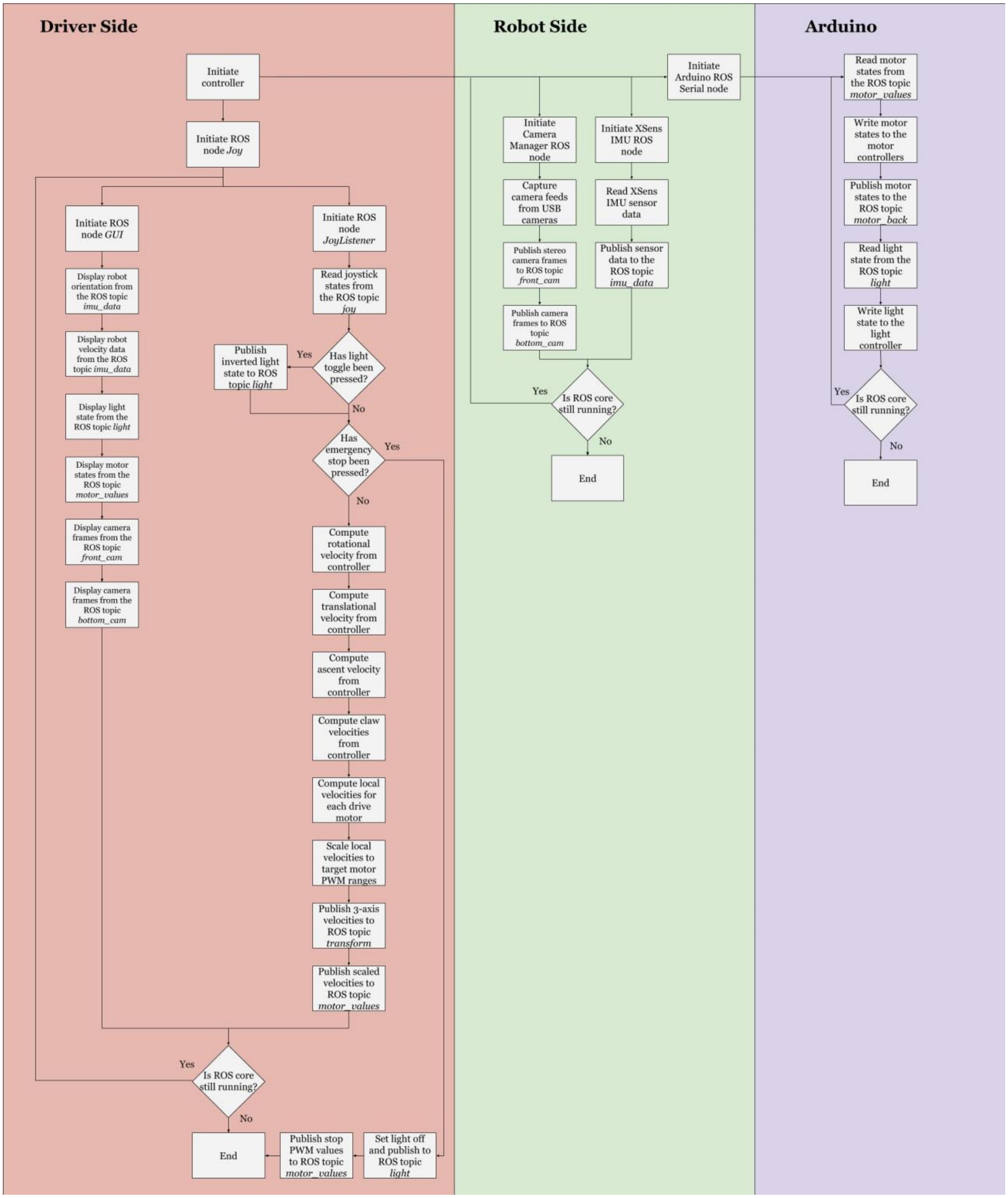


Figure 23: Software Flow Chart

Color	Meaning
Orange	9V
Blue	5V
Black	Ground

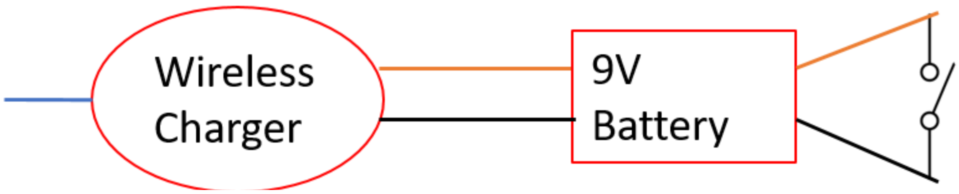


Figure 24: Power Connector

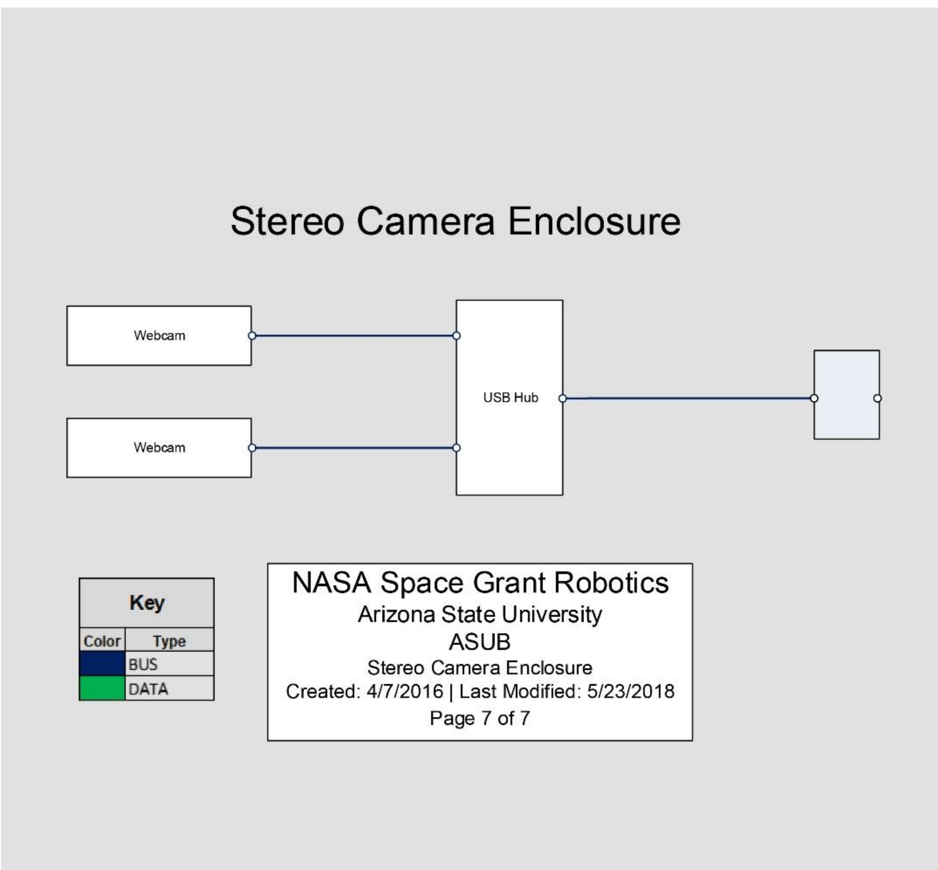


Figure 25: Stereo Camera Enclosure

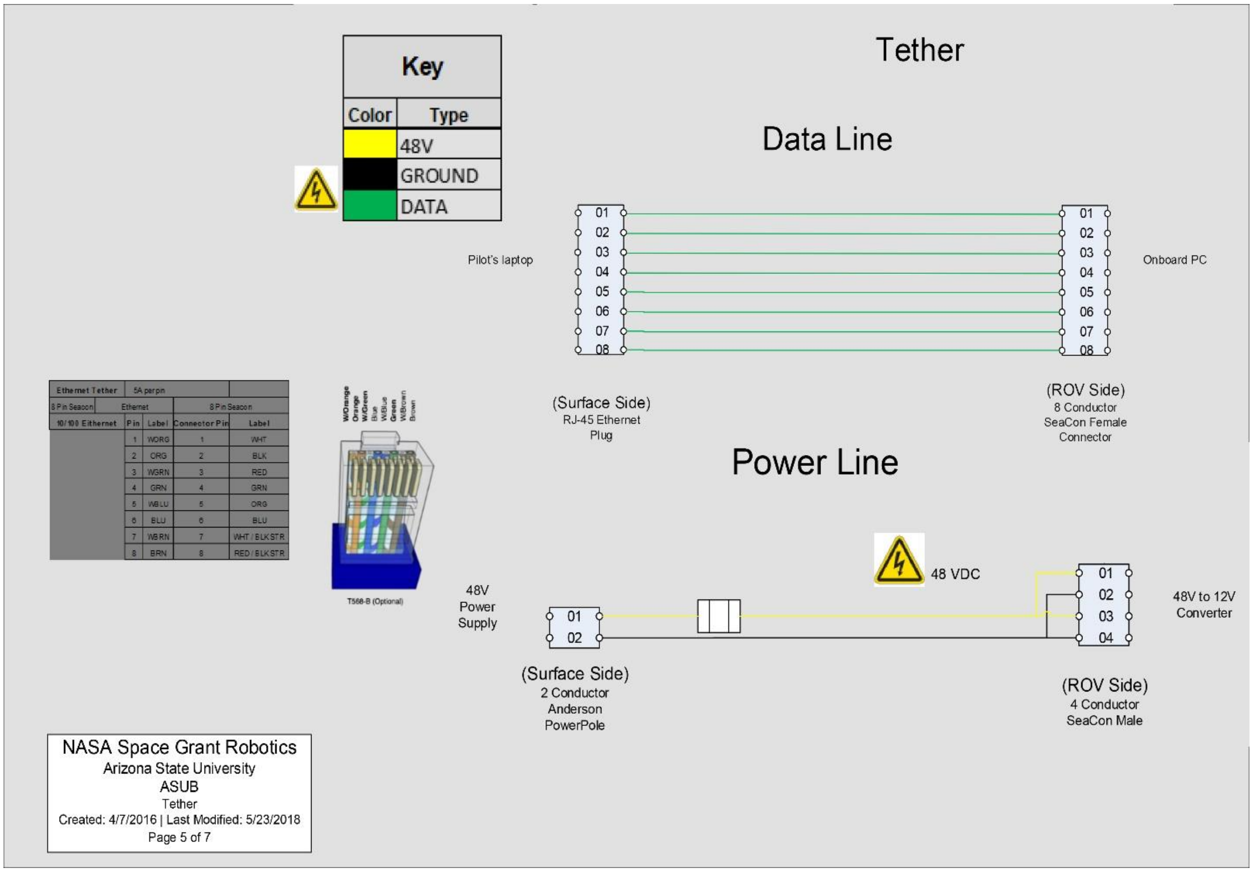


Figure 27: Tether

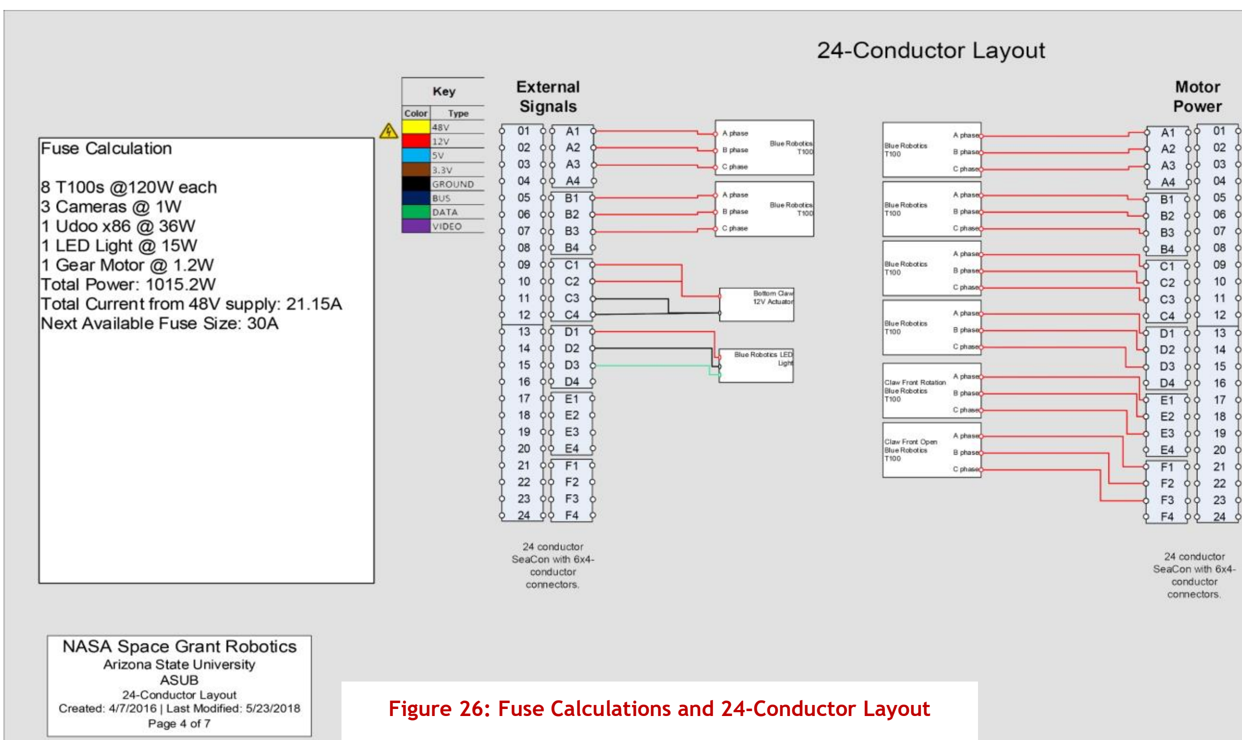
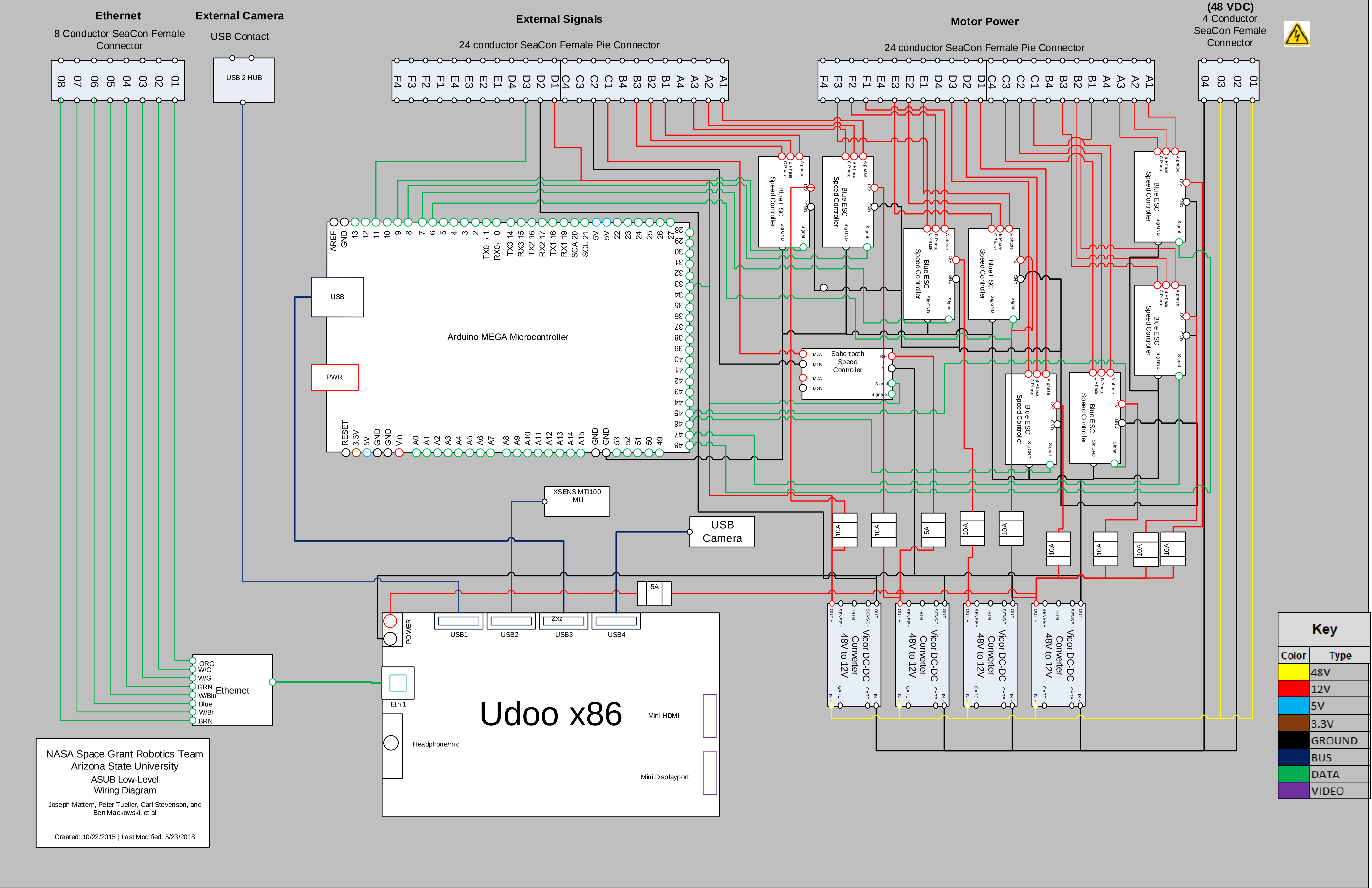
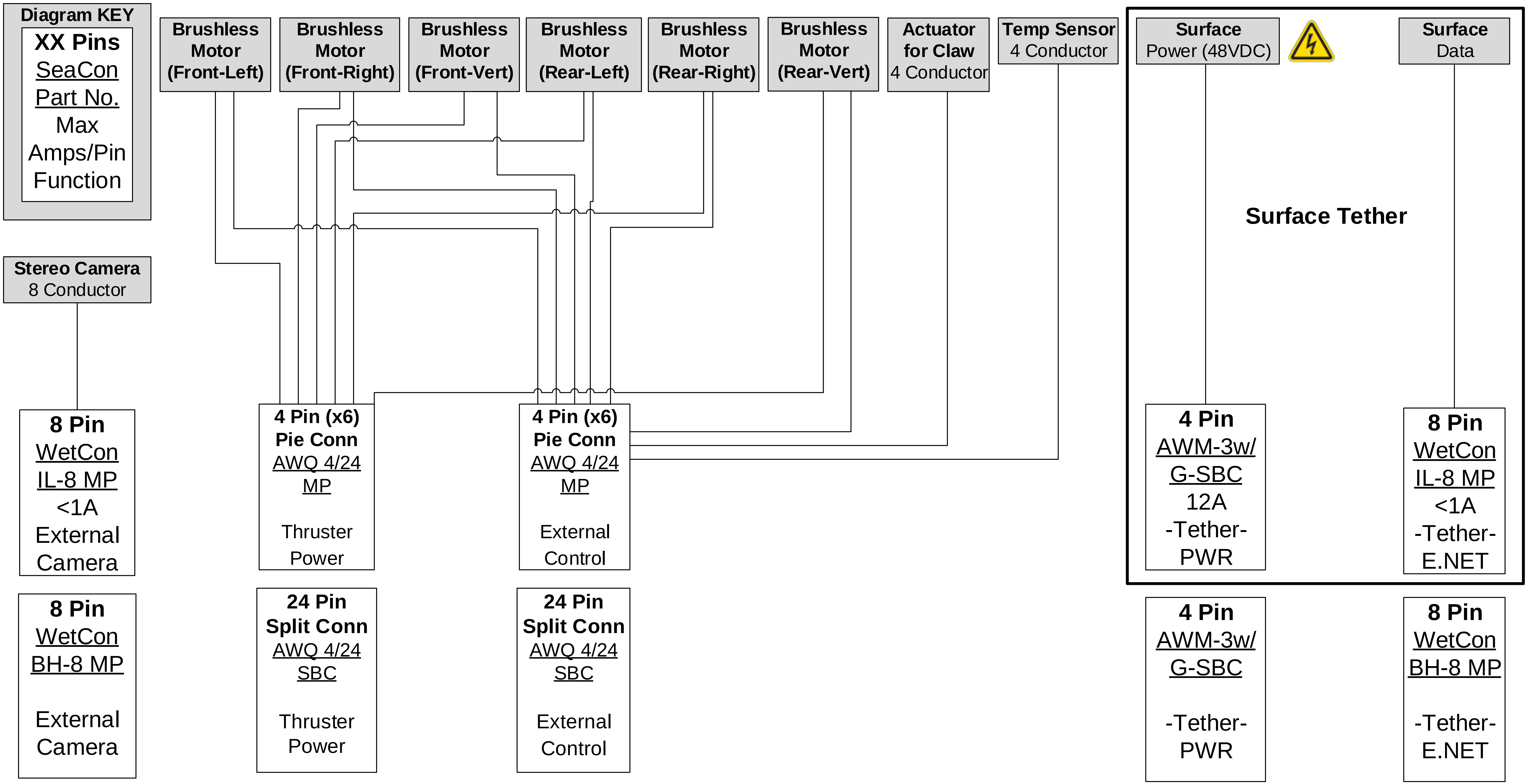


Figure 26: Fuse Calculations and 24-Conductor Layout



Ethernet
8 Conductor SeaCon Female Connector
External Camera
USB Contact
USB 2 HUB
External Signals
24 conductor SeaCon Female Pie Connector
Motor Power
24 conductor SeaCon Female Pie Connector
(48 VDC)
4 Conductor SeaCon Female Connector
Arduino MEGA Microcontroller
USB
PWR
Blue ESC
Speed Controller
Sabertooth Speed Controller
XSENS MTI100 IMU
USB Camera
Vicor DC-DC Converter
48V to 12V
10A
5A
Udoo x86
USB1
USB2
USB3
USB4
POWER
Eth 1
Headphone/mic
Mini HDMI
Mini Displayport
Ethernet
Key
Color
Type
48V
12V
5V
3.3V
GROUND
BUS
DATA
VIDEO
NASA Space Grant Robotics Team
Arizona State University
ASUB Low-Level
Wiring Diagram
Joseph Mattern, Peter Tueller, Carl Stevenson, and Ben Mackowski, et al
Created: 10/22/2015 | Last Modified: 5/23/2018



SeaCon Pin-Out Diagram — Sub Sandwich 1.0

NASA Space Grant Robotics Team
Arizona State University
Waterproof Connector
Pin-out Diagram
Joseph Mattern, Peter Tueller, Carl Stevenson, and Ben Mackowski, et al
Created: 10/22/2015 | Last Modified: 5/23/2018