RoboSub Team Killick

Final Report
Spring Semester 2017

-Full report -

by
Brett Gonzales
Jordan Lankford
Tyler Loughrey
Nate Marquez
Chris McLean
Phil Meister
Seth Purkey
Mitchell Yohanan

Department of Electrical and Computer Engineering
Colorado State University
Fort Collins, Colorado 80523

Project advisor(s): Dr. Anthony Maciejewski
Megan Emmons
Chris Robbiano

Approved by: TBD

Abstract

Everyday automated robotic techniques are being applied to high-risk scenarios to ensure the safety of people. This is highly pertinent to many underwater applications, including those conducted by the U.S Navy.

The RoboSub Project is focused on the construction and implementation of an autonomous underwater vehicle (AUV) that can perform both basic as well as very specific tasks, such as picking up specified objects and placing them in an area of interest. *Team Killick* is the first iteration of the RoboSub Project and is focused on establishing a sustainable project at CSU dedicated to refining the mechanical design, propulsion, navigation, and control of AUV's.

To accomplish this task, the team is split into three subteams: Mechanical, Power and Propulsion, and Vision and Sensors. Each subteam is designed to pursue their respective field of engineering individually, eventually coming together to contribute to an overall integrated system design. The specific fields of engineering are detailed in the following sections.

Mechanical

The focus of the Mechanical subteam is the designing, manufacturing, and testing of the chassis, EH, and failsafe system. Major considerations include: thermodynamics of the EH, buoyancy of the vehicle, CFD in drag and pressure, and the material mechanics for components. The thermodynamics of the EH are simulated in ANSYS, while the initial values of buoyancy were in Excel using drag coefficients from ANSYS and ultimately validated in water testing. The materials were chosen based on their corrosive resistance and inability to dissolve in water.

Vision & Sensors

The focus of the Vision and Sensors subteam is visualization of the world around the vehicle through inertial, pressure, and optical sensing. Optical sensing is used to determine the location and movement decisions of the vehicle whereas Pressure sensing is used to determine depth, aid in vertical motion, and help to determine tilt. Inertial sensing is used to determine speed and rotation. Collection of real world sensor data, transmission, processing, and system integration of sensor data forms a basic navigation system which can be expanded on by future teams.

Power & Propulsion

The focus of the Power and Propulsion subteam is the designing, testing, and validation of propulsion and power systems of the vehicle. The main components include: motors, motor drivers, motor controllers, propeller and shroud design, low and high voltage power supply, and power supply management. The motor drivers for this iteration of the project were

simplified with the selection of an ESC due to the time intensive nature of building a custom multi-phase synchronous motor driver for BLDC motors. The motors, ESC's, motor controllers, propellers, and shrouds were all tested together in a custom 22-gallon tank constructed for the purposes of load testing and vectored coordination of the motors. The power supply was selected in order to give the test rig a 20-minute continuous operating time under assumed *normal* operating conditions.

Table of Contents

Chapter 1 – Introduction

The RoboSub team is an evolutionary senior design project at CSU charged with designing, implementing, testing, and competing with an autonomous underwater vehicle (AUV) in the United States Navy RoboSub competition.

Four electrical engineering (EE) undergraduates, two electrical engineering graduates, one computer engineering (CE) undergraduate, and three mechanical engineering (ME) undergraduates form the core senior design team with OOP underclassmen (EE/CE) forming the basis for future senior design members.

This project has three main aspects: mechanical, propulsion and power, and vision and sensing. Three EE's are focusing on construction, implementation, and testing of motors, power, and controls while one EE and one CE are focusing on the image processing and sensing necessary for navigation. The three ME's are focusing on design, implementation, and testing of vehicle chassis, propulsion requirements, and overall water suitability of the vehicle.

Success in the competition is measured on course completion, event duration, and overall design. Overall design consists of: technical merit, craftsmanship, safety, website design, team coherence (attire and technical vehicle knowledge), and documentation. Event duration consists of completing prescribed courses (comprised of tasks in a systematic order) in the shortest amount of time. The RoboSub rules dictate all static and dynamic event scores, as well as the specific event criteria. Rewards are paid according to position standing, and contribute to any future teams' available funding.

Per the rules and regulations of the 2016 RoboSub Competition, the following has been considered in the design of each aspect of the vehicle. The vehicle needs to be able to follow an orange guide that leads to each obstacle. The Buoy obstacle needs to identify the color of each buoy and touch them in the correct order. The PVC pass over obstacle consists of passing through a "portal" with extra points awarded to "style". The Bins obstacle consists of removing a "lid" from a "bin" and place markers into this "bin". The Torpedoes obstacle consists of firing dummy torpedoes at targets that need to be hit in a correct order. The Recovery obstacle consists of identification of an acoustic pinged that indicates the location of the objects that need to be placed in a certain area to receive maximum points. These obstacles may be modified for the 2017 competition, which at the time of this writing have yet to be released.

Further design constraints have been implemented by the competition rules and other design considerations. The competition implements several strict outlines of what is allowed and how points are awarded. Teams can be awarded additional points if the vehicle is under 84 lbf. There is also a penalty for any vehicle over 84 pounds with a maximum weight of 125 lbf. Any vehicle over 125 lbf will be disqualified. The size of each vehicle must fit inside a 3 ft x 3 ft x 6 ft volume. Any vehicle over this size will not be able to compete. Each vehicle must have markers that fit into a box that is 2 in x 6 in long and weigh less than 2 pounds each. The torpedoes have the same requirements as the markers and cannot exceed a speed that causes a bruise when striking a person. These are the main constraints on the design of CSU's AUV. The competition rules can be found in last year's competition official website [1P].

Additional constraints of safety, vehicle life, and manufacturability have been imposed by each member of Team Killick during the design process. Safety of the vehicle has been aimed to minimize the damage that may inflicted to users or the environment. Vehicle life will be maximized with the use of corrosion resistant materials that can withstand the expected strain for a long period of time. The manufacturability of the vehicle is constrained by the resources available to the team. With the use of a straightforward design and the prudent selection of materials the team can meet the given constraints and stay within the team's projected budget.

This first-year design is not directed at winning the competition, but rather to establish a simple and functional vehicle for future teams to expand upon. The 2016-2017 senior design team has completed most of the basic vehicle structure, propulsion, and navigation. The basic vehicle structure consists of a chassis with proper supports, waterproof enclosure for the electrical equipment, and a fail-safe ballast system. Propulsion consists of high voltage power supply, high amperage out-runner BLDC driven by ESCs, and overall motor control. Navigation consists of image processing for line tracking, inertial sensors communication and measurements, and pressure transducers communication and measurements.

Chapter 2 – History of Previous Work

Autonomous Underwater Vehicles are becoming more popular as unmanned vehicles advance with technology. Initially, the use of AUV's was utilized for commercial use. For example, oil companies used these unmanned vehicles to accomplish cheap geographical mapping of the ocean floor. Now AUV's have found a spot in military and consumer applications. Military applications include scouting, mine countermeasures, payload delivery, and oceanography. Commercial applications include marine life exploration and underwater pipeline surveying and testing. This application is fantastic as it gives users the ability to see and experience locations that were before unreachable or too dangerous to venture into.

The US Navy hosts a competition yearly to promote the expansion and ingenuity of what can be achieved with AUV's. The basis of the completion is to navigate an underwater course made up of obstacles and different objectives including path following, inertial navigation, identifying objects of interest, precision shooting of torpedoes, and accurate control of buoyant forces. Different teams from across the world bring their AUV's to compete. Each year, teams push the boundaries of how fast these objectives can be completed. Teams from Universities such as Cornell and Florida State have been competing in this event for the past fifteen years and are continually top competitors in the competition. Even though this is the first year that CSU is considering the competition, we expect to be amongst this group in the future.

Chapter 3 – Budget and Fundraising

The budget was created by researching past and current RoboSub team's journal papers. The parts listed in these papers were collected and used to create the estimated budget as seen in Appendix B Figure 8. A more detailed breakdown follows the table based on the estimated allotments per category.

Originally the team started out with $1,400 from the CSU ECE Department. Since then, the team has successfully raised an additional $15,200 through sponsorships from Ball Aerospace, Hewlett Packard, and IEEE. This brought the grand total of money raised to $16,600, which gave us a good amount of reserve funds.

No money was spent in the fall semester due to a delay in acquiring a Procurement card from Colorado State University. This problem was resolved and the team began purchasing and acquiring a majority of the needed material in mid-January.

During the spring semester, Killick was very frugal in our spending. From our estimated budget of $11,700, $3813.29 was spent on material cost: making up 33% spent of our estimated budget.

The mechanical subteam has 70% of their budget remaining. The *big ticket* item for the mechanical subteam is the EH, costing $200. The mechanical team saved around $260 by forging and casting the aluminum end cap (Figure 15M).

The power and propulsion subteam has 61% of their budget remaining. The *big ticket* item for the propulsion subteam were BMS components, costing around $267. The propulsion subteam saved around $200 per thruster because they purchased naked motors, waterproofed them in house, and fabricated custom propellers and shrouds.

The sensors subteam has 72% remaining in their budget. They obtained their most costly item, the IMU, via a donation from Sparton NavEx saving $1500. The other big ticket item for the sensors subteam was the IPU costing $350. This increased the processing units budget category but because of the savings on the IMU budget it was deemed cost effective for future teams. Figure 0 shows a breakdown of each of the subteam costs for our estimated budget (based around $11,700). Appendix B shows the breakdown of cost for each subteam.

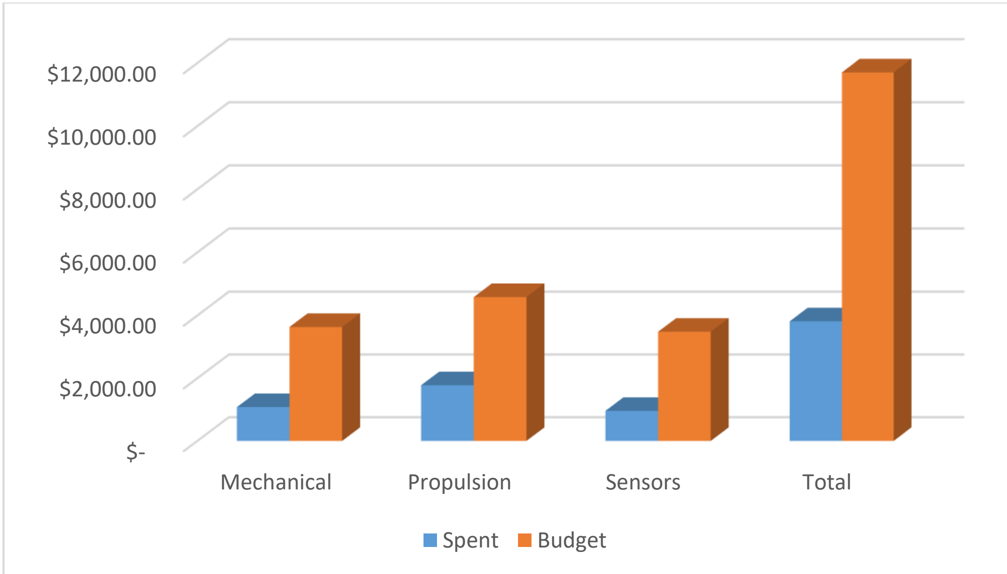


Figure 0 - Overall Budget Breakdown for Subteams

Chapter 4 – Mechanical Subteam

Chassis

Objectives and Constraints

The purpose of the chassis is to provide protection and modular placement. The rules of the RoboSub competition restrict the size and weight of the entire vehicle to be less than a 3 ft x 3 ft x 6 ft volume and less than 125 lbf. Another constraint is the material to be used in the chassis. The material has to be corrosion resistant to operate in an aquatic environment and ideally modular for ease of modification. The material also will be a t-slotted extrusion for this first year. The reason a t-slotted extrusion will be used is to provide modular placement for any design changes that occur. This is important since this is the first year that CSU has had a RoboSub team.

The chassis also needs a way to hold the EH in place. This is accomplished with 3D printed ABS clamps with rubber grips that press to the outside of the EH. The clamps have a slot in them for a hose clamp to fit through them that helps the clamps press against the housing. The reason for choosing ABS as the material was due to its strength, water durability, and lower cost.

Alternative Design Processes

The current design of the chassis had several considerations; the current box design was originally put into a decision matrix to narrow down the considerations for an optimal design. The metrics of the designs were ranked from 1-5, with 5 being the best. The scores from each mechanical team member was averaged and the results are shown in Appendix E.

The decision matrix led the team to consider the sled, box, and x-wing designs as the top designs. The next decision that was decided on was the material to use for the chassis. The chassis has to be corrosion resistant, strong, and provide a modular frame for the motor placement. The t-slotted aluminum extrusion was chosen because it satisfied the material requirements. With the top designs selected, the mechanical team started to layout in CAD some basic designs. While the sled design took the top spot of the decision matrix, the mechanical team decided not to continue considering this design due to limited motor placement and protection. The box and x-wing design are shown in the Figure 1 below.

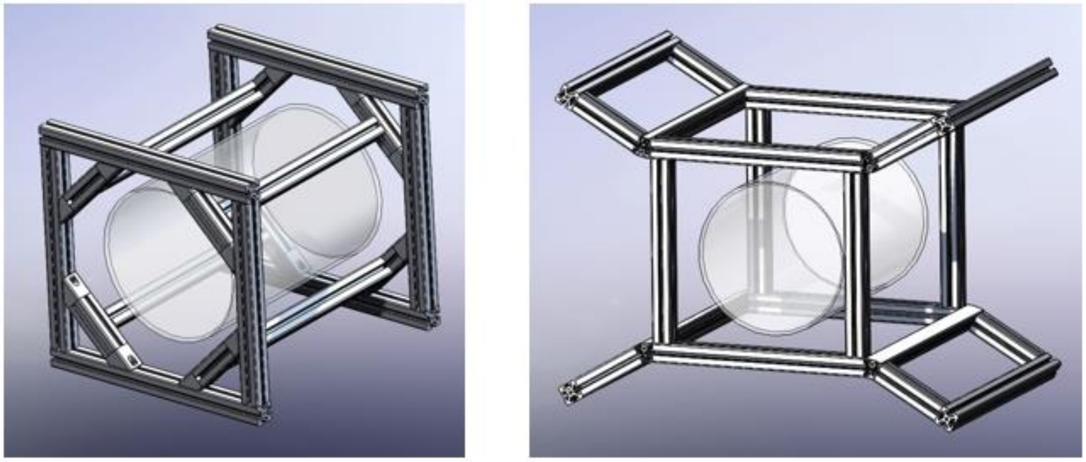


Figure 1– Box (Left) and X-wing (Right)

The x-wing design had unnecessary "wings" that were not structurally sound. This led to the x-wing design to be abandoned and the box became the primary chassis design. The box was improved several times resulting in the current design shown in Figure 2 below.

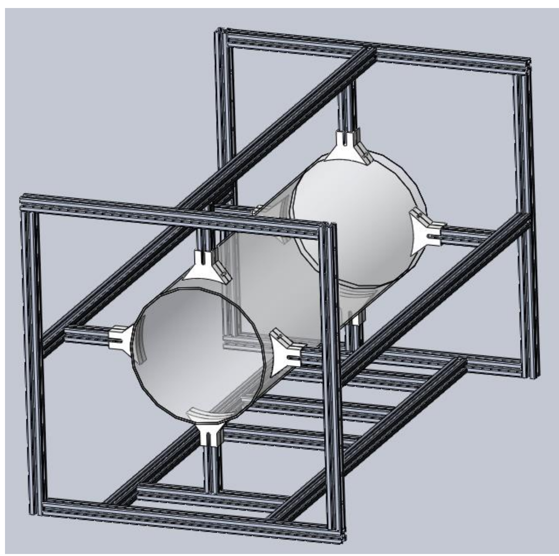


Figure 2– Current Prototype Chassis Design

Manufacturing/Assembly

The final material chosen for the chassis is an aluminum T extrusion that is anodized black, which helps with corrosion resistance. The chassis was assembled using bolts and T nuts that fit in the grooves of the T extrusion. These bolts fit into L brackets that hold each part of the chassis together. A picture of the full chassis can be found in Appendix E Figure 15M- Full Chassis Assembly.

Testing

The chassis is designed to survive an aquatic environment. However, with limited resources tests need to be designed and implemented for validation of the chassis. The tests that the mechanical team have decided to run are as follows: fatigue, impact, corrosion, and dry-land loading. The fatigue test will determine if the chassis will maintain its original shape after multiple simulated crashes. The impact test is will determine that the chassis can maintain structural rigidity while experiencing an impact. This impact force will equate to a collision happening while the vehicle is traveling at maximum velocity. The corrosion test will place a piece of the chassis in salt water, fresh water, and chlorinated water over an extended period of time to see the effects. The dry-land loading test will ensure that the chassis can hold the electronic housing at different angles. For further testing descriptions please see Appendix H for the full testing procedures.

The tests that were performed included the corrosion test as well as the dry land loading test. The loading test was successful and the chassis as well as the 3D printed ABS clamps were able to support the load of the vehicle without yield or fracture. The corrosion test was successful except the steel bolts which corroded slightly. Next year's team should buy corrosion resistant marine grade bolts to replace these.

Risk Mitigation

The chassis needs to mitigate the risk involved with potential failures. The two main functions of the chassis are the protection of the vehicle and mounting the motors. A FMEA was used in order to address the potential failures and what corrective action will be used to minimize the consequences of such failures. This FMEA can be found in Appendix D.

Electrical Housing

Objectives and Constraints

The purpose of the EH is to maintain an ideal environment for the electrical components being housed inside. The housing holds the batteries, sensors, cameras, and processing units necessary for the vehicle to autonomously navigate. Some major considerations in the design of the housing include the seal design, buoyancy, heat dissipation, compartmentalization of components, ease of access, corrosive resistant materials, and strength. These are further elaborated on in the following sections and explained how the final design was concluded.

Alternative Design Processes

The first step in the design of the EH was deciding on an overall shape of the housing. We did this by brainstorming numerous shapes of the housing and narrowing down our decision to three final designs from a decision matrix. Refer to Appendix E, Figure 2M, for the EH decision matrix. The three final designs that were concluded from the decision matrix were the half-capsule, full-cylinder, and semi-sphere. After researching manufacturing costs, we found that the semi-sphere was unreasonable and decided to include the half cylinder in our final three concepts for the EH.

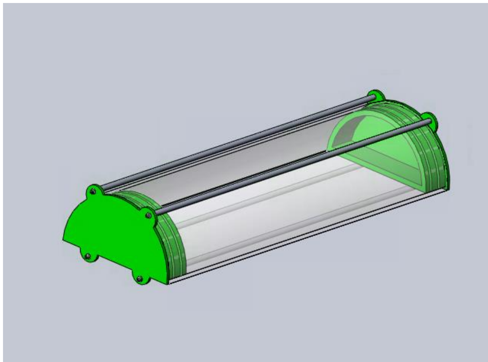


Figure 3- Half Cylinder

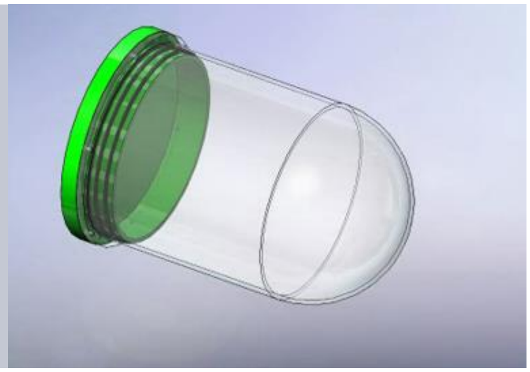


Figure 4- Half Capsule

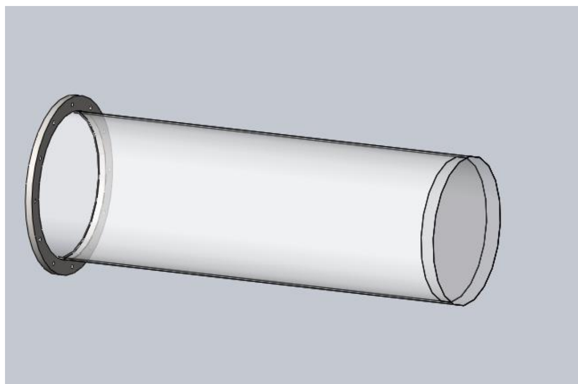
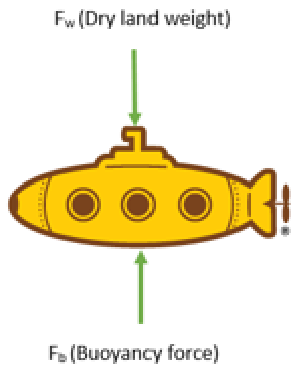


Figure 5-Full Cylinder

Upon further discussion and research of the three potential designs, we finalized our decision to be the full cylinder due to ease of manufacturability and sealing. An O-ring seal design for the end cap of the housing is very common and would not be able to be implemented with a half-capsule or semi-sphere design.

After finalizing the geometry of the housing, the overall dimensions had to be determined. The positive buoyancy generated from the housing was another major design consideration that was used to determine the size of the housing. This limited the size of the housing and overall dry land weight of the vehicle. The upward buoyancy of an object in water is dependent upon the volume of the object and the dry land weight of the vehicle that offsets the upward buoyant force. The vehicle needs to be neutrally buoyant in water to allow the motors to easily navigate to different depths without the vehicle naturally rising or falling.



$$F_b = V_b * \rho * g$$
$$V_b = Submerged\ Volume$$
$$\rho = Water\ Density$$
$$g = Gravitation\ Acceleration$$

Figure 6- Buoyancy Equation

Since the positive buoyancy must be offset by the dry land weight to achieve neutral buoyancy, the size of the housing will set our overall weight. The weight of the vehicle has to be less than 125 lbf as constrained by the competition rules. Refer to Figure 3M in Appendix E for the table that summarizes various dimensions of the EH cylinder along with the required dry land weight.

The final design that we decided on was a 10 in diameter by 31 in long cylinder which sets our weight at 95 lbf. We finalized our design at these dimensions because it gives us a weight that is less than 125 lbf while giving the vehicle able amount of volume to hold electrical components inside. We estimated our electrical components to take up an area of 3 ft x 1 ft.

Another major consideration for the EH is the material composition. The EH material needs to be corrosion resistant and transparent for the OD. It also needs to be transparent in order for us to see visual indicators during testing. This limited us to three materials to choose from: acrylic, clear PVC, and polycarbonate. We finalized our decision to be clear PVC due to it having a high fracture toughness and yield strength. Clear PVC is also more cost effective than polycarbonate.

Another alternative to the clear PVC cylinder that was researched was using a corrosion resistant 440C stainless steel to maximize heat transfer. We could incorporate a clear window for the cameras in this design. A material selection process was done using the CES software with the following performance indices and constraints to find this material.

- Constraints: shape = cylinder
- Fracture toughness > 23 ksi*in^2
- Corrosion resistance in water = Excellent
- Minimize cost performance index (PI 1)
- Maximize heat transfer performance index (PI 2)

Refer to Appendix E, Figures 4M and 5M, for the CES generated graphs which were used to select a material which satisfies the performance indices which minimize cost and maximize heat transfer. For the test rig, we will be using a clear PVC housing due to the low cost and we will use stainless steel 440C if heat becomes an issue from testing.

The housing also needs to be able to maintain a low enough temperature in order for our sensors and electrical components to operate correctly. Due to this, a thermally conductive material was needed to allow heat to be transferred to the outside of the housing. We decided on using a high conductivity metal as the end cap of the housing to assist in this function.

This design was modeled in CFD software Fluent to measure the heat rate through the housing with different end cap designs, thicknesses, and materials as well as different fan placements. The Fluent temperature and vector plot can be viewed in Appendix E Figures 6M and 7M. The results of this simulation showed that an aluminum end cap resulted in 88 W more of total heat transfer compared to a clear polymer. It also showed that adding fins to the end cap significantly increased the heat transfer by 100 W. A surface plot was generated in Minitab to compare a stainless steel cap to an aluminum cap. Each material was also compared with and without fins. This is shown in Appendix E Figure 8M. Using this data, we decided to use a 6061 aluminum end cap with fins and also incorporated two cooling fans into the housing.

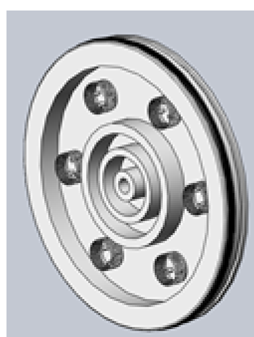


Figure 7- Aluminum End Cap

One of the major functions of the housing is to maintain a dry environment for the internal electrical components. To seal the housing, one side will be a permanent clear PVC window for the front facing camera. The other aluminum end cap will contain two O-rings for sealing and 6 water proof connectors for motor wires to leave the housing. This design was reviewed and validated by industry partners.

Due to the electrical team having the need to easily access and modify components, the housing will incorporate two retractable drawers mounted on A36 steel circular brackets. Refer to Appendix E Figure 9M to view the housing drawer design. The brackets will be mounted in the housing on 3D printed PLA sliders to allow easy adjustment of the brackets to change the center of gravity of the vehicle if needed. Refer to Appendix E for an image of the 3D printed bracket slides

The housing will be mounted to the chassis using eight 3D printed ABS plastic mounts. These clamps will fit over the 80-20 chassis and have a slit in them to allow a hose clamp to fit in them. This pulls the clamps tightly against the housing to ensure that it is secure.

Refer to Appendix E Figures 10M and 11M for images of the clamps.

A full CAD image of the EH incorporated with the chassis is available in Appendix E Figure 13M.

Manufacturing/Assembly

The aluminum end cap is the bread and butter of the EH. Scrap aluminum was donated to the team, which was then forged down with the use of a mold created by the mechanical subteam. It took approximately 17 hours of CNC milling time to fabricate.

The original method of cutting was to use a gun lathe to cut the length of the schedule 40 clear PVC to the correct dimension and apply the correct interior finish so the O-Ring would have proper sealing. However, we found this option inadequate due to the fluctuation (wobble) that occurs while on the lathe. The solution was a custom adapter made out of PVC blocks. Upon receiving the 1 in thick PVC blocks, they were PVC glued together, to create a 2 in block, and then machined down to specifications to create an adapter from the end cap to the EH. The tube slides into place and was PVC glued for the waterproof seal. The other end is open for the end cap and O-Rings to provide the waterproof seal.

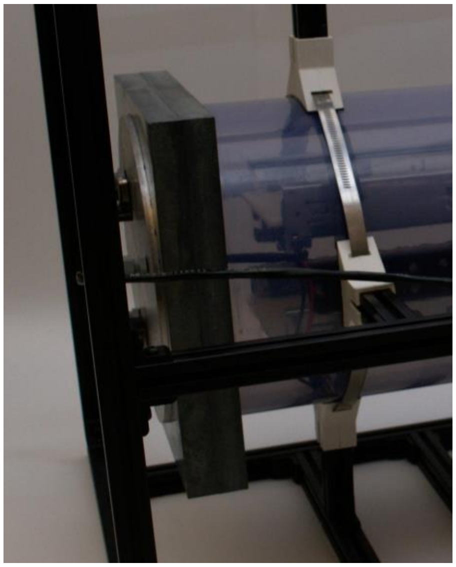


Figure 8- PVC Adapter

Internally the team was creative in making an extremely modular design. The electrical components are mounted on the shelf of the drawer slides. These shelves are made out of

ABS plastic and were cut using a vertical band saw to properly fit within the drawer slides. These drawer slides can come out and are detachable for easy access to work on. The only machining required for the drawer slides was to re-drill hole sizes to match with the location we needed. The drawer slides were mounted to the circular steel brackets. These steel brackets were designed in SOLIDWORKS and then plasma cut to specifications. The brackets not only act as a mount for the drawer slides, but also increase structural integrity for the EH. The team 3D printed custom slides out of PLA to mount to the PVC tube so that the steel brackets could be moved and re-fixed at intervals of one inch. This allows for offsetting weight and correcting the center of gravity for the rig.

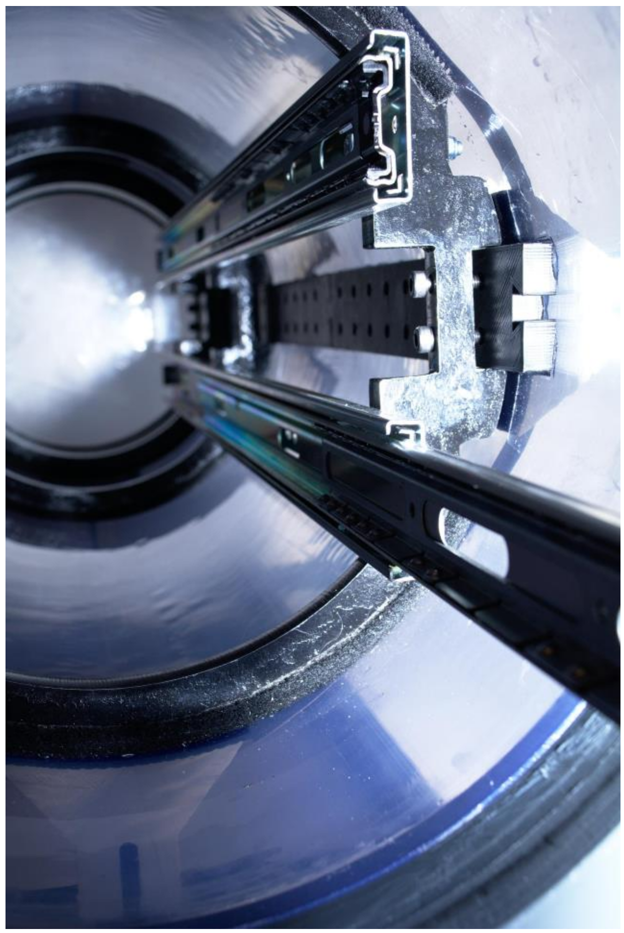


Figure 9- Steel Bracket Mounting

Testing

Two major tests conducted on the EH to validate the design: a water proof timed test, and a heat dissipation test. Refer to Appendix H for a more in depth description of these tests.

The waterproof test was completed at the Glenn Morris Fieldhouse at CSU. From this test, a small hole was found in the aluminum end cap from a fissure that formed during the casting process. This hole was filled in with marine grade epoxy and re-tested at a depth of 7 ft. The second test was successful and the EH is now fully water tight.

Risk Mitigation

The major failure modes of the EH are from the seals leaking and condensation (refer to Appendix D). We plan to mitigate the risk of seal leakage by following all the guidelines listed in the Parker Handbook [1] as well as rating our O-rings for at least 2X safety factor for maximum pressure. We will include a redundancy of 2 O-rings on the cap as well to mitigate this. We will have a water sensor in the housing to initiate the fail-safe in the case condensation is detected.

Fail Safe

Objectives and Constraints

Upon electrical failure the vehicle is required, per the rules of the competition, to have .5% positive buoyancy. Because we are not using a ballast system that manipulates the weight of the vehicle with an intake of water, we had to implement a ballast that's sole purpose is to achieve a small amount of positive buoyancy. A major focus is that the ballast must be highly reliable, simple, and effective.

Alternative Design Processes

The initial fail-safe was to be incorporated with the bladder like ballast system. An example of this can be seen in Appendix E, Figure 12M. Two designs considered were a high pressure pump that would release upon failure and a single high pressure pump with a water/ air dual pump system.

The other potential designs were mass ejection and piston actuation. Mass ejection is the process of releasing a large amount of air from a compressed tank, but upon calculating the needed amount of CO_2 required the design was quickly dismissed. The piston design utilizes compressed air to push a piston open and in turn increase the volume of the vehicle. This idea of the pump designs was eventually dismissed due to the amount of moving parts and reliability of the fail-safe. The design of inflating a bladder with compressed air to increase the vehicles volume displacement was ultimately chosen. This system requires only three components: a CO_2 cartridge, a normally opened solenoid valve, and a malleable, balloon like, material that can withstand the underwater pressure of a max depth of 40 feet. With a safety factor of 2, that max pressure is to be rated to 34.68psi.

Manufacturing/Assembly

The mechanical subteam created an external bladder system that inflates upon electrical failure. The system uses a CO_2 cartridge that inflates 4 arm floaties, which is approximately 4 liters at atmospheric pressure. The arm floaties are positioned on the top 4 corners of the chassis for an equal distribution of buoyancy. The CO2 cartridge is attached to a regulator to control the flow of gas from the cartridge. The regulator required an adaptor for the normally open solenoid. The normally open solenoid valve is then used to keep the CO2 cartridge sealed until the loss of power. The arm floaties are attached to the solenoid valve with tubing and three 3-way connectors. The arm floaties are attached around the aluminum t-slotted extrusion and use a Velcro strip to keep the arm floaties rolled up. Upon the loss of electricity, the arm floaties detach the Velcro for full inflation.

Testing

The fail-safe needs to have an extremely high reliability factor. Due to this, each component along with a fully assembled system will be extensively tested. The first test is to assure the normally open valve actuates upon electrical signal loss. Once this test is completed, the CO_2 cartridge can be attached to the valve and then the test can be repeated to ensure the air is properly ejected. Finally, with the air tight attachment of the bladder, the inflation can be tested for volume displacement and leaks. Each of these tests will be ran through many iterations to ensure reliability. For further reference, see section H in the Appendix.

All tests on the fail-safe have been completed and were successful. Further testing will include in-water tests. Once the fail-safe was assembled, testing was first done to ensure that the arm floaties would not burst from over-inflation. It was found that four floaties are needed for the system from this test. 23 tests on the fail-safe have completed to demonstrate its reliability.

Risk Mitigation

Potential risks with the fail-safe system is failure to properly inflate the bladder. The bladder could potentially get caught within the enclosure as well as potentially tear. Mitigation of these failures is accomplished by using material rated to maximum pressure put out by the CO_2 cartridge as well as making all surfaces smooth and internally lubricated.

Refer to Appendix D for more details.

Fluid Dynamics

Objectives and Constraints

The movement of the vehicle through water is directly correlated to the thrust provided by the externally mounted motors. Due to the high viscosity of water, compared to that of air, the movement of the vehicle through water causes a high drag coefficient and in turn large drag force. Other constraints that affect the movement of the vehicle through water are the shape and weight. The more aerodynamic the shape of the vehicle, the lower the drag coefficient is. Weight affects the inertial movement required to initially and continually move the vehicle. The constraints help determine the force required to move the vehicle at a certain speed. With a known force, the correct motor can be properly picked to ensure proper propulsion.

Alternative Design Processes

To determine the forces acting upon the vehicle while moving, certain variables had to be assumed to run CFD analysis. We were able to find the known values for the surface area, maximum velocity, and time. Through the use of ANSYS, the mechanical subteam was able to determine the drag coefficients for the vehicle. The overall thrust forces required to move the vehicle was then calculated at different accelerations compared shown in Appendix E Figure 14M.

Due to the changing surface area during lateral movement, different thrust is required to reach the same accelerations. Upon calculating the forces for forward and lateral movements, the thrust needed was found to be 11.84lb-f and 22.034lb-f respectively.

Testing

This data gives the propulsion team a good idea of what the motors need to be rated to. The testing will consist of in water tests to determine if the thrust required at max velocity is close to our calculations. Because this data was found using CFD analysis, it is a great approximation of what forces may exist on the vehicle, but not perfect.

Chapter 5 – Vision and Sensors Subteam

Hardware

Optical Devices

Objectives and Constraints

Optical devices are to be added to the final vehicle as a main means of navigation. The optical device chosen in this case is two cameras. One camera is used to track a guiding line along the bottom of the obstacle course. The goal of this camera is to be able to correctly identify the guiding line and tell the position of the vehicle relative to the line. This will in turn tell the motor controllers how the vehicle needs to maneuver in order to maintain course. A second camera is oriented forward for object tracking and obstacle recognition. The goal of this camera is to identify the objective, and decide how the vehicle needs to move to complete the objective, whether it be to shoot a torpedo through a target, navigate through hoops, or bump into color-coded buoys.

For constraints, the camera hardware needs to satisfy the following requirements:

- At least 800x600 resolution
- At least 30 frames per second
- Under 3 Watts power consumption
- Under 1-pound weight
- Able to retrieve raw images from I/O with no need to pre-filter

Alternative Design Processes

A single camera was considered as an alternative design. This was decided to be insufficient, as it would have to track all movement of the vehicle.

The subteam also considered using a hydrophone array as a means of navigation, as it would be able to image the vehicle surroundings. This was decided to be too intensive of a task for the subteam.

Testing

For hardware testing, we tested the resolution and possible frames per second. Unfortunately, we were not able to complete live-stream image capturing tests from the camera.

Risk Mitigation

The only risk that would be mitigated is if the camera simply does not work, in which case it will be returned for a refund, and a new camera will be purchased.

Results

We chose the GoPro Hero 4 Silver for the OD (Figure 1S). We purchased one for now to test, but will need two for the vehicle. This camera was chosen due to its capabilities of live-stream video and clear documentation.

Inertial Devices

Objective and Constraints

The hardware constraints for the IMU are a trade-off between accuracy and cost. The IMU needs to have 9 degrees of freedom (DOF), with an accelerometer, gyroscope, and magnetometer in each orthogonal axis.

Many high-end IMU's have their own filtering for noise-reduction which is used to increase the accuracy from the IMU. Additional filtering to reduce noise may be required which will need to be done by the SPU. The IMU must be able to communicate over either GPIO or USB to the SPU.

Alternative Design Processes

Alternate designs for an IMU have not been considered, as it is the best method of determining position. Some IMU's include an extra DOF as a pressure sensor, however we decided it would be best to use pressure transducers to track our depth in the water.

Testing

The IMU was connected to a computer, and confirmed to be working in a functional condition, including responding to commands. This testing confirms that the I/O voltages and baud rate are correct.

Risk Mitigation

The only risk with the IMU is that it returns incorrect or extremely noisy signals. To reduce this, filtering must be added so that outliers and noise are removed or reduced regardless of on-board noise reduction.

Results

We chose the Sparton AHRS-8 as our IMU for its' extremely high accuracy and performance (Figure 2S). This IMU also has on-board filtering capabilities or the ability to simply output raw data.

Pressure Transducers

Objective and Constraints

The pressure transducers need to be able to withstand approximately 40 psi. The pressure transducers also need to be able to communicate with our SPU. This means that the SPU needs to be able to recognize different voltages and relate them to the current underwater depth. Two pressure transducers, one on each end to sense tilt, is the ideal number.

Alternative Design Processes

An alternate design for the pressure transducers would be to have it contained on the IMU as an extra DOF. However, the IMU is within the vehicle's EH, it will not experience a differential amount of pressure.

Testing

The pressure transducers were not actually tested underwater, but they have been tested at atmospheric pressure and have been found to give reliable readings from both, around the 13 mV range. Testing was done by way of desktop power sources to supply the needed 1.5 mA current and DMMs to read the output initially. Next, testing was done by use of a current source built out of a single PNP transistor, the voltage output of the Raspberry Pi, and the output of a Waveshare A/D expansion board. This A/D expansion board is needed to read the analog output of the transducers, since the Raspberry Pi is not capable of reading analog inputs by itself.

Risk Mitigation

The biggest risk with the pressure transducers would be reporting an incorrect depth. To mitigate this, the vehicle would need to be surfaced to fix the issue.

Results

The hardware that was chosen are the TE 86 compensated pressure transducers which can output anywhere from 0-100 millivolts (Figure 3S). We also use a Waveshare A/D expansion board, in order to read the outputs given by the transducers (Figure 4S).

Sensor Processing Unit

Objective and Constraints

The constraints of the SPU are to be a programmable system that handles raw sensor data and converts data to navigation data.

The SPU needs to have a fast enough processor to be able to handle incoming sensor data and output navigation data within a reasonable amount of time (about 300ms max). It also needs to be able to handle inputs from multiple I/O interfaces, as the IMU, IPU, and pressure transducers do not all use the same I/O protocols. The SPU must also weigh under 2 pounds, and consume a minimal amount of power.

Alternative Design Processes

There were many options considered to fulfill this role. Initially, a miniature windows-capable PC was the choice of the SPU, but after reviewing specifications, specifically power consumption, this was found to be a poor choice.

Testing

The SPU has gone through extensive hardware tests. Heat-up has been considered, and was found to be very low. Power consumption was also found to also be very low, with an input of 5V and 1.5A max. We also tested the I/O capabilities including functioning GPIO pins and USB connection.

Risk Mitigation

Possible failures of the SPU include: fails to retrieve or transmit data from its I/O ports, failure to boot, or failure to meet processing speed requirements. To mitigate these, the SPU will be tested for I/O and boot functionality before the vehicle is submerged, will have an error LED on vehicle that indicates if no input is being received from any of the sensors, and it will have a boot indicator LED.

Results

We chose the Raspberry Pi B Model 3 due to its capabilities as a microcontroller (Figure 5S). This has all of the possible connections that we use to pull data from our sensors, including GPIO pins and USB.

Image Processing Unit

Objective and Constraints

The goal of the IPU is to read in raw images from the OD, pass them through a filtering algorithm, and then determine a navigation decision based on what the filtering algorithm finds. This navigation decision is then sent to the SPU for further processing.

For constraints, the IPU needs to be able to multi-thread in order to complete the filtering of the images in a reasonable amount of time. It also needs to consume less than 50-Watts, be capable of running Linux, and needs to weigh no more than 1 lbf.

Alternative Design Process

Initially, the SPU was chosen to handle images as well as other sensor data. We realized that if we had the SPU perform filtering for every sensor, it would not be completed in a reasonable amount of time. We made the choice to have a separate processor for the images only.

Testing

Testing is expected to start in the Spring, with tests including speed, power consumption, and reliability testing.

Risk Mitigation

Possible hardware risks associated with the IPU include failure to boot, failure to receive or transmit data, or failure to meet processing speed requirements. These can be mitigated by extensive testing of the IPU and connecting systems before even submerging, and an error / boot LED attached to the IPU itself. If it is simply not fast enough, it will be replaced.

Results

We chose the Intel Joule 570x as our IPU due to its capabilities in image processing (Figure 6S). It is capable of processing images very quickly, and does not consume a large amount of power.

The IPU has not gone through extensive testing. It has been tested for heat-up and power consumption both of which fall within the initial constraints.

Software

Sensor Processing Unit

Objectives and Constraints

The software objective of the SPU is to be able to take in raw sensor data, perform certain operations on the data, such as filtering and positional transformation, and then convert this processed data into a navigation decision which will then be sent to the MCU for further processing. This data will take the form of 26 pieces of data, with all IMU readings, two pressure transducer readings, and a movement decision from ODs.

To accomplish this, the software needs to be able to quickly receive data, process it, and output a navigation decision.

Alternative Design Processes

Initially, software languages considered for this objective included C, C++, Java, and Python. The sensors subteam concluded that Python would be used, as it is open source and is easy to learn.

Testing

Extensive software testing of the SPU has been done. Data from the IMU can been read in, filtered and split into individual components. Pressure sensor voltage readings are collected by the IPU although data handling has not been integrated into the SPU coding at this time.

Risk Mitigation

Software risks associated with the SPU are numerous. These include: failure to retrieve filtered images, inertial data, or pressure data, failure to correctly filter pressure or inertial data, failure to correctly identify the pressure read from the pressure transducers, failure to complete the processing in enough time, and failure to initialize code. To mitigate these possible failures, the SPU will be equipped with an error and boot indicator LEDs, be extensively tested before being submerged in the vehicle, and send out test data while being submerged during testing to correct any errors found.

Results

Programs have been developed to read in IMU data, and read pressure transducer voltages. Python is used for the majority of this, although C is used at some points for the pressure transducer readings. Full integration of the data into the vector form has not been achieved, nor has a program to read the camera movement decisions.

Image Processing Unit

Objectives and Constraints

The objective of the IPU software is to retrieve raw images from the cameras, filter the images to find the position of the tracking line at the bottom of the pool, identify objects, and decide which way to move based upon the position of the line and objects.

The constraints of the IPU software are that it needs to be fast and efficient in making a movement decision for the vehicle (300ms max per image) so that way we do not collide with obstacles.

Alternative Design Processes

Several programming languages were considered including C, C++, Java, and Python. With the sensors subteam use of Python for the SPU, Python was also chosen for the IPU. The only difference from the SPU software is that a plugin known as OpenCV is being used to aid in image processing.

Testing

Extensive software testing of the IPU has been completed on a desktop computer. Filtering algorithms have been run and tested to see how well the algorithms work and how quickly they work. Real-life pictures and video have been taken and algorithms are run on them.

The raw images, which had an orange line drawn in them indicative of the line to be followed in the competition, were initially passed through a blurring filter, a threshold filter to remove smaller shapes, an edge filter to find contours, and finally a probabilistic line transform to draw a new line which would then be used for movement decisions. This was found to not work very well on curved lines, which would cause the vehicle to veer off course in an actual test environment.

Next, a "skeleton" method was tested, in which the original line was filtered to form a skeleton, and then probabilistic line transform was performed on this skeleton. This did not work very well on curved lines. Using a different method, the original image was filtered in order to find the largest contour (the line which we want to follow and a ROI was drawn around the line. The ROI was then masked to the original image in order to black out anything that was not within the ROI. Finally, the masked image was filtered so that only the orange of the tape would be seen as red, while everything else was converted to black.

This ROI-masked method was then modified to include a midline on the filtered line, which would help to improve movement decisions. It works well on the simulated images.

Real-life video and still images were captured with the OD. The filtering scheme works well with still images, but video image processing needs threshold refinement for the various filters. There are frames in the live video feed where filtering is inadequate, resulting in the whole image still being present, or the whole image going black.

Objective tracking was implemented using Python with OpenCV libraries, and started on a single objective. The objective chosen was buoy navigation, where we need to bump into buoys in a sequential order based on color. To do this, an image is pulled from a live video feed, filters out the background, and grabs contours. The contours are then compared against the desired shape of a buoy, a circle, and output with their location and color. The buoys are then tracked through sequential images, and follows the buoys as they move through the image, regardless if they move out and then back into the frame.

The software has not yet been developed that will make a movement decision based on the position of the line and the position of objects. This is to be developed by future teams.

Risk Mitigation

Possible software risks with the IPU are similar to the SPU. These include failure to load images, failure to correctly filter images, failure to complete filtering in a timely manner, failure to output filtered images, and failure to initialize code. To mitigate these, the software will be extensively tested before being submerged, be equipped with a failure / boot LED, and have various checks throughout the code.

Results

The resulting software for the IPU is based in Python with programs that are capable of actively finding and identifying simulated buoys and identifying a tracking line to a usable degree. Future teams will need to develop movement decision programs, programs that send these movement decisions to the SPU, and more consistent filtering schemes.

Chapter 6 – Power and Propulsion Subteam

Hardware

Motor Processing Unit

Objectives and Constraints

The purpose of the motor processing unit is to coordinate and control the motor drivers, be those ESCs or custom inverters with sensing. There are no constraints on what kind of MPU can be used; constraints were imposed by the power and propulsion subteam. The MPU needs to communicate via I^2C, CAN, and SPI so any MCU chosen can receive a signal from the MPU. The MPU must also have a sufficiently high resolution to achieve fine motor control. The vehicle needs to be able to slow itself through active braking as well as the ability to reverse course direction in the case of objective overshoot or obstacle collision.

Alternative Design Processes

The separation of the MPU and the MD for this iteration of the project is for rapid prototyping. The separation of these two devices is not actually necessary because the MPU has dedicated PWM channels. Depending on the design, the number of PWM channels needed is number of motors multiplied by three since there are going to be three phases per motor. The MPU can then handle all of the switching that the MD does, thus removing the necessity of the MD. This does however, require the use of off board IGBT's or PFETs to handle the current and voltage.

Testing

The following are the tests that the MPU is going to be subject to: flash test, maximum power consumption, state, and mode. These tests are the core of what we need to know about the device from a system and component point of view. These tests satisfy the requirement of two-way communication, possible motor states, and whether or not the MPU can have a forward, braking, and reverse mode.

See Appendix H for more information. Also see Figure 4P and [14P] for reference.

Results

The MPU chosen is a real-time Texas Instruments TMS320F82069M Piccolo microcontroller (Figure 6P), programmed in Ti Code Composer Studio in embedded C. Initially, it was intended to program and use the Ti MPU to drive the ESC PWM channel. However, the complexity of the Ti controller proved to be fairly high. Instead, an Arduino Uno was used to generate the PWM signal and control the ESCs. Concurrently, the difficulties programming and using the Ti MPU have been resolved and future team will be able to implement the Ti controller in place of the Arduino.

Motors

Objectives and Constraints

The purpose of the motors is to translate electrical energy into a mechanical energy characterized by several electrical and mechanical constraints.

There are 6 degrees-of-freedom the vehicle is bound by: 3 kinematic linear axes and 3 kinematic rotations about each linear axis respectively. This means there must be at least 6 coordinated motors allowing for the dynamic positioning required by the mechanical team.

The weight of each motor cannot be significant due to the 125 lb. limitation of the competition rules: to keep a reasonable initial working basis, the propulsion team decided that motors, in total, should weigh no more than 6 lb. or roughly 1 lb. per motor.

Competition rules limit that maximum operating voltage to 48 VDC but the actual voltage for the motors (and thus battery system) are substantially reduced due to cost and commercial availability: 48 VDC systems are extremely expensive in both lithium battery technology and BLDC motors. Also, 48 VDC motors are built for larger loads and usually start around 25 lb. per motor. AC motors (AC in the driver sense) are not applicable due to large size and are generally far heavier than their DC counter parts. Lastly, 3-phase BLDC motors have become common place replacing the single and double pole brushed DC motors produced up till recently: 3-phase is cheaper and easier to find which allows the team to find motor replacements without major hardware/software rework years from now.

Torque is critical in moving the vehicle: with the vehicle slowing down (drag plus any dynamic braking), speeding up, and changing direction the motors must be able to respond to the varying load characteristics which are a function of the water viscosity, speed, and vehicle geometry. DC motors excel at torque intensive applications. Since torque is realized in amperage and given the 14.8 V limitation imposed by cost and weight, the power supply must be able to supply the motors with at least the maximum current draw plus some allowance for inrush.

Other constraints for motors come as a consequence of the utilization of naked motors for the prototype phase. Those constraints include waterproofing via either PVC or hard machinable wax, building of an in-house shroud of the motor propeller, integrated mounting system for the motor, and custom propeller design.

A LiPo based motor system weighing 1 lbf per motor running at 14.8 V (nominal) with a 60 A(RMS) draw and quiescent current of 1 A satisfies the size, cost, and torque constraints and while providing a cheap "learning" platform for the prototype phase. If successful, additional batteries and motors will be implemented on the final vehicle.

Alternative Design Processes

At the beginning of the Fall 2016-2017 evolution of the RoboSub vehicle, it was presumed that off-the-shelf motors would be purchased from Blue Robotics and used with little regard other than they are *designed* for the RoboSub competition. It was discovered during the research phase that it may be possible to reduce costs by approaching the problem from a more “hands-on” manner, with the caveat that more time and testing would be required to realize the propulsion stage.

Testing

Essential tests for motors are: load characterization, no load characterization, waterproofing, and heat-up testing. These four essential test inform us as to whether the naked motors can be used for not only the physical responses (torque) but the working limits (environment and heat). It also anticipated that these tests for a baseline for future teams to plan and develop upon.

Additional testing will be performed as a coordination test. This will show us latency and response of commands sent to the motors from both the ESC and MPU. It allows for tweaking of software delays and values in accordance with the physical variances of the motor, ESC, BMS, and power source.

See Appendix H for a more detailed explanation of specific tests to be conducted. Also see Figure 1P in Appendix F as well as [6P] for reference.

Results

Waterproofing of the motors with machine wax proved to be extremely successful, adding protection to stationary components of the motor. Moving parts, such as rotor steel bearings proved impossible with wax or urethane and exhibited rust only after a few uses; overall impact to motor performance is unapparent. Ideally, replacement those type of components with hard, high-wearing urethane bearings would prolong the motor life and prevent oxidation (rust) from entering the water testing environment. An added benefit of not machining a specific water proof housing is that motors can be run both in air and water with little heat up.

Initial calculations about the performance characteristics of the T-Motors (Figure 1P) chosen in the fall semester proved to be incorrect. This was due to falsely reported characteristics by both the manufacture of the motors as well as competitor’s motors. Testing revealed the best thrust that could be expected from T-Motor was 5 lbf. Replacement of the T-Motor out-runner motors with Turnigy out-runner motors have produced the desired results required by CFD: 10-12 lbf.

The larger Turnigy motors (Figure 2P), which use 60 A(RMS) rather than the 30 A(RMS) of the T-Motor, require more energy storage, generate more heat, and require larger (both in capacity and size) ESCs. Since the LiPo battery is already undersized for testing purposes, and the ESCs weight and size are not an issue, the only issue to lingering is the heat produced inside the EH, which is hoped to be tested and addressed by future teams.

Power Source

Objectives and Constraints

The purpose of the power source is to provide power at the appropriate input voltages and required amperages to all subsystems of the vehicle: motors, MPU, MCU, OP, SD, ESC, lighting, relays, and any other subsystems that may be added as a consequence of the prototype phase. Due to independence of the team and the variety of subsystems, voltages range from 3.3 V to 14.8 V and 1 mA to 360 A. In addition, the power system must not be mains powered per competition rules. This limits power supply to super capacitors or chemical batteries.

The two largest and dictating design constraints come from motors and the competition rules. Competition rules force an upper limit constraint of 48 VDC while the team constraints further limit that to 14.8 V (nominal), which comes out of the overall fact that higher voltage motors are heavier and more expensive. The motors constrain total instantaneous deliverable amperage: each motor impulse of 60 A for 6 motors gives an upper bound of around 360 A. While this is not realistic for a 20 minute run time, it at least provides some of the most extreme behavior that is expected out of the vehicle during testing.

These two constraints narrow the choices we have at our disposal: NiMH and NiCd--while cheap--cannot supply the burst current; bench-top power supplies cannot be used to power the vehicle underwater at 20 feet deep due to voltage drop. Therefore, only lithium-based batteries can be used: only lithium batteries allow us to keep battery weight low without limiting current response.

Alternative Design Processes

The initial design process involved using of a cheap battery in the prototype phase and a benchtop power supply during benchtop testing.

NiCd and NiMH require a parallel capacitor bank to allow for the high amperage demand used during the impulse of motors from off to full-on power. In addition, NiCd and NiMH have lower voltage levels. These two factors make a test battery composed of NiCd or NiMH just as costly as a mid-high range LiPo but almost 10x the weight: 6 NiCd/NiMH batteries would come in around 10 lb. which is almost 10 times the weight of the LiPo (1.2 lbf).

A benchtop power supply is extremely useful but finding of a higher amperage lower voltage benchtop power supply proved costly and could not allow modeling of system response (motor, controllers, etc.) under a falling voltage level. These two facts eliminate the usage for system characterizations. However, it is still maintained that given the monetary resources, a benchtop power supply could prove useful for programming and endurance testing of the motors.

Testing

Testing of the power supply is one of the easier schemes: by applying a varying load, the current and voltage can be measured over time to give the characteristic curves of the battery. These curves can be used to assess the expected system response and account for those responses in software if necessary. It also allows to design to specific battery behavior: no two batteries are exactly the same and tweaking of the ESC or BMS values (voltage and current) will be necessary.

Any destructive testing of the battery is prohibited, mainly due to cost. It is assumed that the IP68 rating and durability of the battery is in accordance with the manufacturers specifications. Also, due to the destructive nature of running LiPo cells under a 3.0 V level, the BMS must be used at all time with the LiPo cells to prevent permanent damage to the cells.

See Appendix H for a more detailed explanation of specific tests to be conducted. Also see Figure 2P in Appendix F and [21P] for reference.

Results

A 150C 14.8 VDC 8 Ah battery is used to power the ESC, IPU, fail-safe, and motors. It is intended that an additional 100C 4.2 VDC 7 Ah battery is necessary to power the MCU, MPU, IMU, SPU, run lights, and any other 5 V nominal systems future teams may need. Ideally, a DC-DC converter would be chosen by future iterations to eliminate the need for a multi-battery system.

It is estimated that the battery size is undersized by approximately half in achieving the desired runtime: by choosing a smaller LiPo 14.8 VDC (Figure 3P) battery initially, additions of 8 Ah LiPo packs can add any additional run time to the vehicle in a fiscally responsible manner: excessive runtime comes at both financial cost and additional weight to the vehicle.

Due to a generous donation, two additional LiPo batteries are available for testing. While these batteries are of a much lower capacity (2 Ah versus 8 Ah chosen by the team), they allow for additional testing time as well as reserving the larger capacity battery for more underwater testing.

Without a BMS, the charger BMS can be used for land testing to prevent damage to the battery, team, or environment. When the BMS becomes available, the 8 Ah LiPo can be fully utilized for underwater testing.

Battery Management System

Objectives and Constraints

The purpose of the battery management system is to monitor the behavior of the cells in the battery. The only constraint from the competition was that every vehicle must be powered by batteries. Any lithium based battery requires the use of a BMS, due to the thermal properties of lithium as an element. Lithium cells are more unstable and tend to get into runaway states so by using a LiPo power source, a BMS becomes necessary. The BMS needs to perform the following functions: cell balancing, cell monitoring, overvoltage protection, and enforce low voltage drop-out.

The BMS is not only used to protect the health of the batteries, but also for the safety of the team. Since lithium based batteries do have the potential to enter a runaway state, which can result in the battery catching fire or even exploding, the BMS is a method for preventing potential hazards to the team and environment.

Both the hardware and software is comprised of Texas Instruments products. We decided to use Ti products because they met the requirements of our system and allowed us to customize the design to best match those requirements. While it is true that BMS's in themselves can be bought, but due to the high current requirements for our system, we decided it would be more cost effective to design and build our own.

Alternative Design Processes

The choice of power supply dictates the necessity of having a battery management system. Non-lithium based power supplies such as NiMH and NiCd, do not require the use of a battery management system. However, neither NiMH or NiCd are suitable for both current and weight requirements of the vehicle.

Testing

The following is the test that the BMS is going to be subject to: communications test. The BMS needs to disconnect the power supply in the case there is a fault condition detected in the power supply, as wells as disconnect the power supply when a fault condition is detected in one of the other subsystems. Thus, the communication test verifies that the BMS can send and receive a signal.

See Appendix H for a more detailed explanation of specific tests to be conducted.

Results

The BMS is currently being assembled. Communications with the BMS have not yet been tested and the PCB for the BMS is presently under design. Most components put forth by Ti for the construction of the BMS have been acquired.

The purpose of the PCB is to efficiently arrange all electrical components in the space available. The original design of the PCB began in KiCad due to ease of use, short learning curve, and availability at CSU. However, it became cumbersome to create custom component layouts and AutoDesk Eagle has been chosen as a replacement for PCB design.

Motor Driver

Objectives and Constraints

The purpose of the motor driver is to translate PWM signals from the MPU via isolated gate driver stage which in turn drives an inverter stage of PFETs, in either a half-bridge or full-bridge configuration, modulated on a DC bus provided by the power source. Synchronization of the inverter stage is handle by the MPU based on phase and voltage back EMF from the BLDC motors.

To produce a prototype faster and prevent getting stuck in a quagmire of complex system design, the propulsion team has elected to use an ESC in replacement of a custom MD. What makes the prototype phase faster is the software: software is usually the most complex part of the MD along with the feedback hardware. Phase synchronization is now handled by the feedback and microcontroller hardware/software on the ESC. This eliminates the need for the team to figure out phase synchronization before any testing of the motor occurs. It also allows the team to reduce cost: ESCs are cheap and easily replaceable while custom MD are much more expensive due to lack of production quantity effects.

To match the motor characteristics, the ESC must be able to handle 60 A(RMS) continuous per phase (3 phases on the BLDC) at 14.8 VDC nominal. Apart from this, the ESC must be able to split the PWM range in half to allow forward and reverse operation.

Alternative Design Processes

The original intent of the propulsion team was to purchase a highly capable MD from a reputable vendor. However, it became evident very quick that the cost of handling 360 A(RMS) at 14.8 VDC (nominal) was a very difficult task: most drivers designed as embedded systems (MPU plus MD) didn't meet the current requirements and those that did were not designed with usage of 3 phase BLDC motors in mind. This quickly lead us to consider splitting a unified MD into several MD. This in turn raised the complexity of building an MD: we realized the development of a custom MD at this stage was too complex to be accomplished in the timetable developed.

Testing

There are several simple low-level tests that must be done initially with the ESC: the MPU must be connected and configured to verify if the ESC can be communicated with and that the ESC is receiving the proper PWM signals to translate into a motor actuation.

The ESC must be reprogrammed or "re-flashed" in order to capitalize on the split-band forward/reverse functionality necessary for motor control. To keep cooling of the EH effective, the amount of heat produced by the inverter stage under varying power loads must be measured. Lastly, coordination testing must be done from the MPU to at least two ESCs. This will inform the prototype phase about how multiple motors can be coordinated from the MPU and what hardware, if any, may be necessary.

See Appendix H for a more detailed explanation of specific tests to be conducted. Also see Figure 4P and 5P in Appendix F and [11P] for reference.

Results

The ESC has passed the communications and PWM signals test. Present resolution is for the BlueSeries 60 A ESC (Figure 5P) is 910 to 2000 μsec PWM although the Turnigy motors will only respond to 1100 to 2000 μsec due to winding quiescent current. While this limits resolution, it provides a sound basis for testing the vehicle under a variety of control algorithms.

With modification and complete rebuild of ESC firmware (SimonK), forward, reverse, braking, and calibration were enabled. With more time, other software modifications like brake timing and phase latency can be explored. Almost all Blue Robotics software has been abandoned both by competitions teams as well as Blue Robotics itself at the time of this writing.

Coordination testing is currently underway via a PlayStation 2 analog control stick (Figure 9P and 10P) scheme ran via an Arduino Uno. Refinements in analog control, such as variable throttle mapping, needs to be explored since linear throttle control is not suitable for all tasks required by the competition.

Propellers and Shroud

Objectives and Constraints

The purpose of the propellers and shrouds are to translate and focus the mechanical energy from motor torque into thrust.

Since the team chose the route of custom motors, it was necessary to build a shroud and propeller to complete the thruster design. The only constraint placed on the design of the propellers and shrouds by the competition is that the shrouds must surround the prop and have at least 2” (5.1cm) distance between the spinning disk of evolution created by the propeller and the edges of the shroud (front and back).

Alternative Design Processes

To rapid prototype different designs of propellers and shrouds, a 3D printer was used for fabrication. This allows for test and validation of the thrust characteristics of different combinations of shroud and propeller.

Testing

The formal consideration of propellers and shrouds is not included in the FMEA or DTVC from the Fall 2017. However, considerations include thrust capability and rigidity of materials.

The main design consideration for the shroud was the volume of water that the propeller was exposed to both in forward and reverse operation. Forward operation is not a problem because the motor is mounted close to the front of the shroud, but reverse operation suffers due to the necessary extension of the shroud via competition rules mentioned above. To remedy this problem, a honey comb design is implemented to allow the reverse mode and forward modes to exhibit similar thrust characteristics.

For propellers, a main design consideration is maximization of surface area of the propeller to provide maximum thrust while maintaining symmetric forward and reverse thrust characteristics.

Results

The first attempt of the thruster assembly with the T200 motors, solid body shroud, 2.5 in propeller yielded a net thrust of 5 lbf per motor, which was not within the mechanical CFD calculations. The second attempt, with the larger Turnigy motors, the honeycomb shroud, and 4.75 in (Figure 7P and 8P) propeller yields approximately 12 lbf of thrust which was sufficient to overcome the largest static force on the vehicle. With this established, it is necessary to cast the 3D printed parts in a more durable and rigid material.

Software

Motor Processing Unit

Objectives and Constraints

The objective of the software for the MPU is to allow us to quickly accommodate for different types of motors as well as tune the response of the motor control. The software on the MCU must have a simplified HMI as well since this project is on a short time table. Although we are not going to be utilizing the FOC ability of the MPU for this iteration of the project, it makes integrating the MPU and MD stages of the project together much easier for future teams.

Alternative Design Processes

The only alternative to using some pre-built software would be going in and writing it all yourself. As we are on a very restricted timetable, this approach was not adopted for this iteration of the project.

Testing

The most important functions of the MPU are that it boots and that it can be written to.

See Appendix H for a more detailed explanation of tests to be performed.

Results

The MPU chosen is a real-time Texas Instruments TMS320F82069M Piccolo microcontroller, programmed in Ti Code Composer Studio in embedded C. Initially, it was intended to program and use the Ti MPU to drive the ESC PWM channel. However, the complexity of the Ti controller proved to be high. Instead, an Arduino Uno was used to generate the PWM signal and control the ESCs. Concurrently, the difficulties programming and using the Ti MPU have been resolved and future team will be able to implement the Ti controller in place of the Arduino.

Battery Management System

Objectives and Constraints

The objective of the software for the BMS is to allow us to quickly accommodate for different types of batteries and number of cells. The software on the BMS must have a simplified HMI because the BMS has to be rapidly implementable in order for testing to proceed for the vehicle. This feature also ensures that the team is as safe as possible while testing the battery.

Alternative Design Processes

Similar to the MPU, the only alternative to using a prebuilt software package is to write your own software.

Testing

The tests that will inform us of our requirements are: boot test and flash test. The boot test will tell us that the device is functional and the flash test will tell us that the BMS is programmable.

See Appendix H for a more detailed explanation of tests to be performed.

Results

The BMS consists of two main components: an analog front end built by Ti and a microcontroller backend also built by Ti. The software to communicate and program the backend microcontroller is Ti's native battery management software BQStudio. At the present time, it is understood how to communicate with the BMS. However, due to time limitations, actual communication with the BMS has not been established.

Chapter 7 – Future Work

Due to setbacks in funding and agreement among the team regarding personal spending, the entire team has experienced a delay in the prototype testing and manufacture time scope. However, the team estimated such setbacks as this and accounted for a 3 month run-over time. This simply means: the entire team experiences a shift of the prototype testing and manufacture by one month; to be completed by February 1st rather than January 1st.

Each subteam, and the entire team, will outline and determine their own agenda for the 2017-2018 academic year. It is hoped that the continuing teams will build on the work and experience of Team Killick in order to produce a high quality, efficient, and competition ready vehicle by the summer of 2018.

Mechanical

Future mechanical sub-teams have several items that need to be addressed in order to become competition ready. The big items that need to be implemented into the vessel are: fine buoyancy control, torpedoes, reducing the size of the electrical housing (for decreased upwards buoyant forces), custom chassis, and a mechanical armature.

Things that we did not get to but are in need of improvement include: marine grade bolts for chassis, installing a bleed valve to the failsafe & electrical housing, creating a fixture for correcting center of gravity, and cutting down excess pieces of the PVC adapter. These improvements will make the current vessel better.

Sensors

For the future work of the Vision and Sensors subteam, they will need to do numerous thing to fully automate the vehicle. For the IMU, they will need to develop better filtering schemes. For the Pressure Transducers, they will need to convert the voltage readings into an actual pressure reading. For Vision, they will need to develop programs for the competition objectives, improve the line detection algorithm, and develop movement decisions. Finally, they will need to combine all the sensor data into one readable vector for use by the power and propulsion subteam.

Propulsion and Power

From the standpoint of the power and propulsion subteam, this delay has not been a waste: it has afforded the team to verify their calculations which has caught two errors in ordering so far.

It is hoped that the future teams will build upon the Killick team work developed in 2016-2017 academic year, expanding in the key areas:

- PCB for BMS
- Integration of the BMS into power systems
- System integration of MCU to MPU
- Custom MD and integration with MPU
- Algorithm implementation and refinement for MCU
- PCB for power systems integration
- Design and testing of dummy torpedo system
- Design and test of armature for object handling
- Design and test of sonar array and tracking

References

[1M] "Parker O-Ring Handbook," in parker.com/orings, 2007. [Online]. Available: https://www.parker.com/literature/ORD/205700/20Parker_O-Ring_Handbook.pdf. Accessed: Dec. 6, 2016

[2M] J. Heiszwolf, "Submarine technology," 1999. [Online]. Available: http://www.heiszwolf.com/subs/tech/tech01.html. Accessed: Dec. 7, 2016.

[1S] A. Rosebrock, "Be awesome at learning OpenCV, python, and computer vision," PyImageSearch, 2016. [Online]. Available: http://www.pyimagesearch.com/. Accessed: Dec. 7, 2016.

[2S] "OpenCV documentation index,". [Online]. Available: http://docs.opencv.org/. Accessed: Dec. 7, 2016.

[3S] "Stack overflow," 2016. [Online]. Available: http://stackoverflow.com/. Accessed: Dec. 7, 2016.

[4S] A. V. T. GmbHImprint and Legal, "Digital industrial camera solutions," 2016. [Online]. Available: https://www.alliedvision.com/en/digital-industrial-camera-solutions.html. Accessed: Dec. 7, 2016.

[1P] AUVSIFoundation.org. 2016, 2, 12. *RoboSub Competition Official Rules and Mission* (2015). Available: http://higherlogicdownload.s3.amazonaws.com/AUVSI/fb9a8da0-2ac8-42d1a11ed58c1e158347/UploadedFiles/RoboSub/20Competition/20Official/20Rules/20and/20Missi on/20-/202015.pdf

[2P] Jared Carter (EE), Sam Johnson (EE), Will Nordahl (EE), Will Winward (EE), Arrol Bryant (ME), Austin Root (ME), Jocelyn Thompson (ME), Mathias Fochs (MET), Jacob Jenks (CS), Nathan Robertus (CS). *Montana State University Autonomous Underwater Vehicle: Development and Testing of the AUV "Blue November"*. Available: http://higherlogicdownload.s3.amazonaws.com/AUVSI/fb9a8da0-2ac8-42d1-a11ed58c1e158347/UploadedImages/2015/20RoboSub/20/Journal/20Papers/MontanaState_Journ al_RS2015.pdf

[3P] AUVSIFoundation.org. 2016, 2, 12. *18th Annual International RoboSub Competition* (2015). Available: http://www.auvsifoundation.org/competitions/competition-central/robosub/pastrobosub-competitions/2015-robosub

[4P] Justin Koch, Kushal Agarwal, Solomon Chang, Erin Evans, David Flicker, Edward Fouad, Jake Larson, Torkom Pailevanian, Sarah Asano, Brian He, Juliana Kew, Monica Li, Tristan Murphy, Tyler Okamoto, Jeffrey Orenstein, Frank Zhou, Roman Zograbian. 2015, 6, 19. *Design and Implementation of an Integrated, Performant Autonomous Underwater Vehicle*. Available: http://higherlogicdownload.s3.amazonaws.com/AUVSI/fb9a8da0-2ac8-42d1-a11ed58c1e158347/UploadedImages/2015/20RoboSub/20/Journal/20Papers/Caltech_Journal_Pap er_RS2015.pdf

[5P] Pierson Connors, Kyle Harlow, Sean Harrison, Kimi Bourland, Andrew Wydle, Josh Bowen, Kassi Butler, Rod Jafari, Alexander Silverman, Michelle Athay, Daaym Sial, Sam Forgy, Neal Kornreich, Ryan Niedzinski, Matt Salzer, Camella Nasr, Dylan Bossie. *University of Colorado Boulder RoboSub Team: WaterBuffalo II*. Available: http://higherlogicdownload.s3.amazonaws.com/AUVSI/fb9a8da0-2ac8-42d1-a11ed58c1e158347/UploadedImages/2015/20RoboSub/20/Journal/20Papers/Caltech_Journal_Pap er_RS2015.pdf

[6P] Robot Shop. (2016, December 6). *TMotor UAV Brushless Motor MS2814 770Kv* [Online]. Available: http://www.robotshop.com/en/tmotor-uav-brushless-motor-ms2814-770kv.html#Specifications

[7P] Blue Robotics. (2016, December 6). *T200 Thruster* [Online]. Available: https://www.bluerobotics.com/store/thrusters/t200-thruster/

[8P] Blue Robotics. (2016, December 6). *T200 Thruster Specifications* [Online]. Available: http://docs.bluerobotics.com/thrusters/t200/#t100-thruster-specifications

[9P] Blue Robotics. (2016, December 6). *30 A ESC w/ Forward & Reverse* [Online]. Available: https://www.bluerobotics.com/store/thrusters/besc-30-r1/

[10P] Git Hub. (2016, December 6). *blue robotics\tgy* [Online]. Available: https://github.com/bluerobotics/tgy/

[11P] HobbyKing. (2016, December 6). *HobbyKing 40A BlueSeries Brushless Speed Controller* [Online]. Available: https://www.hobbyking.com/en_us/hobbyking-40a-blueseries-brushless-speed-controller.html

[12P] Texas Instruments. (2016, December 6). *The TMS320F2837xD Architecture: Achieving a New Level of High Performance* [Online]. Available: http://www.ti.com/lit/pdf/sprt720

[13P] Texas Instruments. (2016, December 6). *TMS320F2837xS Delfino Microcontrollers Technical Reference Manual (Rev. C)*. [Online]. Available: http://www.ti.com/lit/pdf/spruhx5

[14P] Texas Instruments. (2016, December 6). *LAUNCHXL-F28377S Overview User's Guide (Rev. A)*. [Online]. Available: http://www.ti.com/lit/pdf/sprui25

[15P] Texas Instruments. (2016, December 6). *TMS320F28377S LaunchPad Quick Start Guide*. [Online]. Available: http://www.ti.com/lit/pdf/sprui26

[16P] Texas Instruments. (2016, December 6). *3 to 5-Series Cell Li-Ion and Li-Phosphate Battery Monitor (bq76940 Family)*. [Online]. Available: http://www.ti.com/product/BQ76920

[17P] Texas Instruments. (2016, December 6). bq769x0 3-Series to 15-Series Cell Battery Monitor Family for Li-Ion and Phosphate Applications (Rev. G). [Online]. Available: http://www.ti.com/lit/gpn/bq76920

[18P] Beaver Lake Boaters. (2016, December 6*). Do Your Props Have the Right Cup, Rake, Slip, Pitch and Hub?* [Online]. Available: http://www.beaverlakeboaters.net/boating/doyourpropshavetherightcuprakeslippitchandhub/

[19P] Allen Bradley. (2016, December 6*). AC Drives Using PWM Techniques.* [Online]. Available: https://www.ab.com/support/abdrives/documentation/techpapers/PWMDrives01.pdf

[20P] MPS. (2016, December 6*). Brushless DC Motor Fundamentals Application Note*. [Online]. Available: https://www.monolithicpower.com/Portals/0/Documents/Products/Documents/appnotes/Brushless/20DC/20Motor/20Fundamentals.pdf

[21P] MaxxAmps. (2016, December 6). *LiPo 8000 4S 14.8v Dual Core Battery Pack*. [Online]. Available: https://www.maxamps.com/LiPo-8000-4s-14-8v-dual-core-battery-pack

[22P] "Johnson Matthey battery systems-battery management system," in *Johnson Matthey Battery Systems*, 2014. (2016, December 6). [Online]. Available: http://www.jmbatterysystems.com/technology/battery-management-systems-(bms)

Appendix A – Abbreviations

A

A	Amperes
ABS	Acrylonitrile Butadiene Styrene
A/D	Analog to Digital
Ah	Amp-hour
AUV	Autonomous Underwater Vehicle

B

BMS	Battery Management System
BLDC	Brushless Direct Current Motor

C

CAD	Computer Aided Drafting
CAN	Controller Area Network Bus
CE	Computer Engineer
CES	Ashby Chart
CFD	Computational Fluid Dynamics
CO2	Carbon Dioxide

D

DMM	Digital Multimeter
DOF	Degrees of Freedom
DS	Delta-Sigma Modulation
DTVC	Device Test Validation Characterization

E

EE	Electrical Engineer
EFD	Electronic Failure Device
EH	Electrical Housing
ESC	Electronic Speed Control

F

FET	Field-Effect Transistor
FMEA	Failure Mode Effect Analysis

G

GPIO	General-Purpose Input/Output

H

HFD	Human Failure Device
HMI	Human Machine Interface

I

I^2C	Inter-integrated Circuit bus
IGBT	Insulated-Gate Bipolar Transistor
IMU	Inertial Measurement Unit
IPU	Image Processing Unit
I/O	Input-Output

L

lbf	Pound-Force
LED	Light Emitting Diode
LiPo	Lithium Polymer or Lithium Ion battery

M

mA	milliamp
MCU	Master Control Unit
MD	Motor Driver
ME	Mechanical Engineer
MPU	Motor Processing Unit
m/s	Meters per Second
ms	milliseconds
mV	millivolt

N

NiMH	Nickel Metal Hydride
NiCd	Nickel-Cadmium

O

OS	Operating System
OD	Optical Device

P

PFET	Power Field-Effect Transistor
PI	Performance Index
PLA	Polylactic Acid
PVC	Polyvinyl Chloride
PWM	Pulse Width Modulation

R

RMS	Root Mean Square

S

SD	Sensor Devices
sec	Seconds
SPI	Serial Peripheral Interface Bus
SPU	Sensor Processing Unit

U
UART Universal Asynchronous Receive/Transmit Bus

R
ROI Region of Interest

W
W Watts

Appendix B – Budget

Estimated Budget At-A-Glance:

Item	*Cost*
Motors	$1800
Motor Control / MicroControl	$1000
Power Supply	$800
Sensors	$2500
MISC	$1000
Final Vehicle Chassis	$1500
Prototype Vehicle Chassis	$800
Mechanical Blunders	$1000
Electrical Blunders	$1300
Total	$11,700

Figure 8 – Budget

Budget Breakdown:

-Motors

The dollar allotment for the motors will be utilized in the purchase of 6 Brushless DC motors.

Motors	$ 1800

-Motor Control

Two motor controllers with 2-3 channels per controller coordinated by one Master RMCU.

Primary RMCU	$ 400
Motor Microcontrollers	$ 600

-Power Supply

Power supply consists of two batteries: one battery powering controls and the second powering motors.

Battery Power Supply	$ 700
Controller Power Supply	$ 100

-Sensors/Optics

The IMU is used for navigation in conjunction with cameras. The HS is used for beacon location, and possible navigation.

Inertial Measurement Unit	$ 1200
Hydrophone System (HS)	$ 800
Signal Amplifiers	$ 100
Underwater Cameras	$ 400

-Miscellaneous

All of the connectors will be insulated and water tight.

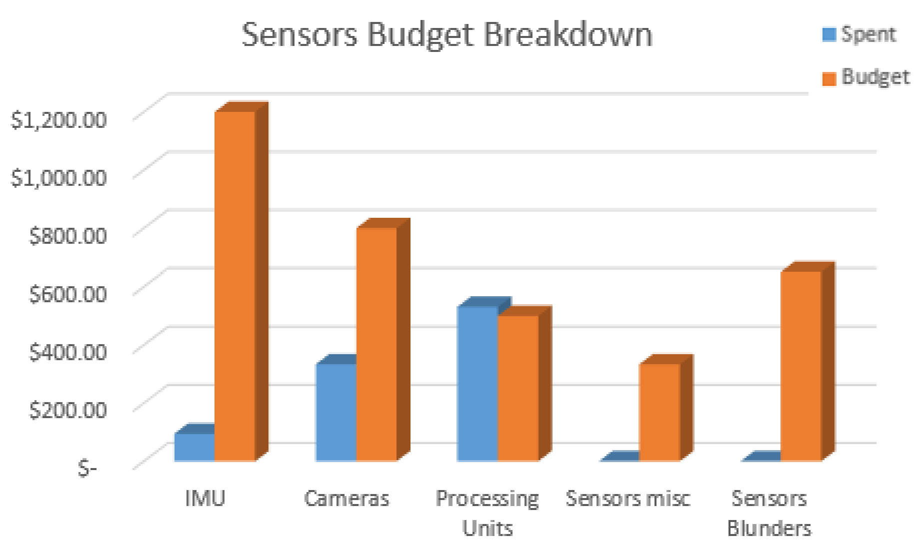
Connectors	$ 500
Gaskets	$ 70
Wires	$ 200
Mechanical Tether	$ 30
Electrical Tether	$ 200

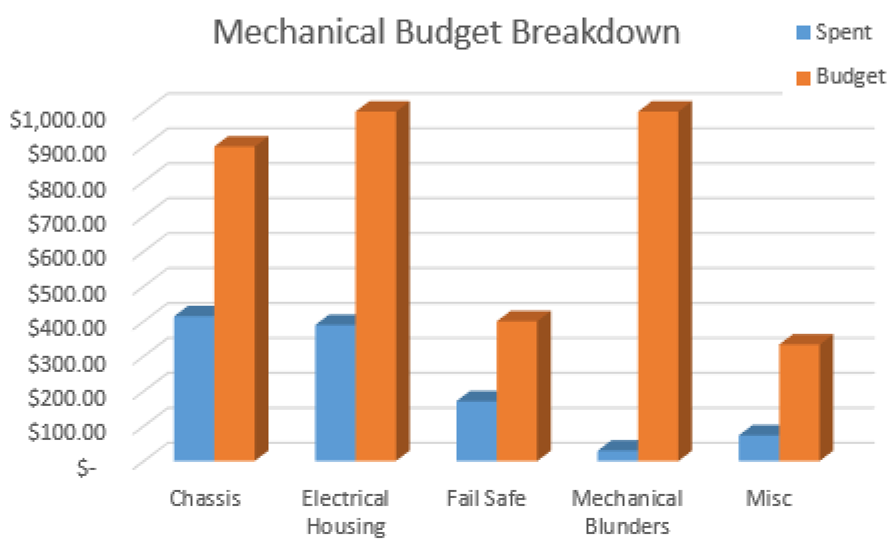
-Prototype Test Vehicle

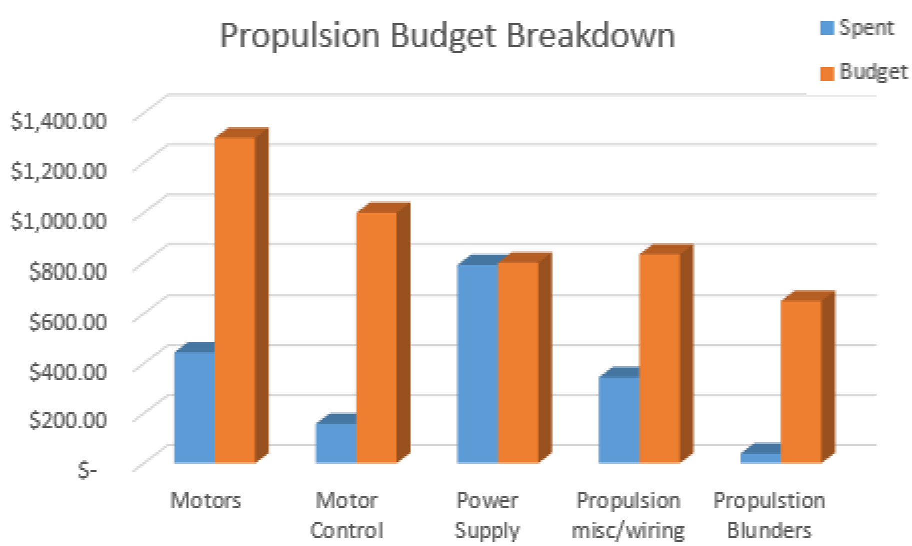
These are the materials for a preliminary test vehicle.

Clear Acrylic Body	$ 600
Sealants	$ 50
Hardware	$ 150
Battery	$ 250
Motors	$ 1200
Inertial Measurement Unit	$ 1200
Underwater Cameras	$ 400
Primary RMCU	$ 400
Motor Microcontrollers	$ 300
Connectors	$ 500
Gaskets	$ 70
Wires	$ 200
Mechanical Tether	$ 30
Electrical Tether	$ 200
Total	$ 5550

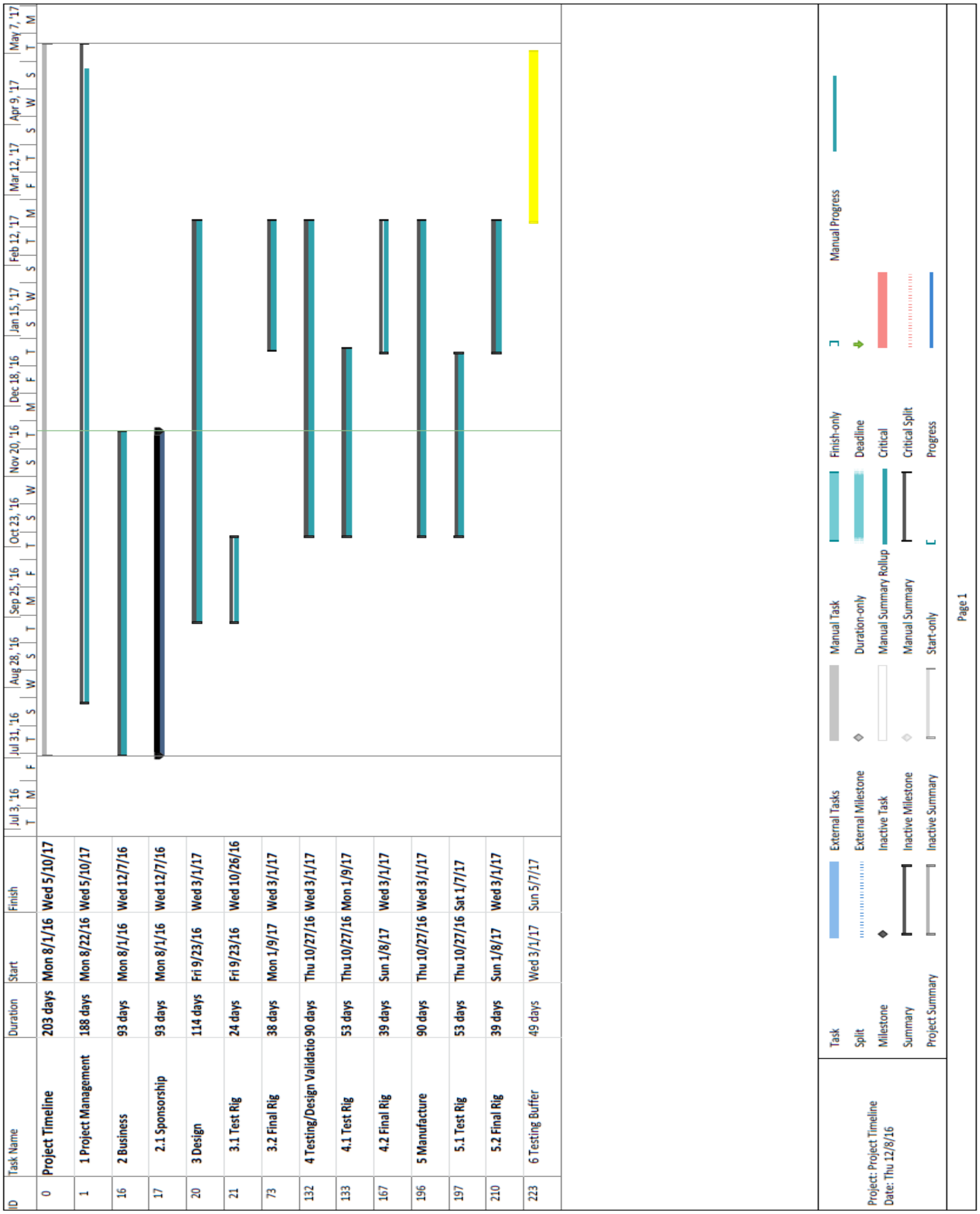
-Mechanical Reserve	
Loss in Materials	
Mechanical Mismatch	$ 100
Poor Manufacturing	$ 700
Leaks (Outer Hull)	
Replace seals	$ 200
-Electrical Reserve	
Motor burn out	$ 600
Battery Damage/Failure	$ 700



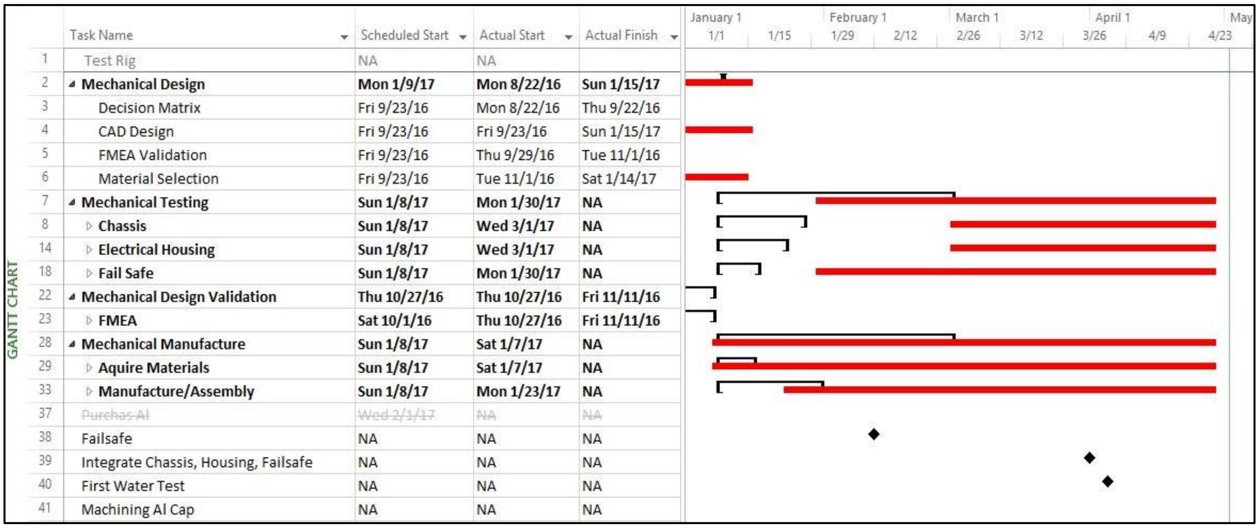

Mechanical Budget Breakdown
Spent
Budget
$1,000.00
$900.00
$800.00
$700.00
$600.00
$500.00
$400.00
$300.00
$200.00
$100.00
$-
Chassis
Electrical Housing
Fail Safe
Mechanical Blunders
Misc


Propulsion Budget Breakdown
Spent
Budget
$1,400.00
$1,200.00
$1,000.00
$800.00
$600.00
$400.00
$200.00
$-
Motors
Motor Control
Power Supply
Propulsion misc/wiring
Propulstion Blunders

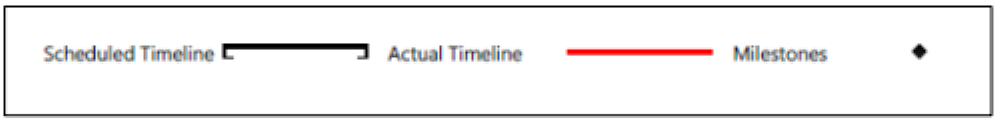
Appendix C – Project Plan Evolution



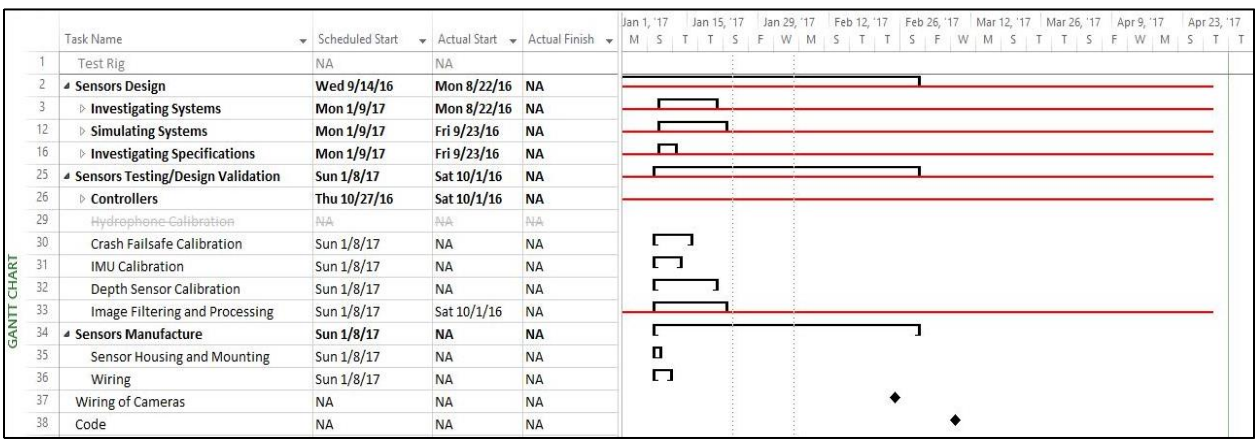
Mechanical Subteam Timeline as of 5/30/17



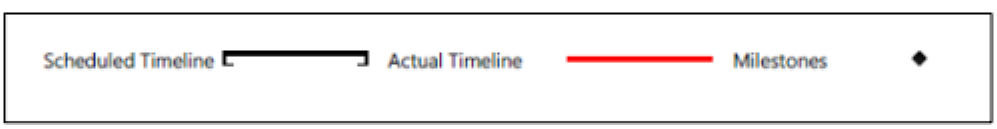
	Task Name	Scheduled Start	Actual Start	Actual Finish
1	Test Rig	NA	NA	
2	Mechanical Design	Mon 1/9/17	Mon 8/22/16	Sun 1/15/17
3	Decision Matrix	Fri 9/23/16	Mon 8/22/16	Thu 9/22/16
4	CAD Design	Fri 9/23/16	Fri 9/23/16	Sun 1/15/17
5	FMEA Validation	Fri 9/23/16	Thu 9/29/16	Tue 11/1/16
6	Material Selection	Fri 9/23/16	Tue 11/1/16	Sat 1/14/17
7	Mechanical Testing	Sun 1/8/17	Mon 1/30/17	NA
8	Chassis	Sun 1/8/17	Wed 3/1/17	NA
14	Electrical Housing	Sun 1/8/17	Wed 3/1/17	NA
18	Fail Safe	Sun 1/8/17	Mon 1/30/17	NA
22	Mechanical Design Validation	Thu 10/27/16	Thu 10/27/16	Fri 11/11/16
23	FMEA	Sat 10/1/16	Thu 10/27/16	Fri 11/11/16
28	Mechanical Manufacture	Sun 1/8/17	Sat 1/7/17	NA
29	Aquire Materials	Sun 1/8/17	Sat 1/7/17	NA
33	Manufacture/Assembly	Sun 1/8/17	Mon 1/23/17	NA
37	~~Purchas Al~~	~~Wed 2/1/17~~	~~NA~~	~~NA~~
38	Failsafe	NA	NA	NA
39	Integrate Chassis, Housing, Failsafe	NA	NA	NA
40	First Water Test	NA	NA	NA
41	Machining Al Cap	NA	NA	NA



Vision and Sensors Subteam Timeline as of 5/30/17



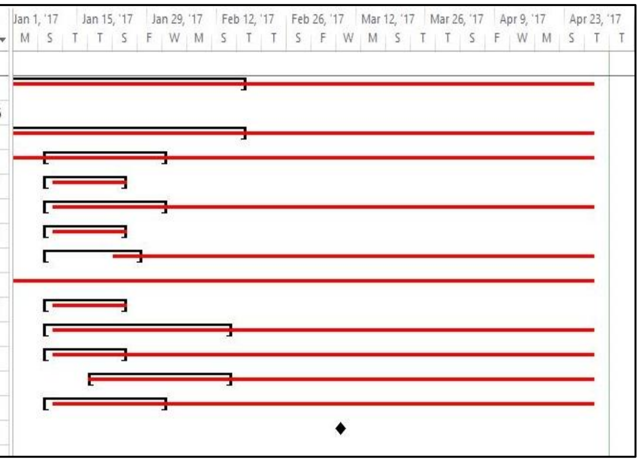
	Task Name	Scheduled Start	Actual Start	Actual Finish
1	Test Rig	NA	NA	
2	Sensors Design	Wed 9/14/16	Mon 8/22/16	NA
3	Investigating Systems	Mon 1/9/17	Mon 8/22/16	NA
12	Simulating Systems	Mon 1/9/17	Fri 9/23/16	NA
16	Investigating Specifications	Mon 1/9/17	Fri 9/23/16	NA
25	Sensors Testing/Design Validation	Sun 1/8/17	Sat 10/1/16	NA
26	Controllers	Thu 10/27/16	Sat 10/1/16	NA
29	~~Hydrophone Calibration~~	~~NA~~	~~NA~~	~~NA~~
30	Crash Failsafe Calibration	Sun 1/8/17	NA	NA
31	IMU Calibration	Sun 1/8/17	NA	NA
32	Depth Sensor Calibration	Sun 1/8/17	NA	NA
33	Image Filtering and Processing	Sun 1/8/17	Sat 10/1/16	NA
34	Sensors Manufacture	Sun 1/8/17	NA	NA
35	Sensor Housing and Mounting	Sun 1/8/17	NA	NA
36	Wiring	Sun 1/8/17	NA	NA
37	Wiring of Cameras	NA	NA	NA
38	Code	NA	NA	NA



Power and Propulsion Subteam Timeline as of 5/30/17

DETAIL GANTT

	Name	Scheduled Start	Actual Start	Actual Finish
1	Test Rig	NA	NA	
2	**Propulsion Design**	**Wed 9/14/16**	**Thu 9/15/16**	**NA**
3	**Investigating Systems**	**Thu 9/15/16**	**Thu 9/15/16**	**Mon 9/26/16**
11	**Investigating Specifications**	**Fri 9/23/16**	**Thu 9/15/16**	**NA**
20	**Propulsion Testing/Design Validation**	Sun 1/8/17	**Thu 10/27/16**	**NA**
21	Motors (M)	**Sun 1/8/17**	Tue 1/10/17	Tue 1/24/17
22	Motor Processor Unit (MPU)	Sun 1/8/17	Tue 1/10/17	NA
23	Electronic Speed Control (ESC)	Sun 1/8/17	Tue 1/10/17	Tue 1/24/17
24	Battery Management System (BMS)	Sun 1/8/17	Sun 1/22/17	NA
25	**Microcontroller (MCU)**	Sun 1/8/17	**Thu 10/27/16**	**NA**
27	Power Source (PS)	Sun 1/8/17	Tue 1/10/17	Tue 1/24/17
28	**Propulsion Manufacture**	**Sun 1/8/17**	**Tue 1/10/17**	**NA**
29	Power Systems	Sun 1/8/17	Tue 1/10/17	NA
30	Propulsion Controls and Feedback	Tue 1/17/17	Tue 1/17/17	NA
31	Propulsion Drive	Sun 1/8/17	Tue 1/10/17	NA
32	BMS	NA	NA	NA



Minimum Required Tasks to Complete Fall 2017 *(Highlighted Yellow)*

Mechanical Design
Decision Matrix
CAD Design
FMEA Validation
Material Selection
Mechanical Testing
Chassis
Impact Test
Fatigue Test
Corrosion Test
Clamp Impact Test
Loading test dry land
Electrical Housing
Water Proof Timed test
Water Proof depth/deflection test
Heat Dissipation Test
Fail Safe
Valve Actuation test
Mass release test
Full Assemply Test
Mechanical Design Validation
Mechanical Manufacture
Aquire Materials
Electrical Housing
Fail Safe
Chassis
Manufacture/Assembly
Chassis
Electrical Housing
Fail Safe

Mechanical Subteam

Sensors Design
Investigating Systems
Crash Failsafes
Controllers
Rasberry Pi
Image Controller
Inertial Measurement Unit (IMU)
Master Control Unite (MCU)
Cameras
Simulating Systems
Cameras
Inertial Measurement Unit (IMU)
Investigating Specifications
Crash Failsafes
Controllers
Rasberry Pi
Image Controller
Inertial Measurement Unit (IMU)
Cameras
Sensors Testing/Design Validation
Controllers
Movement Decisions
Data Collection and Processing
Crash Failsafe Calibration
Depth Sensor Calibration
Image Filtering and Processing
Sensors Manufacture
Sensor Housing and Mounting
Wiring

Vision and Sensors Subteam

Propulsion Design
Investigating Systems
Motors
MPU
Motor Driver
BMS (Battery Management System)
MCU (Main Control Unit)
PID Control
Power Source (PS)
Connectors
Propulsion Testing/Design Validation
Motors (M)
Motor Processor Unit (MPU)
Electronic Speed Control (ESC)
Battery Management System (BMS)
Microcontroller (MCU)
PID Control
Power Source (PS)
Propulsion Manufacture
BMS
Power Systems
Propulsion Controls and Feedback
Propulsion Drive

Power and Propulsion Subteam

Appendix D – Failure Mode and Effects Analysis

Electrical Housing									Formula = (Rank/40)*R.O.O.* D		
Function	Performance Standards	Functional Failures	Failure Modes	Failure Effects	Consequence Category	Rank (Total out of 40)	Rate of Occurrence	Detectibility	Risk Ranking(0.1 = Lowest; 100 = Highest)	Normalized Rank (1= high, 0 = low)	Mitigation
Protection to electrical components	Dry environment	Water inside housing	Seal leaks	Electronics Damaged	Non functional Vehicle, electrical components unusable, seals	1 (E), 1(S), 9(O), 8(NO)	1	1	0.475	0.18627451	Design with multiple seals , water sensor initializes to cut power
			Housing fractures	Electronics Damaged	Non functional Vehicle, electrical components unusable, housing unusable	1(E), 1(S), 9(O), 8(NO)	1	1	0.475	0.18627451	Place moisture absorbant material inside, water sensor initializes to cut power
			Condensation	Electronics Damaged	Non functional Vehicle, electrical components unusable	1 (E), 1(S), 8(O), 7(NO)	3	2	2.55	1	Design housing to withstand 2X safety factor of max stress / Upon failure, humidity sensor initializes to cut power
	Heat dispation	Excess temperature	Electrical components fail	Vehicle does not function	Non functional Vehicle, electrical components unusable	1 (E), 1(S), 6(O), 5(NO)	3	2	1.95	0.764705882	Use proper heat dissipation with heat syncs and convection / Upon reaching elevated temperatures, heat sensor cuts power.
			Seals Melt	Shorts electronics	Non functional Vehicle, electrical components unusable, seals unusable	1 (E), 1(S), 9(O), 8(NO)	1	1	0.475	0.18627451	Use materials that exceed 2X safety temperature operation / Upon reaching elevated temperatures, heat sensor cuts power.
			Housing Fractures	Vehicle does not function	Non functional Vehicle, electrical components unusable, housing unusable	1(E), 1(S), 9(O), 8(NO)	1	1	0.475	0.18627451	Use materials that exceed 2X safety temperature operation / Upon reaching elevated temperatures, heat sensor cuts power.
	Isolation	Temperature threshold exceeded	Fire within vessel	Vehicle does not function	Non functional Vehicle, vessel unusable	5(E), 3(S), 9(O), 8(NO)	1	1	0.625	0.245098039	Design thermally isolated compartments / Upon reaching elevated temperatures, heat sensor cuts power.
		Damage to Components	Electrical components fail	Shorts electronics	Non functional Vehicle, electrical components unusable	1(E), 1(S), 7(O), 6(NO)	2	2	1.5	0.588235294	Design insulated compartments / Constant checks of electrical systems, any failure cut power

Ballast									Formula = (Rank/40)*R.O.O.* D		
Function	Performance Standards	Functional Failures	Failure Modes	Failure Effects	Consequence Category	Rank (Total out of 40)	Rate of Occurrence	Detectibility	Risk Ranking(0.1 = Lowest; 100 = Highest)	Normalized Rank (1= high, 0 = low)	Mitigation
Safely bring vessel to surface upon failure	Positive buoyancy upon electrical failure	Bag Does Not Inflate	Bag Tears	Sub does not surface	Bag unusable, water enters housing, electrical components damaged	1(E), 1(S), 10(O), 7(NO)	1	1	0.475	0.18627451	Choose bag material that withstand full CO2 ejection
			Bag Seal Breaks	Sub does not surface	Seal unusable, water enters housing, electrical components damaged	1(E), 1(S), 10(O), 7(NO)	1	1	0.475	0.18627451	Seals must withstant max pressure
			Obstuction of bag	Sub does not surface	Adjustment of bag needed	1(E), 1(S), 5(O), 1(NO)	3	2	1.2	0.470588235	Design must not have objects near bag
		C02 does not Eject	C02 Leaked	Sub does not surface	Co2 Cartridge unusable	1(E), 1(S), 7(O), 1(NO)	1	1	0.25	0.098039216	CO2 connector must withstand CO2 pressure
			Valve does not actuate	Sub does not surface	Valve unusable	1(E), 1(S), 10(O), 2(NO)	1	1	0.35	0.137254902	Choose reliable valve

Chassis									Formula = (Rank/40)*R.O.O.* D		
Function	**Performance Standards**	**Functional Failures**	**Failure Modes**	**Failure Effects**	**Consequence Category**	**Rank (Total out of 40)**	**Rate of Occurrence**	**Detectibility**	**Risk Ranking(0.1 = Lowest; 100 = Highest)**	**Normalized Rank (1= high, 0 = low)**	**Mitigation**
Protection to Components	Barier between components and harmful objects	Frame does not hold shape	Frame fractures	Components break	Components unusable, non functioning sub	1(E), 1(S), 9(O), 9(NO)	1	1	0.5	0.196078431	Choose strong material with at least 2X safety factor to max applied
				Components damaged	Components need repair, poor performance or nonfunctioning	1(E), 1(S), 7(O), 7(NO)	1	1	0.4	0.156862745	Choose strong material with at least 2X safety factor to max applied stress.
			Frame bends	Components break	Components unusable, non functioning sub	1(E), 1(S), 6(O), 6(NO)	2	1	0.7	0.274509804	Choose strong material with at least 2X safety factor to max applied
				Components damaged	Components need repair, poor performance or nonfunctioning	1(E), 1(S), 5(O), 5(NO)	2	1	0.6	0.235294118	Choose strong material with at least 2X safety factor to max applied stress.
		Joints become loose	Joints disconnect	Components break	Components unusable, non functioning sub	1(E), 1(S), 6(O), 6(NO)	1	1	0.35	0.137254902	Design joints to withstand 2X safety factor of max applied
				Components damaged	Components need repair, poor performance or nonfunctioning	1(E), 1(S), 5(O), 5(NO)	1	1	0.3	0.117647059	Design joints to withstand 2X safety factor of max applied stress
			Joints are unstable	Components break	Components unusable, non functioning sub	1(E), 1(S), 5(O), 4(NO)	2	1	0.55	0.215686275	Design joints to withstand 2X safety factor of max applied
				Components damaged	Components need repair, poor performance or nonfunctioning	1(E), 1(S), 5(O), 5(NO)	2	2	1.2	0.470588235	Design joints to withstand 2X safety factor of max applied stress
Holds Components in Place	Holds components rigidly	Frame is unstable	Components fall off	Components damaged	Components need repair, poor performance or nonfunctioning	1(E), 1(S), 6(O), 6(NO)	2	1	0.7	0.274509804	Design component connections to be able to withstand 2X safety factor of max stress
			Components shifted	poor performance	Components need adjustment	1(E), 1(S), 5(O), 1(NO)	4	2	1.6	0.62745098	Design component connections to be able to withstand 2X safety factor of max stress
				Components damaged	Components need repair, poor performance or nonfunctioning	1(E), 1(S), 5(O), 5(NO)	2	1	0.6	0.235294118	Design component connections to be able to withstand 2X safety factor of max stress

Appendix E – Mechanical Figures

Chassis		Designs					
Consideration	Importance	Box	Sled	Ram	UFO	X-wing	Classic
Cost	4	2.66	3.66	1.33	2.33	3.66	2
Adaptability	5	4.66	3.33	2	2.33	3.33	4
Part Aquisition	4	3.66	4	1.33	2.66	3.66	2
Weight	5	2	4.66	1.66	3.66	3.33	2.5
Size	5	2.33	4	2.66	3.66	3.33	2
Ease of Build	4	4	3.33	1	2.66	4	1.5
Durability	3	5	3.33	3.66	2.66	4	4
Strength	3	5	3	3	2.66	4	4
Ease of Repair	3	4.33	4.33	1.33	3	4.33	2
Time to Build	3	3.33	4	1.33	2.66	3.66	2.5
Protection	3	5	3	3.66	3	4	5
Portability	2	4.33	4.33	2.66	2.66	3.33	3
	Total:	162.87	165.55	90.5	126.11	161.86	123
	1	2	3				
Top 3:	Sled	Box	X-wing				

Figure 1M: Chassis Decision Matrix

		Designs				
Consideration	Importance	Half-Capsule	Half-Cylinder	Semi-Sphere	Box	Full-Cylinder
Cost	3	2.66	3.33	2	5	3.33
Strength	5	3.66	3	4	2.33	3.33
Water-Seal	5	4.66	3.66	3.66	2	3.66
Weight	4	3	3	3	3	3
Durable	5	3.66	3	3.33	2.66	3.33
Ease of Repair	4	2	2	1.66	4	3.33
Ease of Build	4	4	2.66	3.33	2.66	3
Part Acquisition	3	2.66	3.33	2.66	4.66	3.33
Time	3	4	3	3.66	3.33	3.33
Safety	3	4	3.66	3.66	3.33	3.66
	Total:	135.86	118.9	122.85	122.55	129.87
		1	2	3		
	Top 3:	Half-Capsule	Full-Cylinder	Semi-Sphere		

Figure 2M: Electrical Housing Decision Matrix

	Electrical Housing				Chassis				
	Dia (in)	Length (in)	Vol (Gal)	Buoyant Force EH (lb	Total 80-20 length (in	Weight of 80-20 (lb)	volume of 80-20 (ft^3)	Buoyancy force of 80-20 (lb)	Total buoyancy (lb)
	10	24	8.15997	67.97257308	372.48	16.38912	0.096805198	6.217797859	74.19037094
	10	25	8.49997	70.80476362	376.48	16.56512	0.097844773	6.284569744	77.08933337
	10	26	8.83997	73.63695417	380.48	16.74112	0.098884347	6.351341628	79.9882958
	10	27	9.17997	76.46914471	384.48	16.91712	0.099923922	6.418113512	82.88725822
	10	28	9.51997	79.30133526	388.48	17.09312	0.100963497	6.484885396	85.78622065
	10	29	9.85997	82.1335258	392.48	17.26912	0.102003071	6.551657281	88.68518308
	10	30	10.2	84.96571635	396.48	17.44512	0.103042646	6.618429165	91.58414551
Final Design	10	31	10.54	87.79790689	400.48	17.62112	0.104082221	6.685201049	94.48310794
	10	32	10.88	90.63009744	404.48	17.79712	0.105121796	6.751972933	97.38207037
	10	33	11.22	93.46228798	408.48	17.97312	0.10616137	6.818744817	100.2810328
	10	34	11.56	96.29447853	412.48	18.14912	0.107200945	6.885516702	103.1799952
	10	35	11.9	99.12666907	416.48	18.32512	0.10824052	6.952288586	106.0789577
	10	36	12.24	101.9588596	420.48	18.50112	0.109280095	7.01906047	108.9779201
	10	37	12.58	104.7910502	424.48	18.67712	0.110319669	7.085832354	111.8768825
	10	38	12.92	107.6232407	428.48	18.85312	0.111359244	7.152604239	114.7758449
	10	39	13.26	110.4554313	432.48	19.02912	0.112398819	7.219376123	117.6748074
	10	40	13.6	113.2876218	436.48	19.20512	0.113438393	7.286148007	120.5737698
Max	10	41	13.94	116.1198123	440.48	19.38112	0.114477968	7.352919891	123.4727322
	12	17	8.32317	69.33202454	363.76	16.00544	0.094538925	6.072235152	75.40425969
	12	18	8.81277	73.41037892	367.76	16.18144	0.0955785	6.139007036	79.54938596
	12	19	9.30237	77.48873331	371.76	16.35744	0.096618074	6.20577892	83.69451223
	12	20	9.79197	81.56708769	375.76	16.53344	0.097657649	6.272550804	87.8396385
	12	21	10.2816	85.64544208	379.76	16.70944	0.098697224	6.339322689	91.98476477
	12	22	10.7712	89.72379646	383.76	16.88544	0.099736799	6.406094573	96.12989104
	12	23	11.2608	93.80215085	387.76	17.06144	0.100776373	6.472866457	100.2750173
	12	24	11.7504	97.88050523	391.76	17.23744	0.101815948	6.539638341	104.4201436
	12	25	12.24	101.9588596	395.76	17.41344	0.102855523	6.606410226	108.5652698
	12	26	12.7296	106.037214	399.76	17.58944	0.103895097	6.67318211	112.7103961
	12	27	13.2192	110.1155684	403.76	17.76544	0.104934672	6.739953994	116.8555224
Max	12	28	13.7088	114.1939228	407.76	17.94144	0.105974247	6.806725878	121.0006486

Figure 3M: Housing Dimensions and Buoyancy

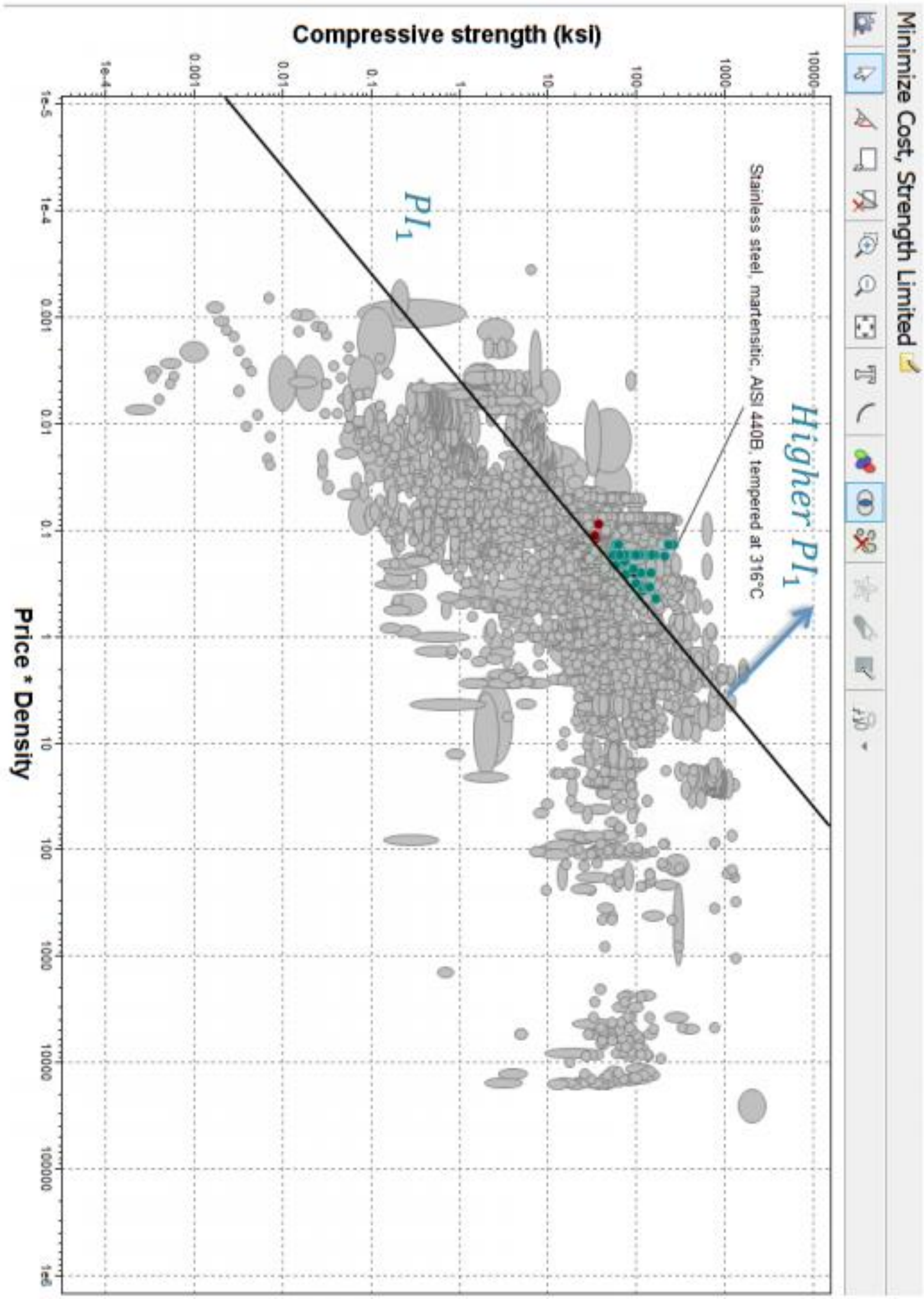


Figure 4M: Minimize Cost CES Graph

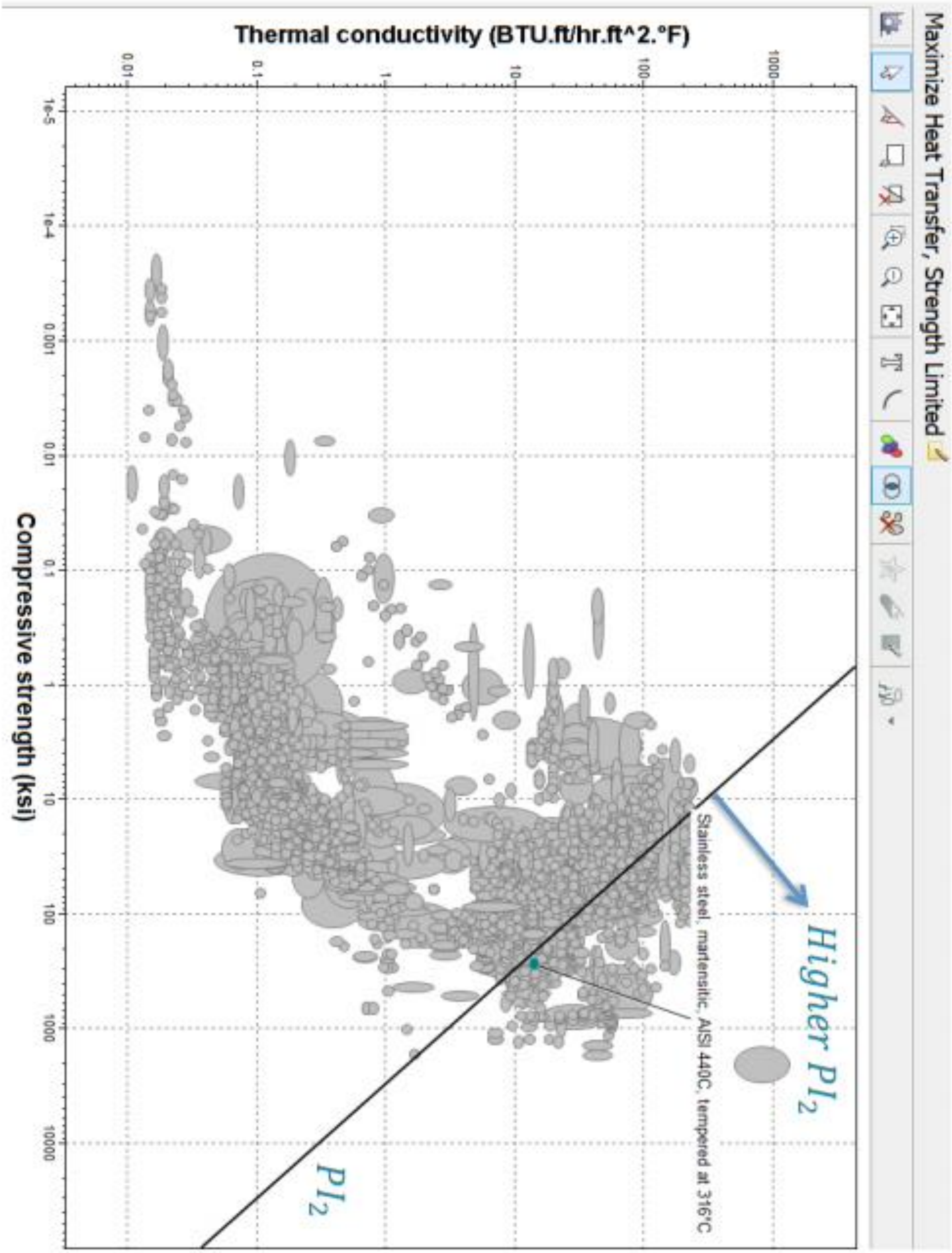


Figure 5M: Maximize Heat Transfer CES Graph

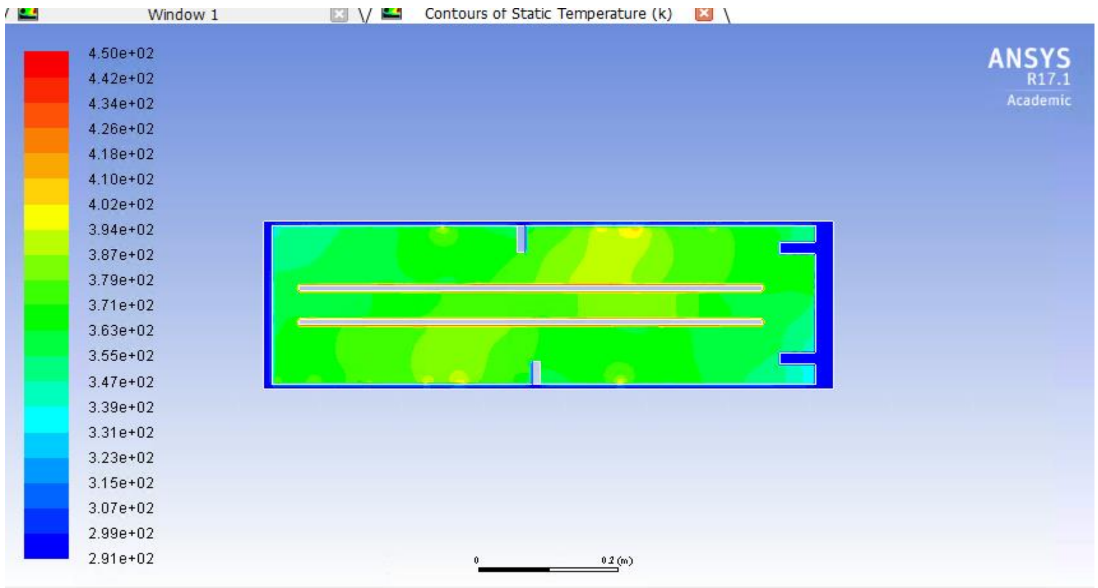


Figure 6M: Fluent Temperature Plot

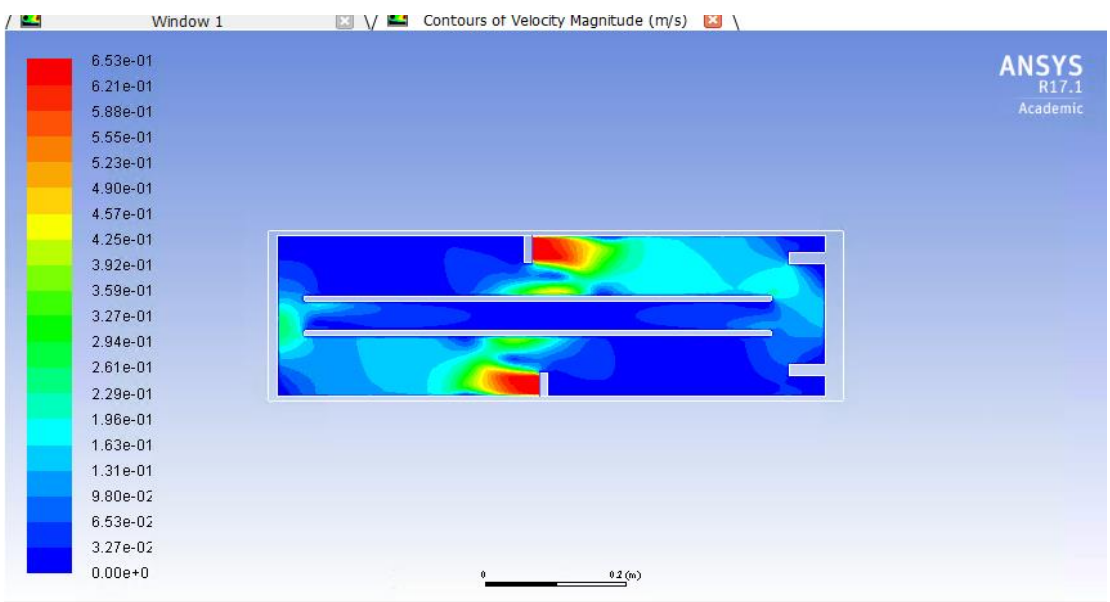


Figure 7M: Fluent Vector Plot

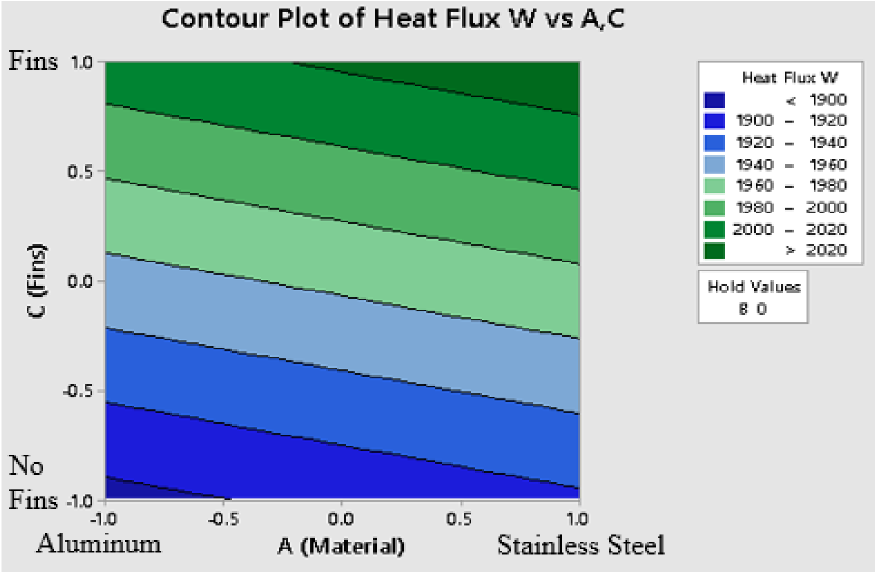


Figure 8M: Minitab Response Surface

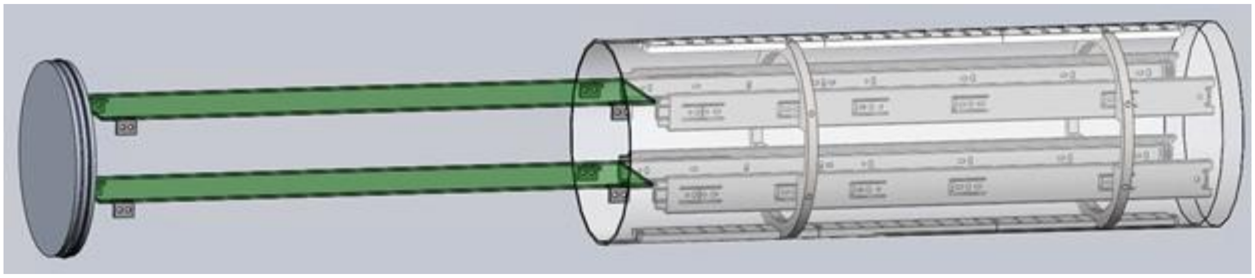


Figure 9M: Housing Drawer Design

Figure 10M: 3D Printed Bracket Rail

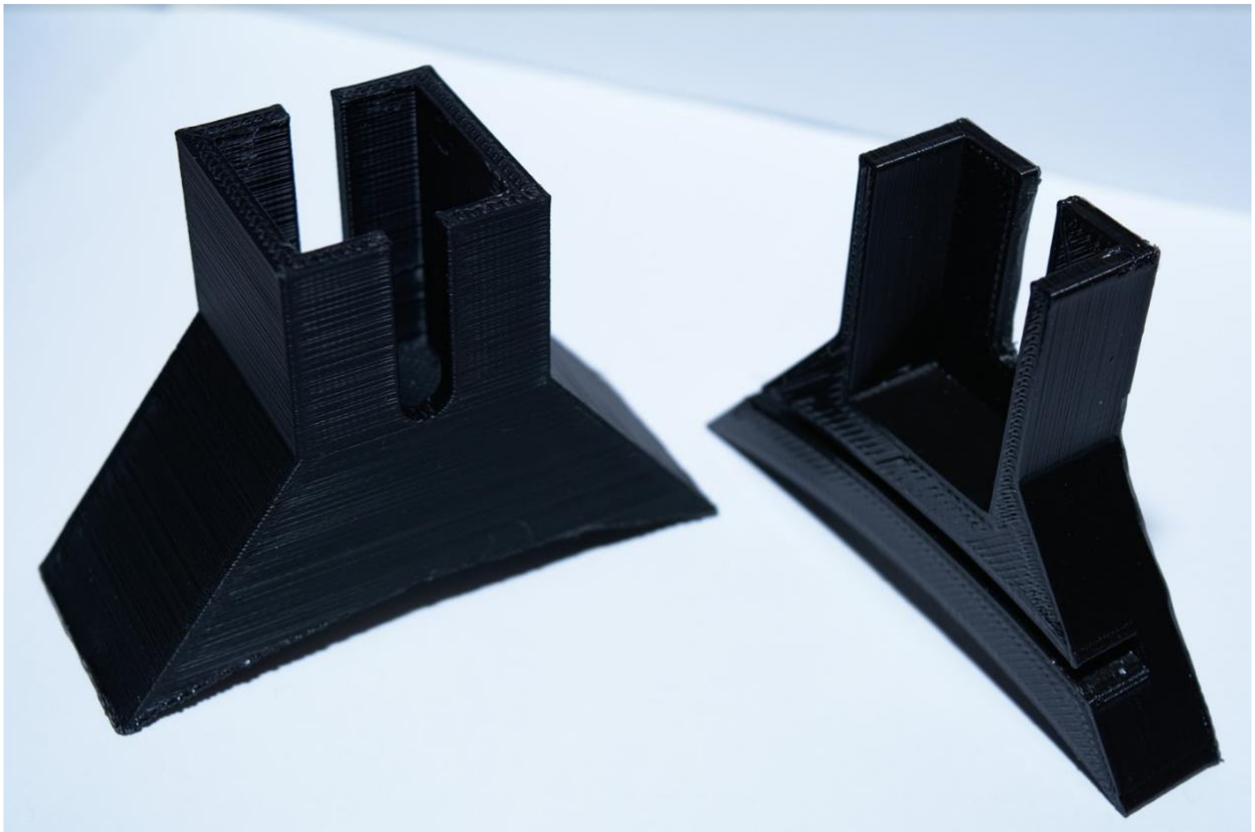


Figure 11M: 3D Printed Housing Clamps

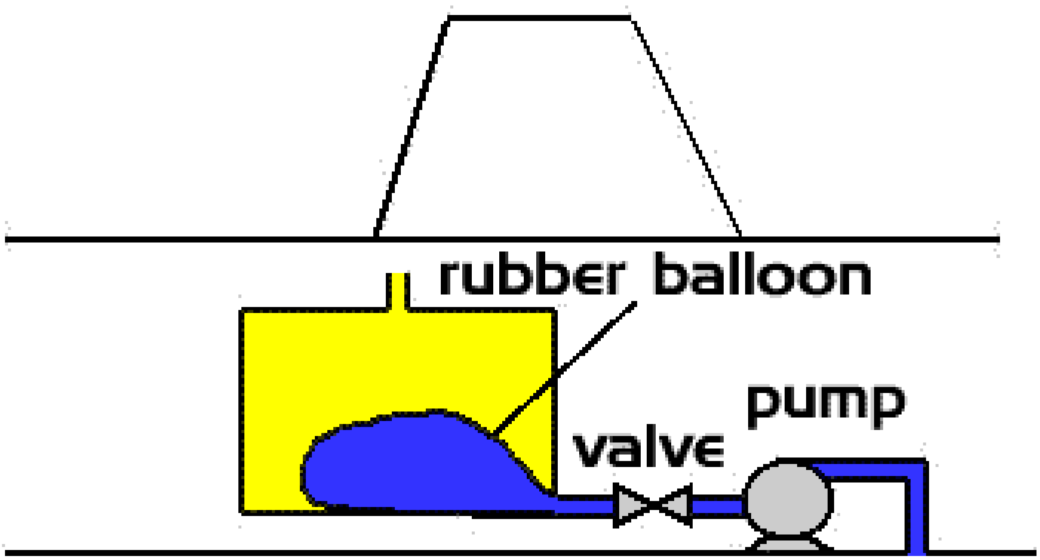


Figure 12M: Flexible Ballast Design

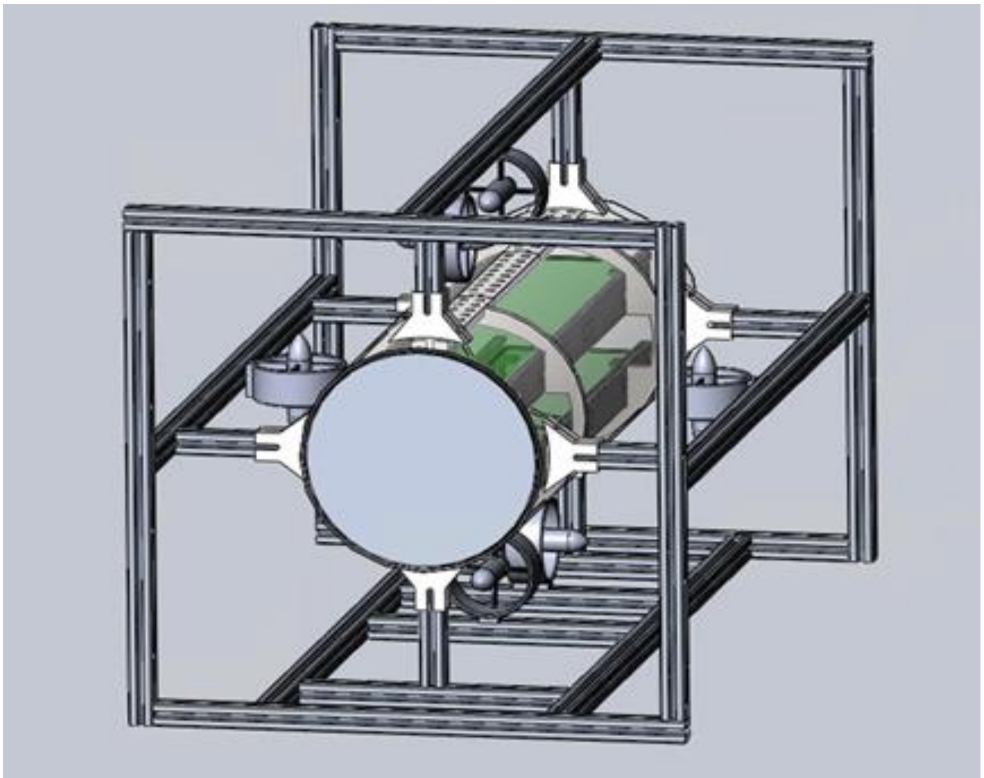


Figure 13M: Full CAD Image

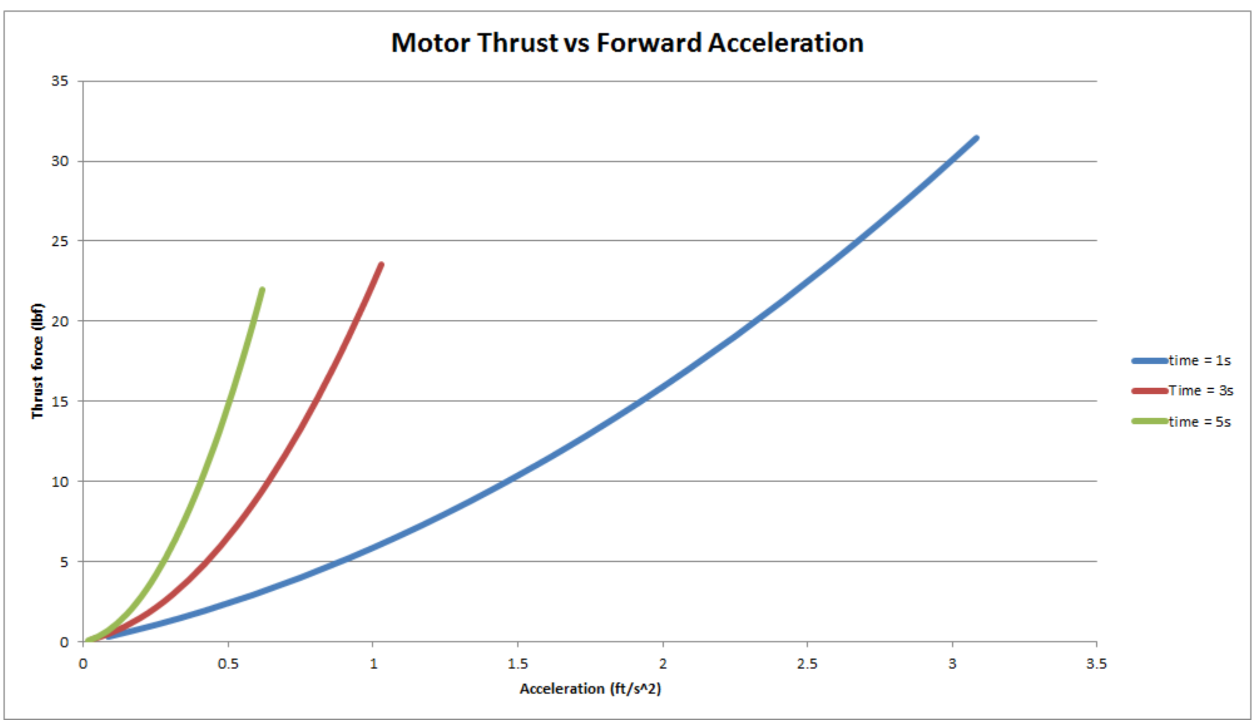


Figure 14M: Motor Thrust at Different Accelerations

Figure 15M: Aluminum End Cap

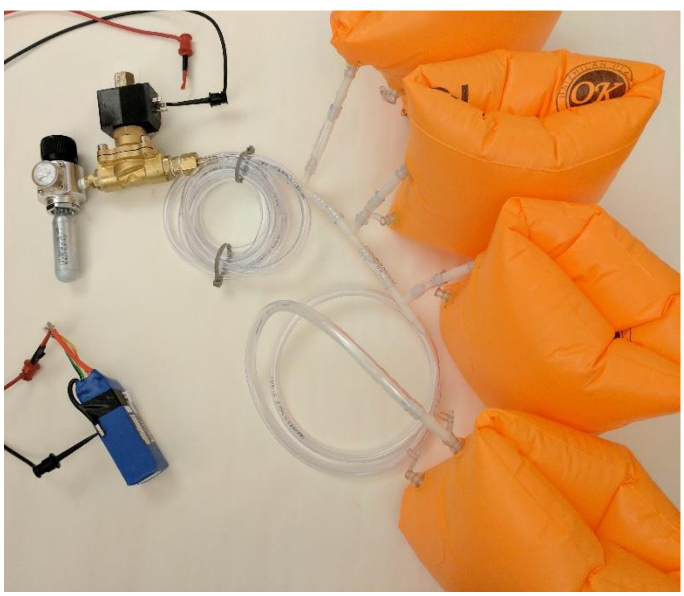


Figure 16M: Inflated Fail Safe

Appendix F – Power and Propulsion Figures

Figure 1P: TMotor 3 Phase BLDC; 1.5in x 1.5 in

Figure 2P: Turnigy Motor 3 Phase BLDC; 2.5in x 2.5 in

Figure 3P: MaxxAmps 8000 mAh LiPo Battery; 1.5in x 5.5 in x 1 in ; 1.6 lb.

Figure 4P: Blue ESC 40 A ; 2in x 1in; 1 oz.

Figure 5P: Blue ESC 60 A; 2in x 1in; 1 oz.

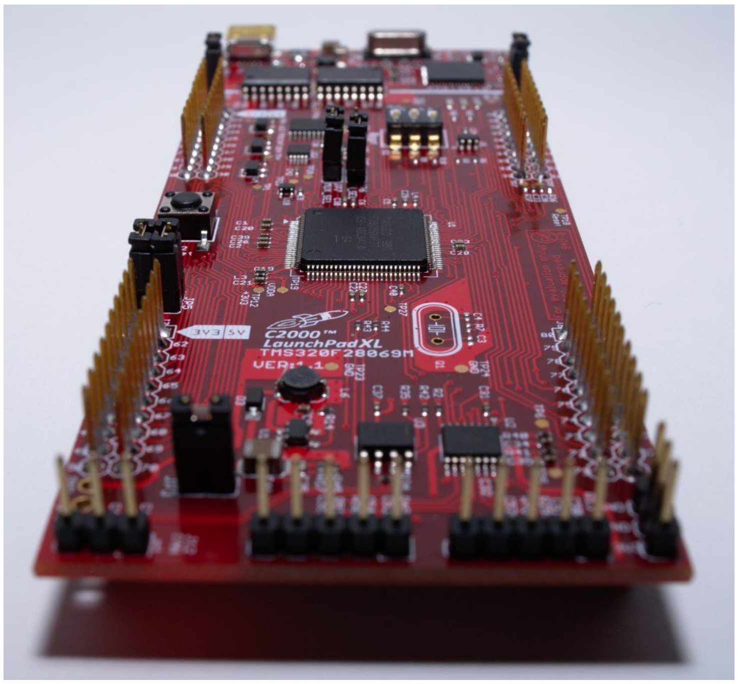


Figure 6P: Ti C2000 Piccolo MPU on LaunchPad XL Development Board; 2in x 5in

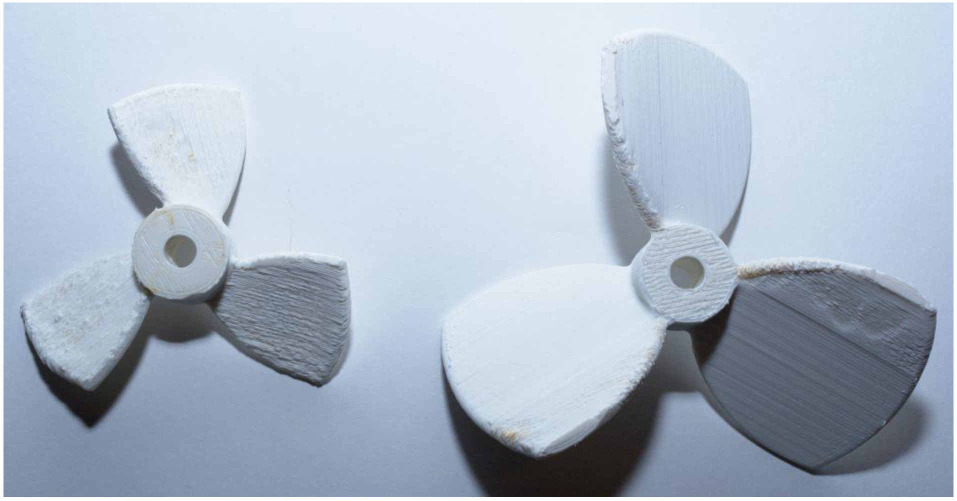


Figure 7P: 3 in. and 4.75 in. Propellers

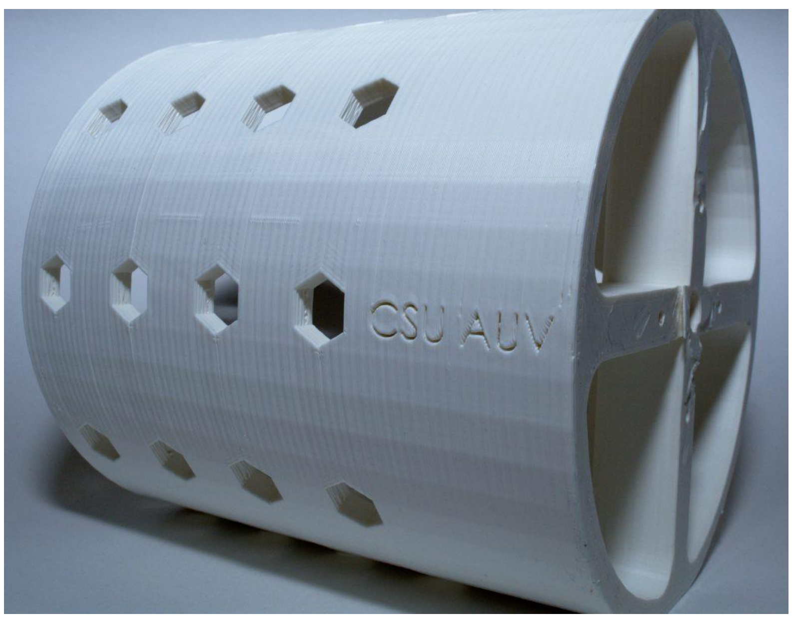


Figure 8P: 5 in. x 6.6 in. Motor Shroud

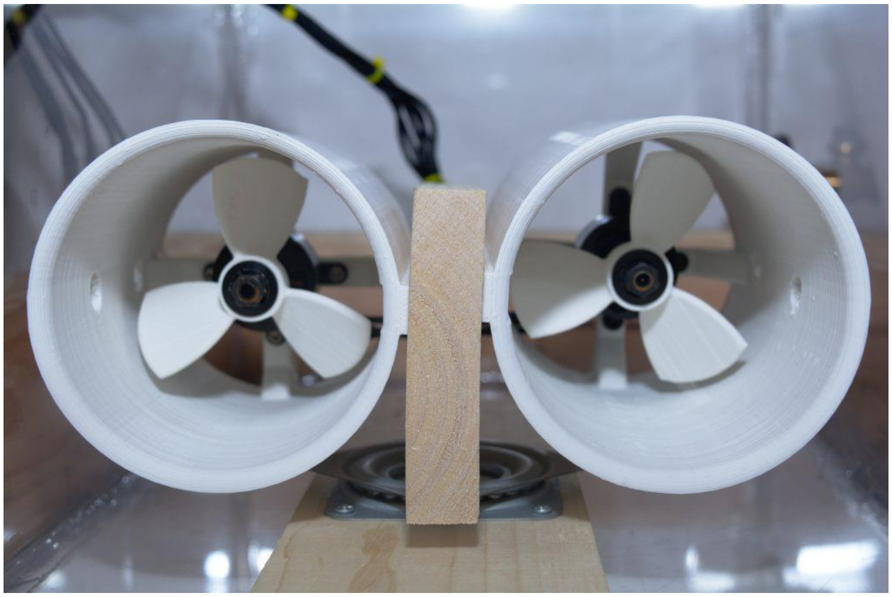


Figure 9P: Motor Test Rig

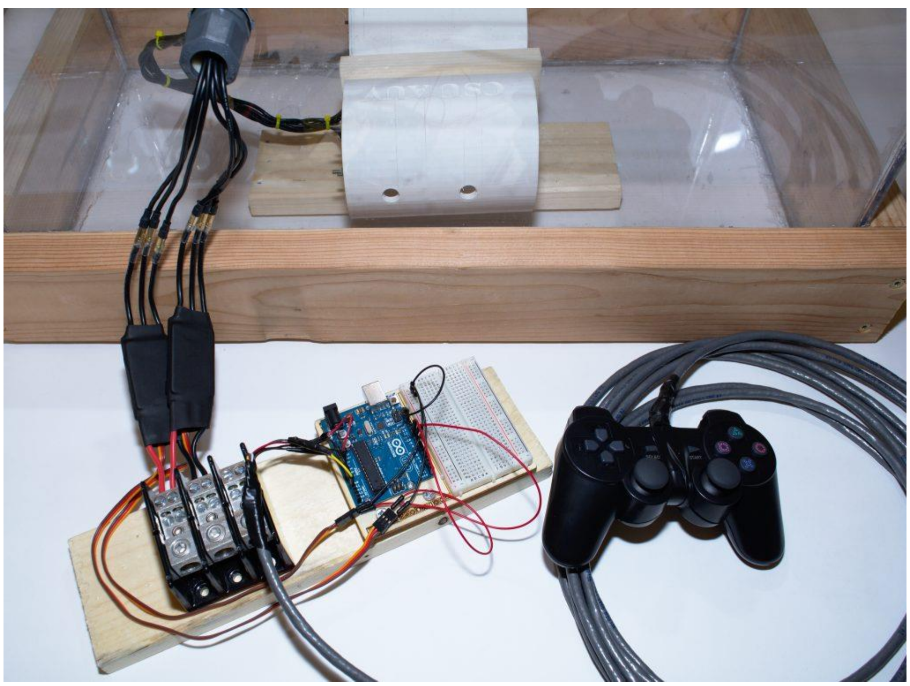


Figure 10P: Motor Test Rig with Controls Setup

Appendix G – Sensor Figures

Figure 1S: GoPro Hero 4 OD

Figure 2S: IMU w/ Interface Board

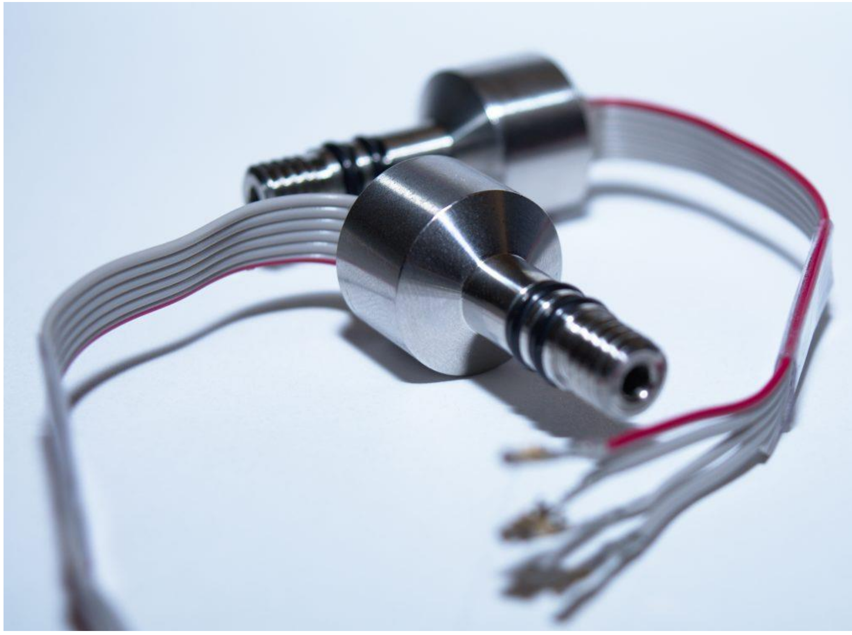


Figure 3S: Pressure Transducers

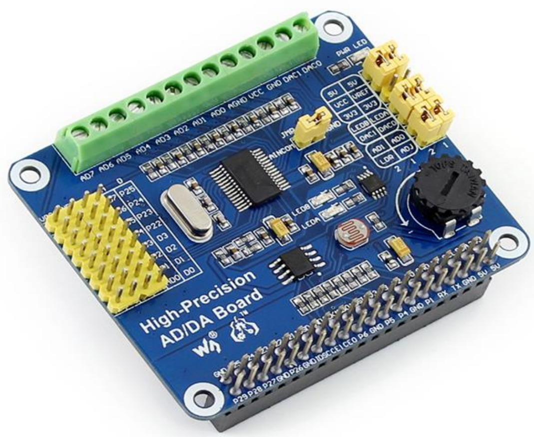


Figure 4S: Waveshare A/D Expansion Board

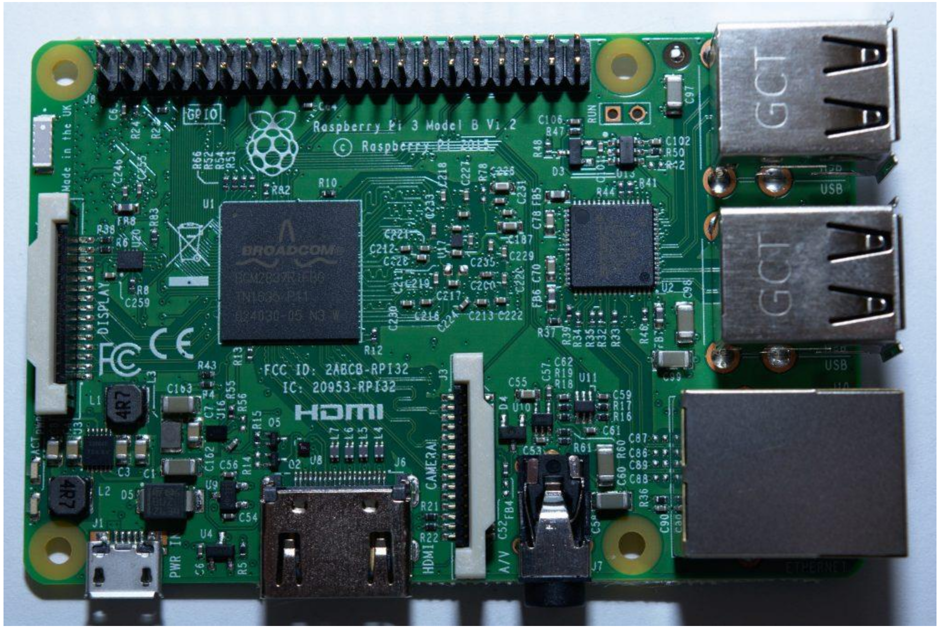


Figure 5S: Raspberry Pi 3 Model B

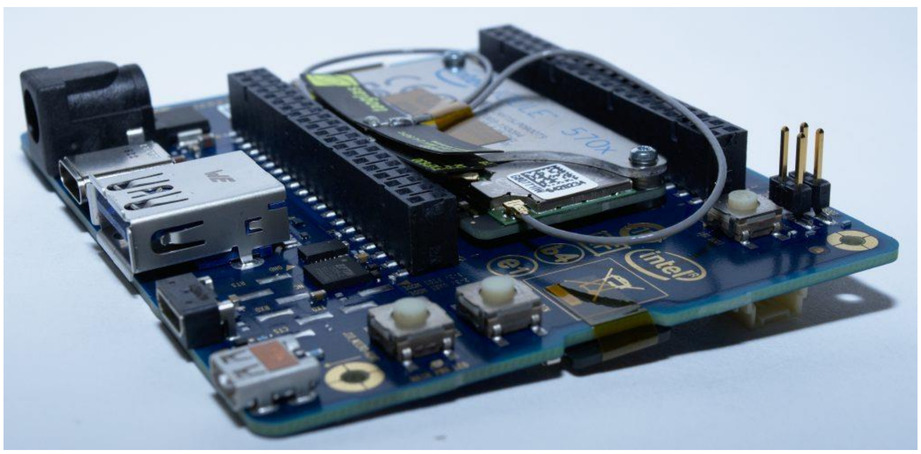
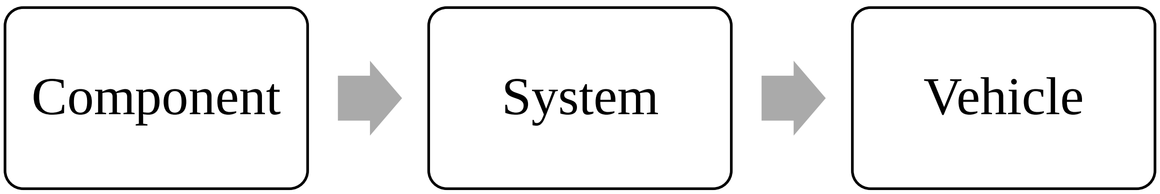


Figure 6S: Intel Joule IPU

Appendix H – Device Test, Validation, & Characterization (DTVC)

DTVC Structure

Structure for the DTVC is a three "test gate" system:



How this works

1. We each start with our respective subteam component level stuff and run through the steps listed on the next page.

2. Then take the component level and integrate all the components into your respective subteam system, and again go through the same steps.

3. Once that has all been done, we can then take all three subteam systems and integrate them all into the vehicle. This step still follows the exact same steps as before.

How to use these steps

1. Take gate and apply metrics.
2. Come up with tests for all the material tests.
3. Come up with tests for the required spec of the gate.
4. Take all the tests you have come up with and run them through the Test Screener.
5. If a test fails then try to come up with a work around, if not possible then we have to forsake that test.

Testing Criteria

At each of the gates we ask the following questions about how to satisfy our metrics.

* All metrics are performance metrics as well as the testing metrics*

Metric A: Efficiency-

Can you change your response for changing environment?

Metric B: Endurance-

How long (time, distance, whatever metric is pertinent) can you do what you were designed to do?

All tests must satisfy both metric A and B:

1) Material Tests
    - External and Internal Event Tests
        i. Humidity
        ii. Pressure
        iii. 0 to 100% (0 = Dry and 100% = Wet)
        iv. Ambient temperature
        v. Medium changes
        vi. Durability Characteristics
2) Perform-desired-function- test

Test Screener

- Meta Test Metrics
- Duration back to original state
    - How quickly can I test?
- Cost
    - Can we afford effective testing?
- Time
    - Can we begin and finish testing in a realistic amount of time?
- Location
    - Where can we test?
- Repeatability
    - Can I do it exactly the same every time?

DTVC Overview

Last Edited By: Tyler Loughrey

Date: 11/30/16

I. Mechanical Overview

a. Component
b. System
c. Vehicle

II. Electrical Overview

a. Sensor
    i. Component
    ii. System
    iii. Vehicle

b. Propulsion
    i. Component
    ii. System
    iii. Vehicle

Date: 10/25/2016

Modified: 10/25/2016

Team: Mechanical

Gate: Component

a) **Material Test**
    - i) Chassis
        - (1) Impact test (Metric A)
            - (a) Says that chassis maintains original shape
        - (2) Fatigue test (Metric B).
            - (a) Says if chassis can withstand multiple impacts
        - (3) Corrosion test (Metric A B)
            - (a) Says if corrosion will occur on chassis
        - (4) Loading test dry land (Metric A B)
            - (a) Says if chassis can withstand max load of vehicle
    - ii) Electrical Housing
        - (1) Water proof timed test (Metric B)
            - (a) Says if housing maintains dry environment
        - (2) Water proof depth test (Metric A B)
            - (a) Says if housing maintains dry environment
        - (3) Heat dissipation (Metric A B)
            - (a) Says if housing reaches and maintains appropriate operating temperature
        - (4) Deformation test (Metric A)
            - (a) Says if electrical housing plastically deforms under applied heat
    - iii) Fail Safe
        - (1) Valve actuation test (Metric A)
            - (a) Says if valve actuates upon electrical loss
        - (2) Mass release test (Metric A)
            - (a) Says if mass is released upon valve actuation
        - (3) Inflation test

(a) Says if 'balloon' inflates and stays inflated (Metric A B)

iv) Clamps

(1) Impact test (Metric A)

(a) Says if the clamps can withstand the applied impact load

(2) Loading test dry land (Metric A B)

(a) Says if the clamps can withstand the weight of housing for specified time

(3) Loading test water (Metric A B)

(a) Says if the clamps can withstand the weight of housing for specified time

Date: 10/26/2016

Modified: 11/30/2016

Team: Sensors

Gate: Component

1) **Material Test**
    a) External Tests
        i) IMU
            (1) Static vs. Dynamic Temperature Test (Metric A, B)
                (a) Static
                    (i) Underwater as sole running unit
                (b) Dynamic
                    (i) Underwater with all other units running simultaneously
        ii) Pressure Transducers
            (1) Water suitability (Metric B)
                (a) Says if transducers operate correctly in water; watertight.
            (2) Temperature Test (Metric A, B)
                (a) Submerged in water
        iii) Cameras
            (1) Manufacturer's Specifications Test (Metric A)
                (a) Says if cameras meet Manufacturer's Specifications
            (2) Static vs. Dynamic Temperature Test (Metric A, B)
                (a) Static
                    (i) Underwater as sole running unit
                (b) Dynamic
                    (i) Underwater with all other units running simultaneously
        iv) Sensor Processing Unit (Metric A)
            (1) Says if it boots
            (2) Says if outputs are within expected range
    b) Internal Tests
        i) IMU

(1) Manufacturer's Specifications Test (Metric A)

(a) Says if IMU meets Manufacturer's Specifications

(2) Communication Test (Metric A)

(a) Says if information can be retrieved

(b) With motion input, says if it gives representative output

ii) Pressure Transducers

(1) Manufacturer's Specifications Test (Metric A)

(a) Says if transducers meet Manufacturer's Specifications

(2) Load Characterization (Metric A)

(a) Voltage/Amperage/Power characterization

(3) Output Test (Metric A)

(a) Says if a voltage within expected range is output

iii) Cameras

(1) Manufacturer's Specifications Test (Metric A)

(a) Says if cameras meet Manufacturer's Specifications

(2) Communication Test (Metric A)

(a) Says if information can be retrieved

iv) Sensor Processing Unit (Metric A)

(1) Heat up test

(2) Manufacturer's Specifications Test

(a) Says if SPU meets Manufacturer's Specifications

2) Perform-Desired-Function Testing

a) IMU

i) Calibration test (Metric A)

(1) Says if IMU gives accurate movement output

ii) Software Testing (Metric A)

(1) Says if software handles any expected and unexpected output from IMU

(2) Says if software handles calculations correctly

b) Pressure Transducers

i) Calibration test (Metric A)

(1) Says if transducers give accurate pressure change

ii) Software Testing (Metric A)

(1) Says if software handles any expected and unexpected voltage from transducers

(2) Says if software handles calculations correctly

c) Cameras

i) Software Testing (Metric A)

(1) Says if software handles any expected and unexpected image from cameras

(2) Says if software handles image manipulation correctly

d) Sensor Processing Unit

i) Software Testing (Metric A)

(1) Says if software handles all inputs from sensors

(2) Says if software ignores or handles bad inputs

(3) Says if software calculates meaningful data

ii) Stress Testing (Metric B)

(1) Measure change in temperature, voltage, and current

Date: 10/24/2016

Modified: 10/28/2016

Team: Propulsion

Gate: Component

1) **Material Test**
    a) External Test
        i) Motors
            (1) Spin/Bump test (Metric A)
                (a) Says if motor runs
            (2) Water suitability (Metric B)
                (a) Says if motor runs in water; watertight
            (3) Manufacturer's Specifications Test (Metric A)
                (a) Does motor meet Manufacturer's Specifications?
            (4) Load characterization (Metric A)
                (a) Volt/Amp/Power characterization
            (5) Static vs. Dynamic Temperature Test
                (a) Dynamic (Metric A,B)
                    (i) Large body with motion (in water) of motor under varying voltage/current conditions
                (b) Static (Metric A,B)
                    (i) Small body without motion of motor underwater varying voltage and current conditions
    b) Internal Tests
        i) Battery (as naked cells)
            (1) Load Characterization (Metric A)
                (a) High resistance load test to get loading current
            (2) Temperature Test (Metric A)
                (a) How much heat up under 10%, 20%, … 100% load
        ii) BMS

(1) Communication Test (Metric A)

(a) Does it talk?

(b) Can it be talked to?

iii) ESC (Metric A)

(1) With input, does it give a representative output?

(2) Heat up test

(a) How much heat up under 10%, 20%, … 100% load

(i) Don't really need, but it would be nice…

iv) MPU (Metric A)

(1) Does it boot?

(2) Can we flash it?

(3) Does output work?

(4) Heat up test

(a) How much heat up under 10%, 20%, … 100% load

(5) Power drop

v) HFD (Metric A)

(1) Does it meet Manufacturer Specifications?

(2) Does it actuate?

vi) EFD (Metric A)

(1) Does it meet Manufacturer Specifications?

vii) Cabling and Connectors (Metric B)

(1) Is conductor insulation electrically sound?

(2) Do connectors suit/fit the conductor number/size?

viii) MCU (Metric A)

(1) Does it boot?

(2) Can we flash it?

(3) Does output work?

(4) Heat up test

(a) How much heat up under 10%, 20%, … 100% load

(5) Power drop

2) **Perform-desired-function testing**

   a) Motors – MPU (Metric A)

      i) Motion Test

         (1) Does it go forward, backward, and braking?

      ii) Coordination Test

         (1) Do motors give coordinated response?

            (a) i.e. we say left and we move left

      iii) Stress Testing (Metric B)

         (1) Pulse motors forward and backward till something happens

         (2) Measure delta temperature, voltage, and current

         (3) Want to model the worst random walk ever

   b) MPU

         (1) State test

            (a) Has X distinct states for position and that maps to X distinct motor states.

            (b) Confirms no dead states

   c) HFD/EFD

         (1) Test switching via push button (Emergency Disconnect)

         (2) Timed software based failure (Software generated fault)

DTVC Expected Testing Outcomes

Last Edited By: Phil Meister

Date: 10/28/16

III. Mechanical Overview

a. Component
b. System
c. Vehicle

IV. Electrical Overview

a. Sensor
    i. Component
    ii. System
    iii. Vehicle

b. Propulsion
    i. Component
    ii. System
    iii. Vehicle

Date: 10/25/2016

Modified: 10/28/2016

Team: Mechanical

Gate: Component

1) **Material Test**
   a) Chassis
      i) Impact test (Metric A)
         (1) Chassis will withstand a collision traveling at 0.508 m/s
      ii) Fatigue test (Metric B)
         (1) Chassis will be able to withstand 20 impacts @ .508 m/s
      iii) Corrosion test (Metric A B)
         (1) Chassis will not corrode from H20 and Air interaction over 1 year
         (2) Chassis will not corrode from weak chlorine
         (3) Chassis will not corrode in salt water
      iv) Loading test dry land (Metric A B)
         (1) The chassis will withstand a weight of 125 lbf
   b) Electrical Housing
      i) Water proof timed test (Metric B)
         (1) Will be water tight for 1 hour of continuous immersion in water
      ii) Heat dissipation (Metric A B)
         (1) The EH will maintain a temperature below the maximum electrical operating temperature
   c) Fail Safe
      i) Valve actuation test (Metric A)
         (1) The fail safe valve will actuate upon electrical failure
      ii) Mass release test (Metric A)
         (1) The mass will release upon valve actuation
   d) Clamps
      i) Loading test dry land (Metric A B)

(a) The clamps will withstand a weight of 125 lbf

Date: 10/26/2016

Modified: 10/26/2016

Team: Sensors

Gate: Component

1) **Material Test**
    a) External Tests
        i) IMU
            (1) Static vs. Dynamic Temperature Test (Metric A, B)
                (a) Static
                    (i) Underwater as sole running unit, IMU will not heat over 3^{o}C over long periods of time (>30 minutes)
                (b) Dynamic
                    (i) Underwater with all other units running simultaneously, IMU will not heat over 3^{o}C over long periods of time (>30 minutes)
        ii) Pressure Transducers
            (1) Water suitability (Metric B)
                (a) Transducer will only have water on pressure sensor.
                (b) Transducer will operate underwater for >30 minutes.
            (2) Temperature Test (Metric A, B)
                (a) Transducers will not heat up over long or short term use (>30 minutes)
        iii) Cameras
            (1) Static vs. Dynamic Temperature Test (Metric A, B)
                (a) Static
                    (i) Underwater as sole running unit, cameras should not heat over 3^{o}C over long periods of time (>30 minutes)
                (b) Dynamic
                    (i) Underwater with all other units running simultaneously, cameras should not heat over 3^{o}C over long periods of time (>30 minutes)
        iv) Sensor Processing Unit (Metric A)

(1) Will boot.

(2) Output can be measured using oscilloscope or test rig.

b) Internal Tests

i) IMU

(1) Manufacturer's Specifications Test (Metric A)

(a) IMU will have accuracy and noise characteristics of manufacturer's specs.

(2) Communication Test (Metric A)

(a) Communication will be one-way.

(b) Communications will be at least 90% reliable (1 in 10 signals fail)

ii) Pressure Transducers

(1) Manufacturer's Specifications Test (Metric A)

(a) Pressure Transducers will meet input and output voltage and current characteristics per manufacturer's specifications.

(2) Output Test (Metric A)

(a) Pressure Transducers will output a linear voltage based on current pressure.

iii) Cameras

(1) Manufacturer's Specifications Test (Metric A)

(a) Cameras will have the framerate and resolution of manufacturer's specs.

(2) Communication Test (Metric A)

(a) Communication will be one-way.

(b) Communications will be at least 90% reliable (1 in 10 signals fail)

iv) Sensor Processing Unit (Metric A)

(1) Will operate at near peak performance up to at least 100°C

(2) Manufacturer's Specifications Test

(a) SPU will meet processing characteristics of manufacturer's specs.

2) Perform-Desired-Function Testing

a) IMU

i) Calibration test (Metric A)

(1) IMU will be accurate within 5% of real movement.

ii) Software Testing (Metric A)

(1) Software will handle any expected or unexpected output from IMU.

(2) Software will calculate IMU data correctly.

b) Pressure Transducers

i) Calibration test (Metric A)

(1) Transducers will be accurate within 5% of real pressure.

ii) Software Testing (Metric A)

(1) Software will handle any expected or unexpected output from transducers.

(2) Software will calculate transducer output correctly.

c) Cameras

i) Software Testing (Metric A)

(1) Software will handle any expected or unexpected image from camera.

(2) Software will manipulate images correctly.

d) Sensor Processing Unit

i) Software Testing (Metric A)

(1) Software will handle all inputs from all sensors.

(2) Software will ignore bad inputs.

(3) Software will output meaningful data.

ii) Stress Testing (Metric B)

(1) Under full load, SPU will continue to operate.

Date: 10/24/2016

Modified: 10/24/2016

Team: Propulsion

Gate: Component

1) **Material Test**
    - a) External Test
        - i) Motors
            - (1) Spin/Bump test (Metric A)
                - (a) Motor will run unimpeded under manufactures voltage/amperage specs
            - (2) Water suitability (Metric B)
                - (a) Motor will have no water in it
                - (b) Motor will run underwater for >30 minutes
            - (3) Manufacturer's Specifications Test (Metric A)
                - (a) Motor will not have the speed/voltage characteristics per manufactures specs
                - (b) Motor will not have the torque/amperage characteristics per manufactures specs
            - (4) Load characterization (Metric A)
                - (a) Motor characterization will be with 10% of manufactures specs in voltage, amperage handling characteristics as well as thrust
            - (5) Static vs. Dynamic Temperature Test
                - (a) Dynamic (Metric A,B)
                    - (i) Motor will exhibit no heat up and perform as if "cold"
                - (b) Static (Metric A,B)
                    - (i) Motor will exhibit heat up after substantially shorter time than in dynamic test
                    - (ii) Motor characteristics will degrade but not beyond the point of usability
    - b) Internal Tests
        - i) Battery (as naked cells)
            - (1) Load Characterization (Metric A)

(a) Battery cells will exhibit poor performance (read as ability to respond) over 20 minutes

(b) Battery cells will be able to respond to all loads when fully charged

(c) Battery cells will drop no more than 1% in power output for each 1% load increase

(2) Temperature Test (Metric A)

(a) Battery cells will heat no more than 5 °C over long term use (>20 minutes)

(b) Battery cells will not heat up under short term use (< 10 minutes)

ii) BMS

(1) Communication Test (Metric A)

(a) Communication will be bi-directional

(b) Communication from controllers will disable batteries

(c) Communications will be at least 90% reliable (1 in 10 signals fail)

iii) ESC (Metric A)

(1) Voltage/Phase will have a 1-1 relationship with input signal

(2) Will heat up more under heavy load than light load

(3) Will handle rated amperage and voltage +10%

(4) Will have phase but not amplitude/switching issues upon heavy load

(5) Heat (within spec) will not cause any more than phase distortion

iv) MPU (Metric A)

(1) Will boot

(2) Will take at least 10,000 flashings (typical for solid-state)

(3) Output will be tested in hardware; actuated in software

(4) Power consumption will be no more than 700kJ for 30 minutes

(5) Will operate at near peak performance up to at least 100°C

v) HFD (Metric A)

(1) Will be within manufactures spec +/- 10%

(2) Will actuate 100% of the time

(3) Will break under rated load (measured in Amperes)

vi) EFD (Metric A)

(1) Will be within manufactures spec +/- 10%

(2) Will actuate 100% of the Will break under rated load (measured in Amperes)

vii) Cabling and Connectors (Metric B)

(1) Conductors will handle 1.5x times rated voltage

(2) Multi-conductors will not exhibit insulation failures

(3) Connectors will be chosen to physically and electrically fit conductors

2) Perform-desired-function testing

a) Motors – MPU (Metric A)

i) Motion Test

(1) Does it go forward, backward, and braking?

ii) Coordination Test

(1) Do motors give coordinated response?

(a) i.e. we say left and we move left

iii) Stress Testing (Metric B)

(1) Pulse motors forward and backward till something happens

(2) Measure delta temperature, voltage, and current

(3) Want to model the worst random walk ever

b) MPU

(1) State test

(a) Has X distinct states for position and that maps to X distinct motor states.

(b) Confirms no dead states

c) HFD/EFD

(1) Test switching via push button (Emergency Disconnect)

(2) Timed software based failure (Software generated fault)