Test Equipment Data Package (TEDP)

AMSAR:
Autonomous.Maritime.Search.and.Rescue
Challenge 1: Surface Autonomous Vehicle for Emergency Response (SAVER)

State University of New York at Buffalo
Buffalo, NY 14260

UB AIAA Micro-g NExT Research Team

Team Contact
Vladimir Tattybayev
vtattyba@buffalo.edu
(716) 352 3883

Faculty Advisor
Paul Schifferle
paul.schifferle@calspan.com
(716) 804 4259

Team Members
Vladimir Tattybayev | Captain | vtattyba@buffalo.edu | Senior | Computer Science
Liam Field | Co-Captain | liamfiel@buffalo.edu | Senior | Aerospace Engineering
Mirka Arevalo | Safety/Outreach Lead | mirkaare@buffalo.edul | Senior | Mech & Aero Engineering
Sean Flynn | Electronics Lead | spflynn2@buffalo.edu | Senior | Civil Engineering
Teresa Bompczyk | Research Lead | tbompczy@buffalo.edu | Junior | Computational Physics
Joshua Duell | Structures Lead | jjduell@buffalo.edu | Sophomore | Mech & Aero Engineering
Allison Gardener | Safety Member | aagarden@buffalo.edu | Junior | Mech & Aero Engineering
Tamaghan Maurya | Software Member | tamaghan@buffalo.edu | Junior | Computer Science

II. Abstract

Within search and rescue missions there are inherent limitations, the mitigation of which is Autonomous Maritime Search and Rescue's (AMSAR) foremost priority. Acting as an extension of [wo]man power in the event of an unplanned egress, its primary mission objective is to ensure a successful transfer of emergency supplies to a downed astronaut within a maritime environment. AMSAR's design interfaces multiple software-dependent sensing systems (e.g., ultrasonic and visual object avoidance, direction-finding, impact monitoring, motor control) capable of detecting and moving to a 121.5MHz distress signal (via software-defined radio) with adherence to realistic time constraints and proper safety measures. The TEDP provides a detailed overview of AMSAR's technical design, covers analysis and testing of the system in relation to the challenge goals, lists operational procedures and handling, addresses hazards while proposing solutions, and proposes the team's forward plan for the finalized AMSAR prototype.

III. Background

NASA's Artemis Program intends to bring humanity back on the Moon, as a stepping stone of our path to Mars. At the forefront of the mission is ensuring the well-being of NASA operatives. In the unlikely event of an egress, successful search-and-rescue requires a timely procedural response. AMSAR is a proposed solution to improve response time via an integrated, fully autonomous system, designed to search for and deliver aid to distressed astronauts in a maritime environment.

A fortified SLA resin hull structure ensures the integrity of interior equipment, allowing rapid deployment via a Group 1 close-range UAV. Upon impact from the drop, AMSAR's acceleration threshold will be surpassed, activating direction-finding of the ANGEL Beacon's 121.5MHz homing signal. A software-defined radio (SDR) using a circular antenna configuration will pinpoint the beacon signal, converting that information into a direct route unit vector for guidance. This prompts autonomous manipulation of the power and steering systems, where a nozzle at the rear end enables the bidirectional steering by degrees. To increase precision and mission success, sensor sub-systems consisting of both object detection via TensorFlow-enabled camera and proximity detection via an ultrasonic sensor are implemented.

IV. Hardware Design

A. Technical Description

Listed below are the key technical aspects of AMSAR, which link to the referenced tables and figures in the Appendix:

Description	Relevant Figure in Appendix
List of main electrical components, their common names, and primary function.	Table 1
Main electrical components, including their weights, quantities, and volumes.	Table 2
Electrical subcomponents chart including their weights, quantities, and volumes.	Table 3
All structural components in current design, including their weights, quantities, and volumes.	Table 4
NBL approved materials listing including adhesives, sealants, coatings, etc.	Table 5
Cross Sectional View of AMSAR	Figure 14
Overall Dimensions of AMSAR	Figure 15
General dimensions of the propulsion system	Figure 16

Labeling

Labels will be located near potential hazards as well as for operational information. Below is a list of labels which will be used on AMSAR:

1. Warnings
    1.1. Cargo bay handle and hatch.
        1.1.1. For personnel recognition of finger or clothing trap hazards.
    1.2. Propulsion nozzle and servo
        1.2.1. Clear indication to stay clear of this area during operation.
    1.3. Electrical Connection
        1.3.1. Clear indication that AMSAR can only be powered by a 12V 25A connection.
2. Informational
    2.1. Cargo bay handle and hatch
        2.1.1. Informs reader to open hatch with a clockwise rotation and to pull it open.

2.2. System state LED lights
    2.2.1. Informs reader of the system state based on the LED lights on the hull.
2.3. Electrical Connection
    2.3.1. Informs reader of the banana plug connection.

Handling

In transporting AMSAR from its delivery container to the test environment, it will have to be held by on-site personnel. The brim around the perimeter of the cover provides a solid grip for this purpose. AMSAR should not be held by the nozzle on the stern of the vehicle, and personnel should attempt to hold the hull level with the horizontal plane. The hooks on the cover of AMSAR allow for easy connectivity with the crane.

Design Changes

The AMSAR vehicle has undergone several design changes since the design from the original proposal. The manner in which the vehicle accomplishes locating and delivering survival aid has not changed, rather the structural and electrical designs are now refined to best suit this challenge. Changes were both based strictly on engineering design considerations, or made out of necessity due to hardships imposed on the team by the COVID-19 pandemic. The major design changes are as follows:

Circuitry & Wiring

The most significant change from the proposal is the addition of a second Raspberry Pi4B. After testing computational time with the entire software suite on one Pi, it was found that significant performance drops occurred. The TensorFlow API used for object detection was giving inaccurate results due to a lack of computational power. This was remedied with processing the KerberosSDR data on a second Raspberry Pi4B, and the other Pi interfacing with all the other components and software.

DC step down converters (DCC) were added to the circuit to regulate the voltage coming from the PDB to the major components. The PDB distributes voltage from the power source to the nodes in parallel. This presents an issue for the Pis and SDR as they require a lower voltage than the power source provides. The DCC’s will lower the voltage from the source 12V to the required 5V. The motor doesn’t require one as 12V is sufficient for its function.

3A fuses were added between the DCCs and the Pis and SDR. This was done as a safety measure for the components to ensure they do not get damaged or become a hazard.

Structural Shape

The overall shape of the vehicle has evolved to have greater stability, be more streamlined, and practical to manufacture. A visual comparison of both the current and prior design are respectively portrayed below. Refer to Figure 14 for annotated cross sectional view.

The current hull design is significantly wider than the design from the proposal. This provides a larger righting moment to keep the vehicle from capsizing from disturbances to its orientation. This hull design also proved to be more stable than the old design in tests of 3D printed scale models.

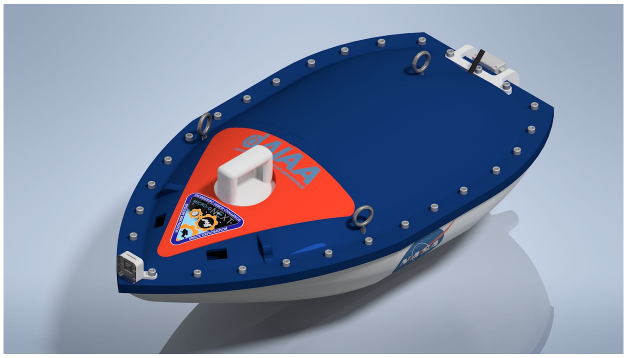


Figure 1: Current Design of AMSAR

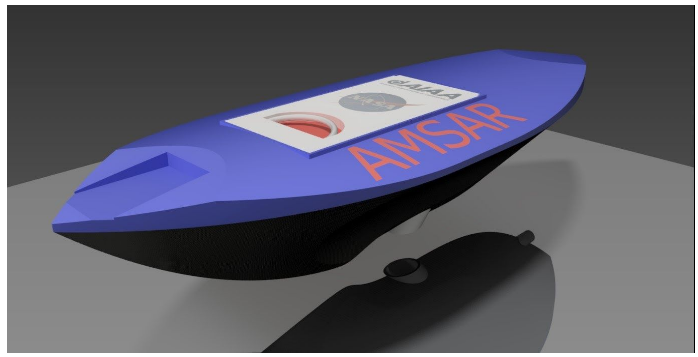


Figure 2: Former Design of AMSAR

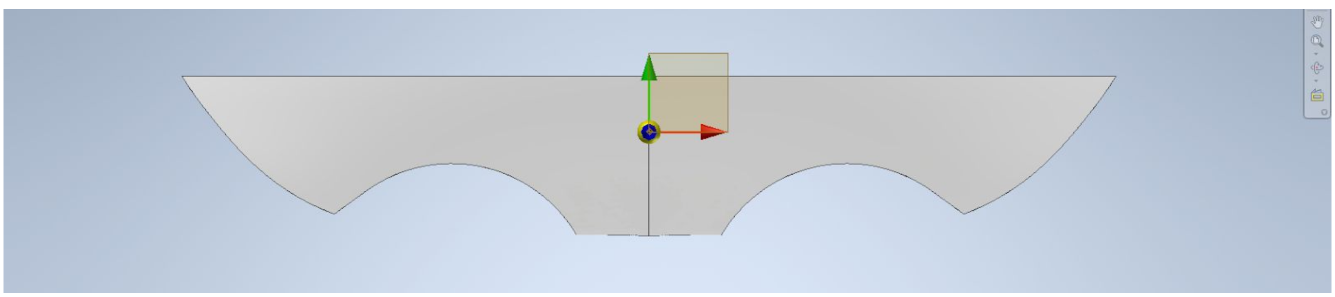


Figure 3: The center of buoyancy for the submerged part of the hull

Hull Material

Due to COVID-19, University at Buffalo closed for the remainder of the semester, and access to lab space was lost. Without lab space, we were required to adjust the hull from fiberglass to 3D printed SLA resin. This new material provides a lower Young's Modulus at 3.25x10^5 psi for ABS-like tough resin compared to a minimum of 10.44x10^6 psi for fiberglass. However, even with the lower Young's Modulus, the tough resin material maintains a factor of safety of rangining from 1.99-15 under the expected maximum loading on the vehicle as determined from an Autodesk Inventor Finite Element Analysis of the hull. This maximum loading occurs during impact with the surface of the NBL pool following release from the crane at the start of the test. Refer to Analysis and Testing for factor of safety and FEA.

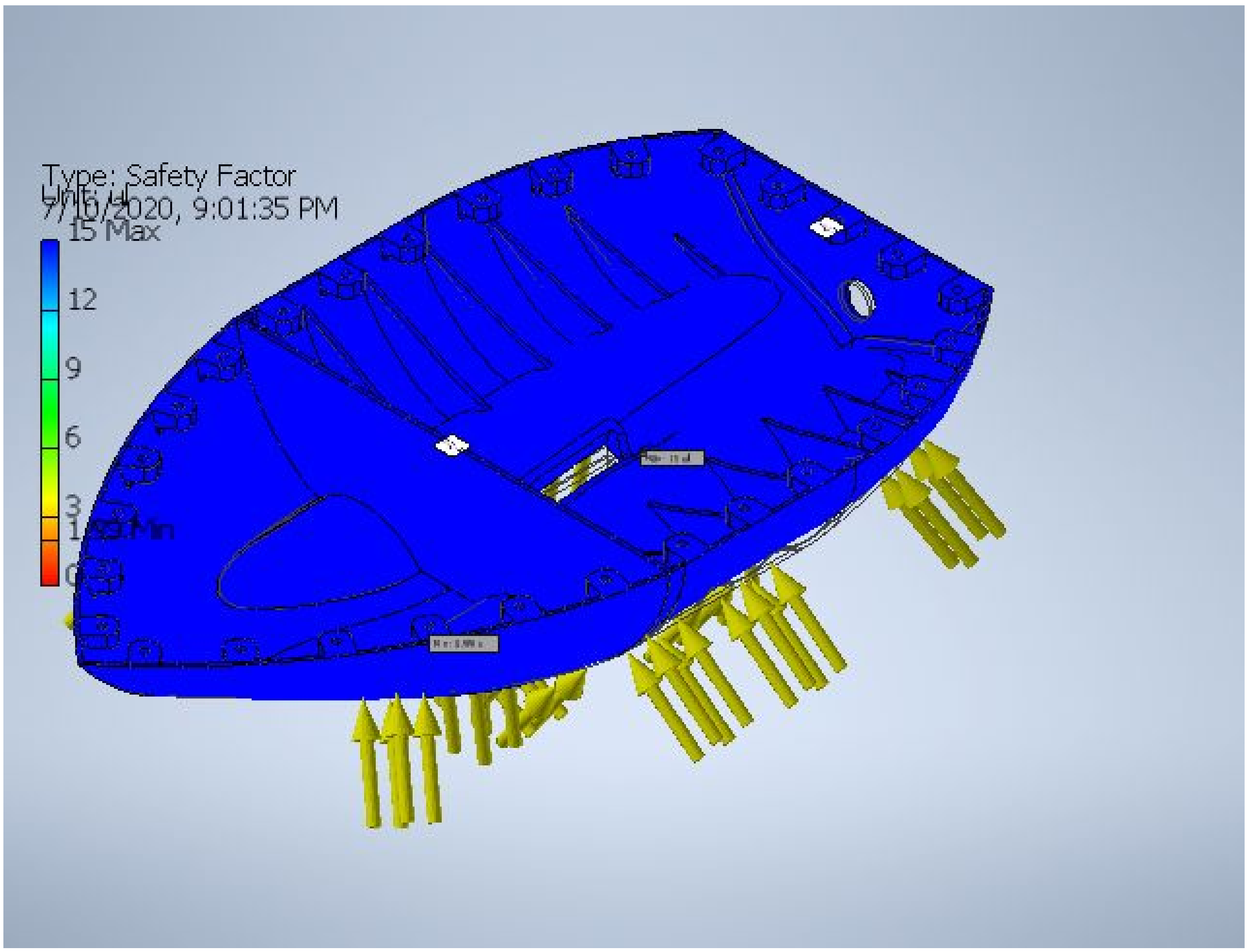


Figure 4: Visual Representation of Factor of Safety Results

B. Functional Description

Software

AMSAR is a fully autonomous system that must undergo multiple mission procedures in order to attain its goal state. Figure 4 [pp. 3] shows the System Block Diagram which defines the exact actions and states within the AMSAR system. The sensors required for mission success include the accelerometer, Kerberos SDR, motor software, TensorFlow object detection, and ultrasonic proximity detection/object avoidance.

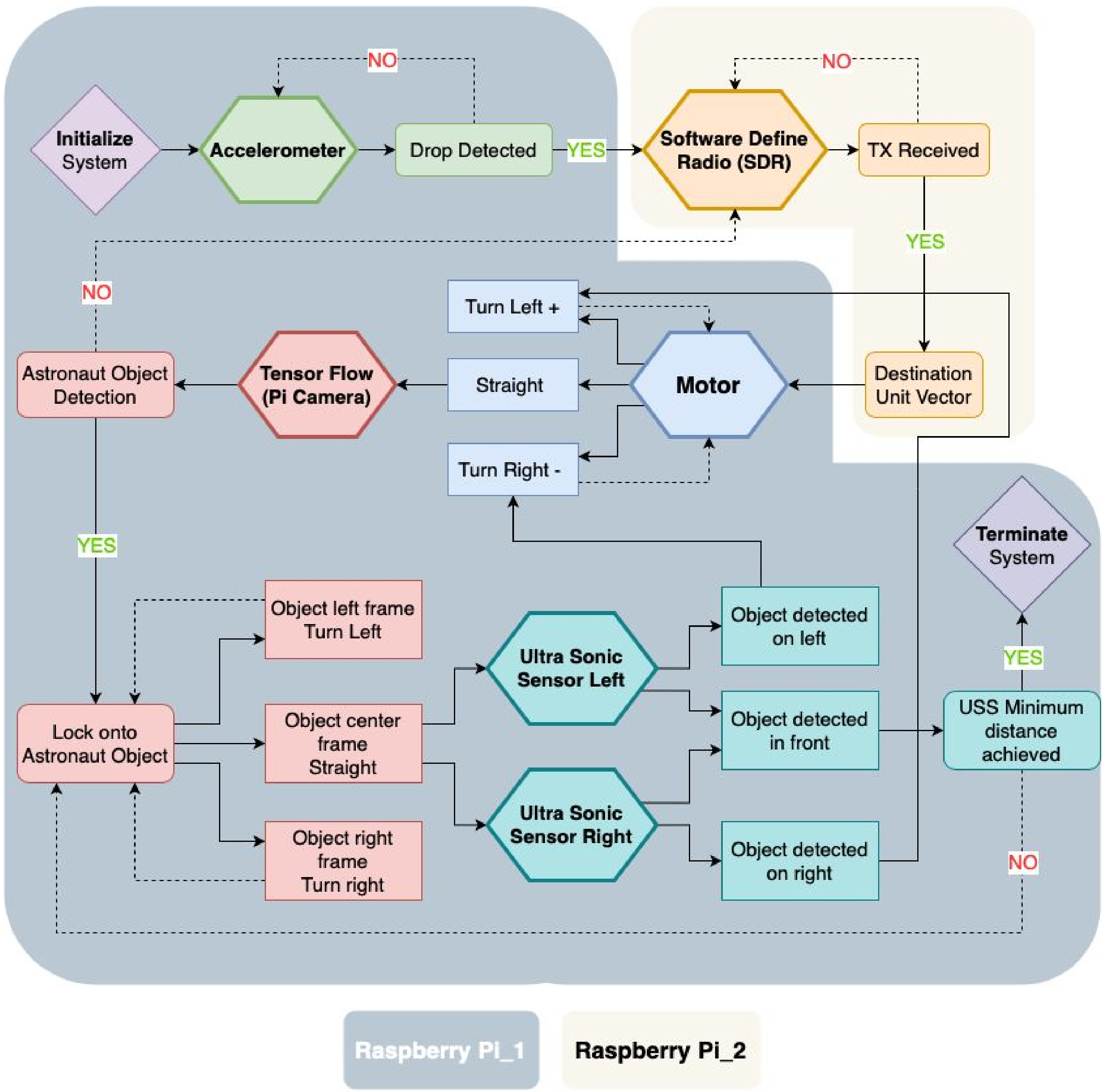


Figure 5: System Block Diagram defining specific actions and states of the AMSAR system.

Accelerometer ADXL337

To detect significant acceleration changes that indicate that AMSAR has been released by the drone and made an impact with the water, AMSAR will be equipped with the ADXL337 triple-axis accelerometer. The force of impact, tested to be 2.3g's from the drop, will initialize KerberosSDR, TF object detection, and USS object avoidance/proximity detection.

KerberosSDR

In order to receive transmissions from the ANGEL beacon, the KerberosSDR and its corresponding open-source software will be utilized. This encompasses a frequency range from 24 MHz to 1.7 GHz, allowing for testing in 121.5 MHz and 406MHz. Four omnidirectional antennas with a spacing factor of 0.15(λ) will be arranged in a uniform circular array and let AMSAR detect a relative unit vector toward the ANGEL beacon. The KerberosSDR will be occupying all of the computational power of one of the two Raspberry Pi's.

Motor Control

There are two divisions of motor control: throttling (dependent upon a drive motor) and steering (contingent with the servo motor). A script allowing inputs of the radio frequency for direction finding, object detection, and proximity detection will run both motors. The defined maximum throttle is active when the KerberosSDR is the only sensor returning an output. Upon visual detection, the throttle will be reduced and the triggering of the ultrasonic sensor will halt the throttle completely. The initial destination vector shall be determined from the SDR's output, which then allows AMSAR to steer until its forward-facing unit vector is aligned with that of the destination relative unit vector. Turning shall only be dependent on the SDR and the object detection outputs. Fine steering control during the final approach will be informed by the output of the TensorFlow computer vision software. Nozzle horizontal movement shall be controlled via a servo motor connected at the top of the nozzle refer to *Cross Sectional View of the AMSAR Propulsion System[Figure 17]*. As the KerberosSDR requires an entire computational unit, all of the motor scripts will be processed on the second Raspberry Pi. Along with this all of the proximity sensors and visual sensors are being processed via the second Raspberry Pi.

Object Detection

Once the vehicle has started advancing towards the astronaut in distress, the AuviPal Raspberry Pi Camera shall begin the detection process, utilizing TensorFlow's open API. The model will be trained for person recognition in a maritime environment. Upon target recognition, the position of the astronaut within the camera's frame will determine subsequent turning and throttling as follows: if the target is located at the center of the frame, AMSAR shall throttle forward; when the target is situated to the left of the frame, AMSAR shall turn left, then proceed to throttle; if the target is to the right of the frame, AMSAR shall turn right, then proceed to throttle. The degree of turn shall be directly correlated to the offset between the detected astronaut centroid and the frame center. The first Raspberry Pi will have the Google Coral TPU as an attachment optimizing our performance significantly, the current average

FPS return is 38.00 FPS relative to the initial 4.0 FPS we had upon starting.

Proximity Detection/Object Avoidance

The utilization of a single-view AuviPal Raspberry Pi Camera makes the system incapable of depth perception. To compensate for this, AMSAR shall utilize 2x Waterproof Ultrasonic Module JSN-SR04T. These sensor shall be running after the initial drop and can detect objects in a straight path up to four meters. Acquisition of a target within this range will begin AMSAR's deceleration until the ultrasonic sensor is also triggered, meaning the system has successfully reached the astronaut. As a safety precaution, AMSAR will cut power to the motor if there is no visual feed but an object is detected by the ultrasonic sensor. The software governing AMSAR has been integrated with a median filter to prevent false readings. Power and connection will be provided through the secondary Raspberry Pi 4 (Figure 4).

Circuitry & Wiring

The power source provided by the NBL issues DC current through a 5-millimeter female banana plug connector at 25 amps, 12 volts. Two 75-foot leads (coded positive ≡ red, grounded ≡ black) bridge the power supply and power distribution board (PDB) for the proper dispersion of current. All power-reliant equipment branches from the PDB in one of its four parallel sub-circuits: in **Figure 6**, from upper-left corner on the PDB and circling counter-clockwise: upper-left sub-circuit α, lower-left β, lower-right ɣ, upper-right δ.

Main power connections are represented by solid lines, while dashed lines show connections that include data transfer. It can be assumed that all components listed in a specific sub-circuit are connected in series (with the exception of the dependent Pi_1 components). For added measures of safety, each sub-circuit is designed to draw less than the maximum ratings of the lowest-rated equipment, while a blade-style fuse and DC step-down converter are placed between the PDB一sub-circuit interface. This ensures the proper voltage is being distributed to the equipment and prepares a mechanical watch-dog in the event of a spontaneous, high-current draw.

Within the sub-circuits, power distribution is optimized for equipment requiring stable current flows, such as the KerberosSDR and two Raspberry Pi's.

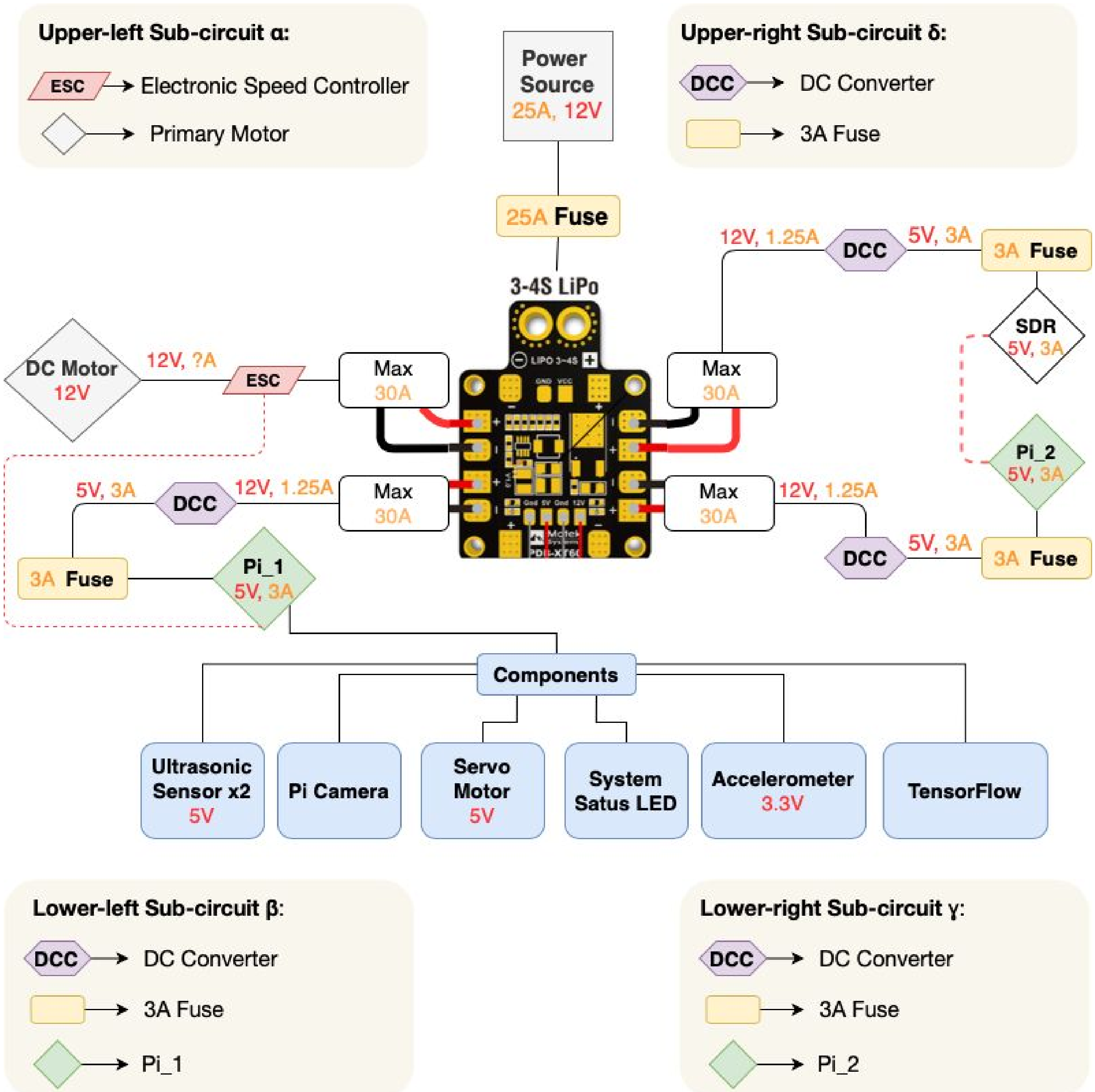


Figure 6: Electronic Circuit Diagram

---

*Components listed under Pi 1 are powered by and connected through USB buses or GPIO pins

Structure

Propulsion System

The propulsion system for the vehicle is based on a dual internal propeller system. Water comes in through the inlet on the bottom of the vehicle, and is accelerated by the first propeller through the aluminium ridges in the cooling block. The cooling block dumps heat from the electronics into the water. The second propeller accelerates the water again to make up for energy losses from friction and turbulence caused by the cooling fins. The water exits through the nozzle at the rear of the vehicle, which is pivoted by a servo motor to provide steering control.Refer to Figure 16 for a diagram of the propulsion system with overall dimensions.

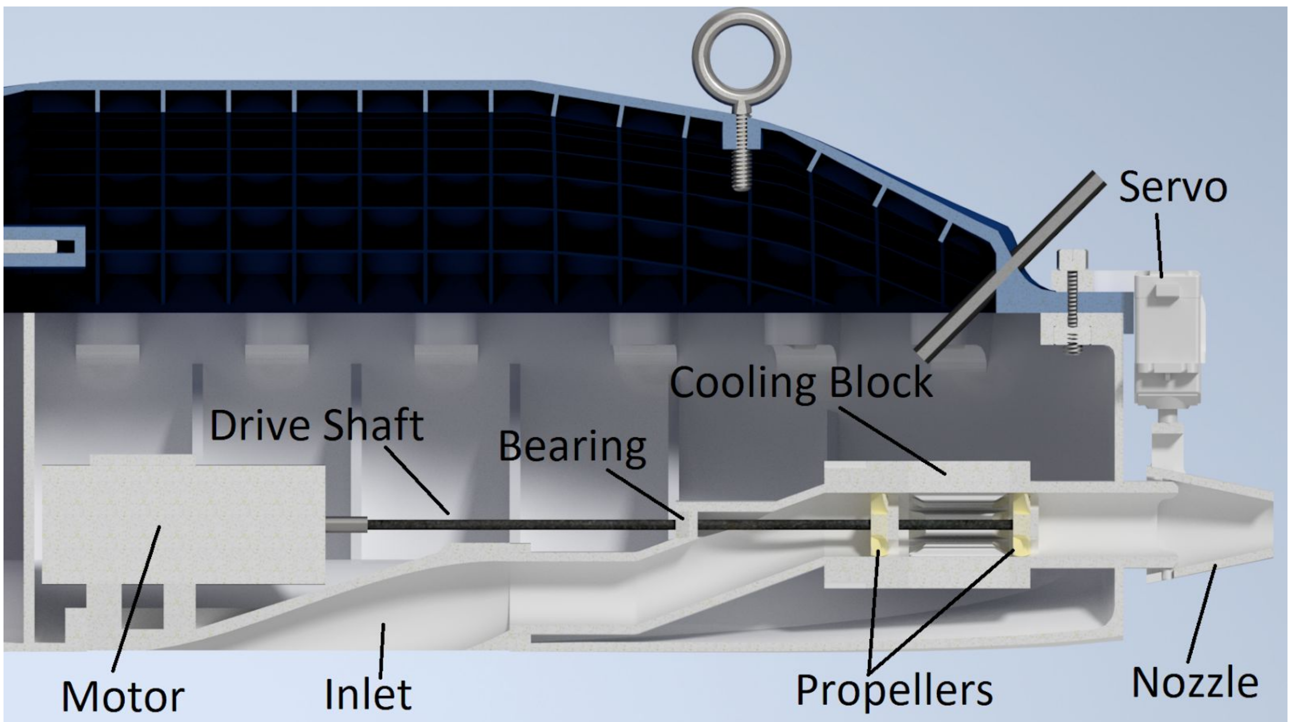


Figure 7: Cross Sectional View of the AMSAR Propulsion System

Cargo Bay/Handle

Previously, the cargo bay was designed as a rectangular box located at the underside of the vehicle cover. The updated design places the cargo inside the front hull segment, accessed through the hatch in the cover. This placement utilizes the internal volume of the vehicle more efficiently than the previous design. The cargo bay and the electronics bay are separated by an internal hull wall. The mechanical latch has been redesigned to feature a protruding handle to provide better grip and access for the user. To access the cargo bay, the handle is rotated until it stops, then the hatch is lifted out of the vehicle.

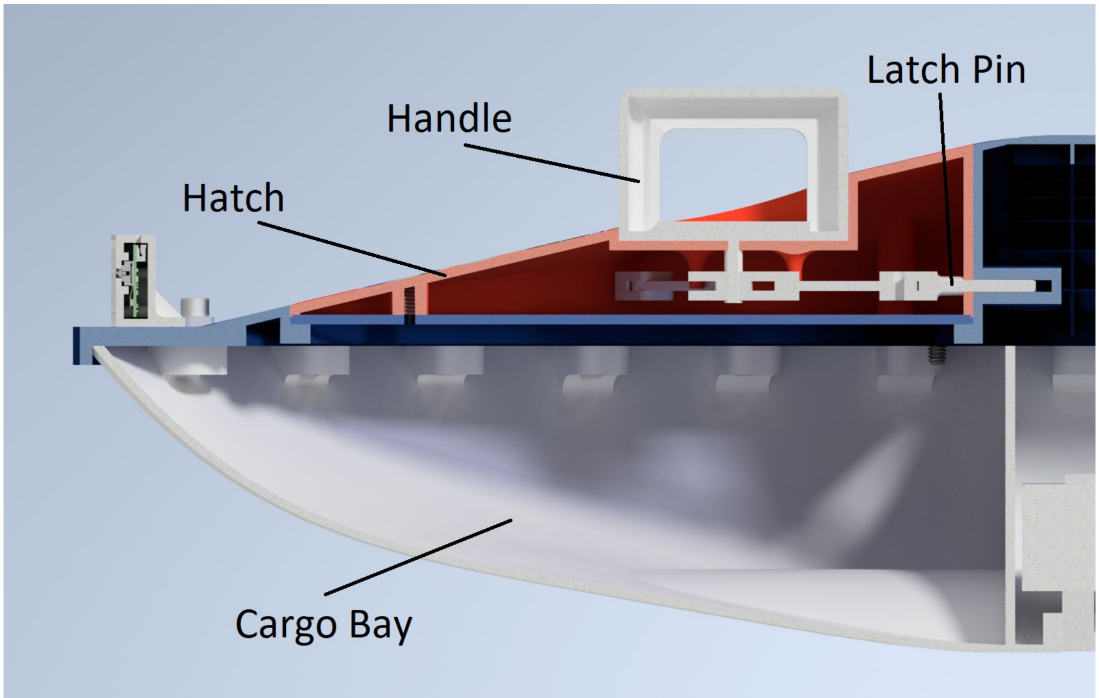


Figure 8: Annotated Cargo Bay Diagram

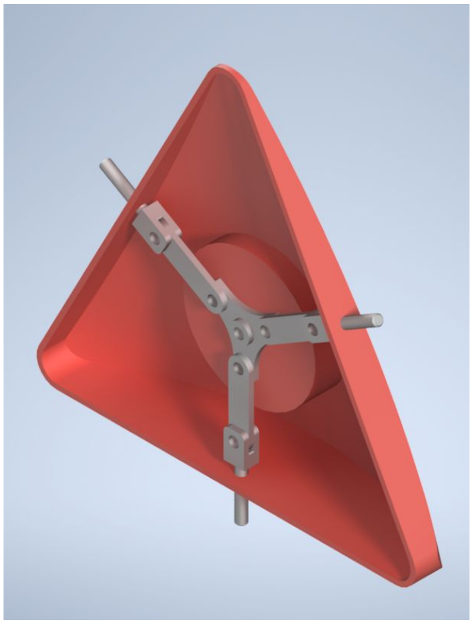


Figure 9: Hatch Pins Engaged

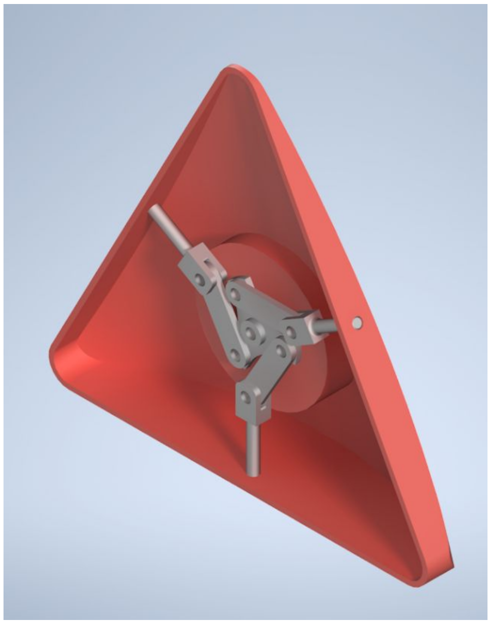


Figure 10: Hatch Pins Disengaged

C. Functional/Technical Requirement Compliance Matrix

Req No.	AMSAR Requirement Design Justification
1	The hull is constructed from ABS-like “Tough Resin” 3D printed using stereolithography. This design has been analysed with finite element analysis in Autodesk Inventor and these results show a minimum factor of safety of 1.99 under the expected impact loads(See Hull Material in Section III). The structure of the vehicle consists of a cover and a hull, which are each printed in 2 pieces which are joined using an NBL approved epoxy along a lip and groove interface. The cover will be joined to the hull using aluminium socket head screws with a rubber gasket layer in between.
2	The vehicle is extremely compact, the maximum dimension being the length at approximately 26 inches. This small size, lightweight materials, and a hull thickness of ~0.1 inches for most of the vehicle, leads to an extremely light weight of ~11 lbs without cargo. Using only 55.9% of the mass budget for a group 1 UAV.
3	AMSAR has a cargo bay located in the front section of the hull with a usable cargo volume of ~4 liters. Our team calculated that this should be enough space to carry all required mission cargo. The cargo bay will remain watertight until the hatch is opened using a simple rotating handle mechanism detailed in Section III Cargo Bay/Handle.
4	KerberosSDR shall be utilized to receive the ANGEL Beacon’s transmission. A circular configuration of four omnidirectional whip antennas with a spacing factor of 0.15λ will allow AMSAR to maintain a directional unit vector toward the beacon. The equipment’s range is from 24MHz - 1.7GHz, allowing for a received signal tailored to the mission needs through KerberosSDR’s open-source software.
5	Upon impacting the water surface, AMSAR’s SDR will initialize its radio direction finding algorithm. This provides the Pi with a unit direction vector towards the homing signal. The propulsion system is then commanded to align AMSAR with the unit vector. During this phase, USS and the PiCam are detecting objects. AMSAR will avoid objects detected, and will return to the unit vector path once it detects no objects in its path. A Video stream created by the PiCam is processed using TensorFlow object detection, which has been trained to detect a person in water. Once the person has been detected, AMSAR will perform maneuvers to maintain the person in the center of the frame and head towards them. With the person centered, the USS will be able to detect them at a safe distance of 9 feet and come to a stop within a 5 foot radius. This process is entirely automated and reliant upon the electrical system embedded in AMSAR.
6	Measures have been taken to ensure AMSAR is safe to personnel in the test environment. For software, a watchdog has been implemented that will detect time out protocols in the system. Upon detection, the software will force that specific system to reinitialize. AMSAR itself will have warning labels for possible hazards. There are numerous fuses throughout the electrical system which ensures component safety in the event of hazardous failure. An in-depth examination of hazards and their mitigation can be found in Section VII.

V. Analysis & Testing

A. Engineering and Structural Analysis / Results

⊟ Material(s)

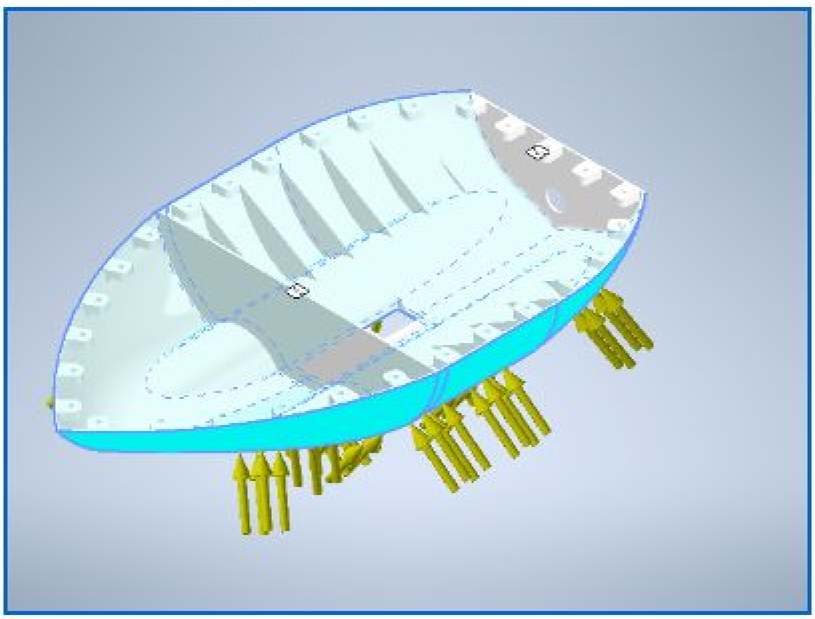
Name	ABS Plastic	
General	Mass Density	0.0382949 lbmass/in^3
	Yield Strength	2900.75 psi
	Ultimate Tensile Strength	4293.12 psi
Stress	Young's Modulus	324.885 ksi
	Poisson's Ratio	0.38 ul
	Shear Modulus	117.712 ksi
Part Name(s)	AMSAR Hull MK 5 Rear.ipt AMSAR Hull MK 5 Front.ipt	

⊟ Operating conditions

⊟ Pressure:1

Load Type	Pressure
Magnitude	0.300 psi

⊟ Selected Face(s)



⊟ Result Summary

Name	Minimum	Maximum
Volume	55.672 in^3	
Mass	2.13195 lbmass	
Von Mises Stress	0.0000566686 ksi	1.45902 ksi
1st Principal Stress	-1.71077 ksi	0.320404 ksi
3rd Principal Stress	-3.24895 ksi	0.0673714 ksi
Displacement	0 in	0.009761 in
Safety Factor	1.98815 ul	15 ul
Stress XX	-1.73359 ksi	0.185969 ksi
Stress XY	-0.210431 ksi	0.0936639 ksi
Stress XZ	-0.101588 ksi	0.105007 ksi
Stress YY	-3.24452 ksi	0.303336 ksi
Stress YZ	-0.177143 ksi	0.0876867 ksi
Stress ZZ	-1.86627 ksi	0.150722 ksi
X Displacement	-0.00391771 in	0.00391814 in
Y Displacement	-0.000725842 in	0.00934689 in
Z Displacement	-0.00157111 in	0.00122018 in
Equivalent Strain	0.000000162632 ul	0.00476982 ul
1st Principal Strain	-0.0000146013 ul	0.0011389 ul
3rd Principal Strain	-0.00579492 ul	0.00000585118 ul
Strain XX	-0.00083021 ul	0.000796579 ul
Strain XY	-0.000893842 ul	0.000397853 ul
Strain XZ	-0.000431513 ul	0.000446036 ul
Strain YY	-0.00577611 ul	0.000668418 ul
Strain YZ	-0.000752444 ul	0.000372463 ul
Strain ZZ	-0.000361983 ul	0.000342932 ul
Contact Pressure	0 ksi	0.671229 ksi
Contact Pressure X	-0.0742023 ksi	0.104265 ksi
Contact Pressure Y	-0.0972671 ksi	0.110063 ksi
Contact Pressure Z	-0.612838 ksi	0.669244 ksi

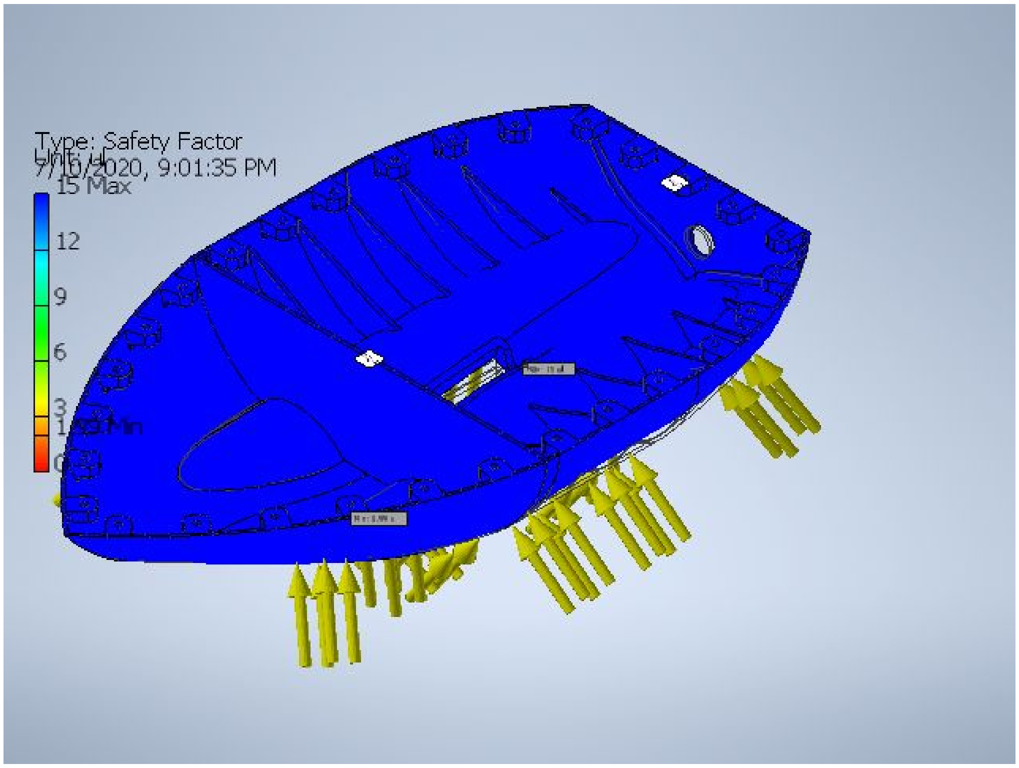


Figure 11: Safety Factor Visual Representation

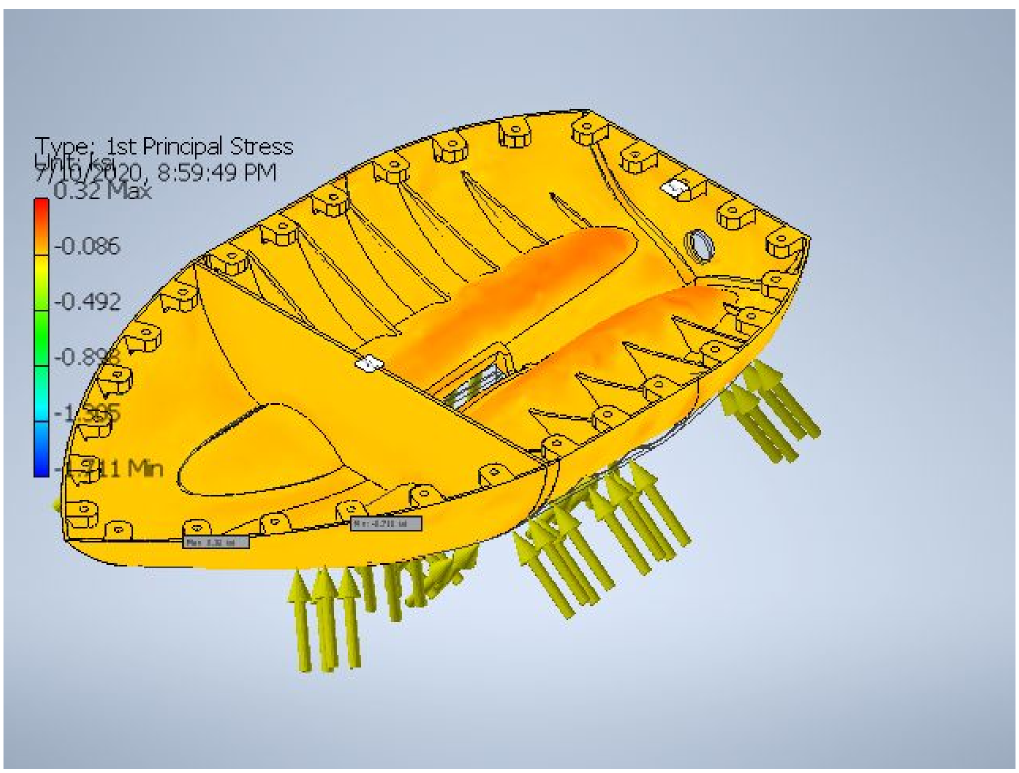


Figure 12: Principle Stress Visual Representation

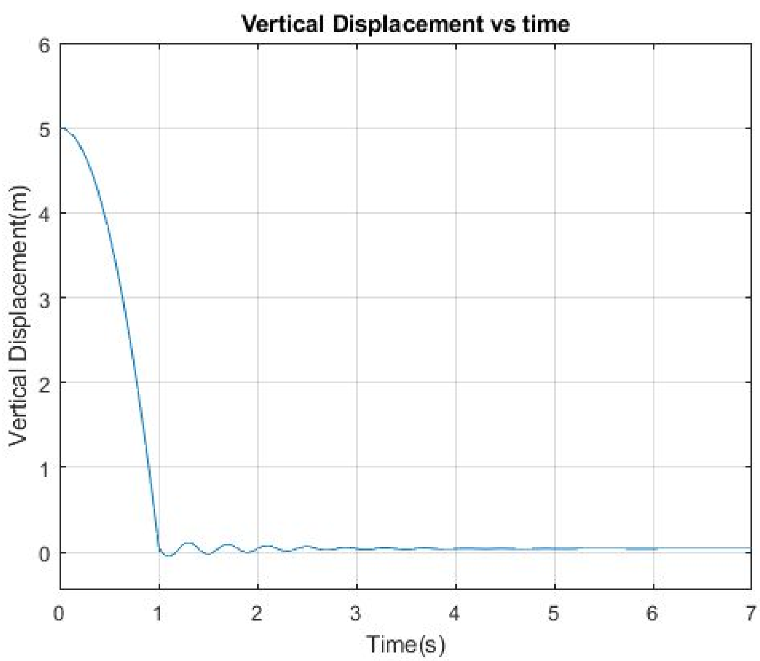
B. Testing Description and Results

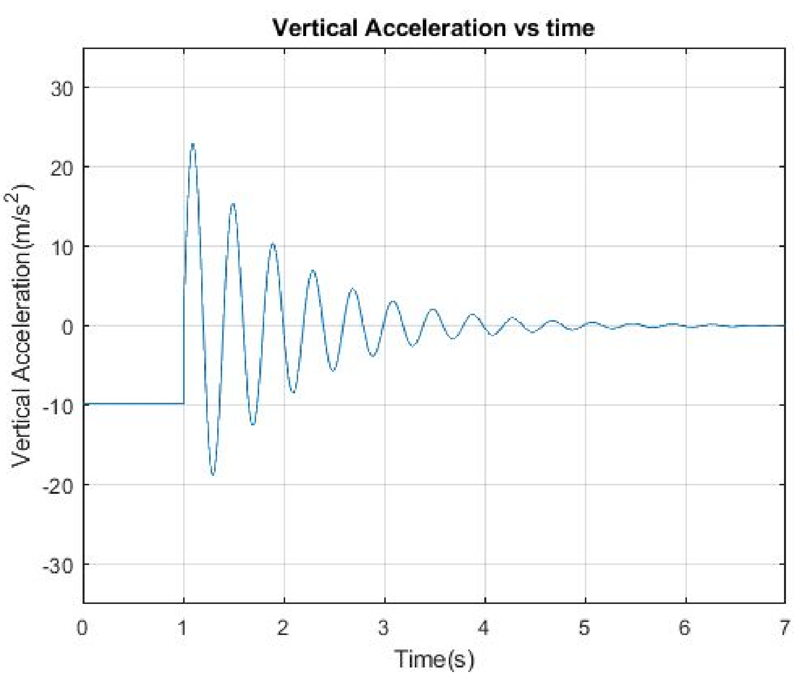
Finite Element Analysis Setup Rational

The forces used in the Finite Element Analysis were determined using the mass of the vehicle and the drop height to determine the velocity of the vehicle just before impact with the surface of the NBL pool. This was done by using the kinematic equations for constant acceleration. For this phase of the calculation, the vehicle is approximated by a point located at the center of mass. The impact with the water is modeled as an infinite impulse over zero time using the Dirac delta function. The approximate solution to this differential equation is shown by the MatLab output below. All integration constants were tuned by hand until they provided a reasonable approximation.

$$y(t) = (\mathrm{heaviside}(t - 1.0096) - 1)\ (4.9050\,t^2 - 5) - \mathrm{heaviside}(t - 1.0096)\ (0.1000\,e^{1.0096-t}\sin(15.7873\,t - 15.9395) - 0.0394)$$

```
The physical constants in the equations need to be calibrated, but these
plots show the kind of behavior that can be expected from the drop test in the NBL.
Constant acceleration freefall until impact, then decaying harmonic oscillation as energy dissapates.
```





Given the uncertainty in these calculations, an instantaneous acceleration of 30 m/s^2 was chosen for calculating the impact force on the vehicle. The differential equations were solved in metric, and the force results were converted to US customary units to work with the information provided by the cad model.

$$Weight = 20lbs = 88.96N = F_g$$

$$F_g = m * g\,,\ m = 88.96N/9.81\tfrac{m}{s^2}\,,\ m = 9.07kg$$

$$\Sigma F = m * a\,,\ \Sigma F = 9.07kg * 30\tfrac{m}{s^2} = 272.1N = 61.17lbs$$

$$Hull\ Area = A = 277.631in^2$$

$$Pressure = P = F/A = 61.17lbs/277.631in^2 = 0.22psi$$

The FEA was performed with a uniform surface pressure of 0.3 psi across the surface of the hull that will impact the water. This pressure was rounded up for a worst case scenario, due to the uncertainties involved and the fact that higher pressures will be experienced by some areas as the hull splashes down. The area over which the force is applied grows as more of the vehicle impacts the water. Based on the approximations and assumptions that went into the FEA, the simulation can be presumed to represent the real world behavior of the system reasonably well.

VI. Operations Plan

A. Device Configuration

AMSAR will be received as stored in a reinforced container upon arrival. The case will include foam to prevent movement, as well as bubble wrap to protect against impact. Below are the recommendations for handling the device on delivery.

1. Upon arrival AMSAR will be ready and assembled.
2. As a precautionary measure we recommend the rear cover be removed in order to verify no internal hardware components are damaged during shipping.
3. To remove the rear cover unscrew all of the labeled socket head screws, and pull the rear cover off.
4. Examine the hardware components for any visible damage or any wire disconnect. An expected layout will be shipped with AMSAR.
5. Reattach the rear cover and screw the socket screws back in their corresponding positions.
6. The shipping container will also contain four antennas that need to be screwed in by hand in their corresponding positions.
7. The position where the antennas need to be screwed in will be labeled, the antennas do not have a specific order and can be placed in any of the four positions.
8. Ready for testing.

B. System Test Objectives

The system test objectives will be separated into 3 different sections: Primary Test Objectives, Secondary Test Objectives, and Post Test Objectives. Primary objectives are in relation with the mission critical portions of the test. Secondary objectives are non-mandatory testing requirements. Post objectives will focus on portions of the test that can only be performed after running the system for an extended period of time.

Primary Test Objectives

1. Maintain safe functionality of the system upon initial drop into the maritime environment.
2. Reach personnel/beacon in a maritime environment without colliding with any objects.
3. Reach personnel/beacon in a maritime environment within a certain point of accuracy which shall be a radius of 5 feet.
4. Halt system within 5 foot radius of the personnel/beacon.
5. Personnel shall be able to open the system hatch to access safety equipment.

Secondary Test Objectives

1. Upon reaching personnel/beacon does status LED update from glowing red to blinking red as an indicator of arrival.

Post Test Objectives

1. Verify temperature did not exceed 60°C on Raspberry Pi's during operation using internal health monitoring systems. Systems can be checked on site using an external SSH or by sending the SD card back to the University at Buffalo.

2. Verify that the expected time of arrival is at most 50% faster than actual time of arrival. Systems time can be checked on site using an external SSH or by sending the SD card back to the University at Buffalo. Assuming post test the NBL will provide the distance of shortest path.

C. Test Procedure / Hardware Operation

The following test procedure is designed to test the autonomous capabilities of the AMSAR.
AMSAR is operating under the assumption that the personnel will have the ANGEL beacon in the NBL pool.

1. Open the cargo bay by turning the labeled cargo hatch handle clockwise until it halts and then lift upwards.
2. Place TBD safety equipment in the cargo bay, in the corresponding orientation and position. More information will be provided upon the finalized equipment list.
3. Close the cargo bay by placing the cargo hatch back in the original orientation and turning the cargo hatch handle counterclockwise until halt.
4. Attach AMSAR mounting mechanism to designated crane mount.
5. Raise AMSAR to designated height with the crane.
6. Power AMSAR by plugging in the 75ft wire cable into the power supply.
7. Wait for AMSAR to initialize by waiting for the exterior LED to turn on and maintain a solid green light.
8. If AMSAR LED is blinking green, reinitialize the system by switching external power supply off and on.
9. Have personnel turn on the ANGEL beacon and transmit at 121.5 MHz.
10. Release AMSAR from the crane using the release mechanism.
11. Upon colliding with the water AMSAR shall begin its initial protocol and home onto the ANGEL beacon's transmitter. At this point a secondary LED will glow a solid red. AMSAR shall begin moving to the estimated location of the ANGEL beacon. Upon detecting personnel in the water, AMSAR will begin its next phase, maneuvering to focus the personnel in the center of the PiCam stream.
12. In the event of objects being in the path of AMSAR, the system shall redirect continuing to attempt to find a path to the ANGEL beacon.
13. Once within the predetermined range of the ANGEL Beacon, AMSAR will come to a halt and the secondary red LED will begin to blink, signaling to the personnel it is safe to approach.
14. The designated personnel should now turn the cargo hatch handle until halt, which will be labeled clearly, clockwise and lift upwards.
15. AMSAR will now shut down upon opening the cargo hatch.
16. Have personnel remove all safety equipment from the cargo bay.
17. Power off or disconnect the wire that is leading to AMSAR.
18. Return AMSAR to its initial starting position.
19. Repeat steps 1 - 18 a total of three times, if time permits.

VII. Hazard Analysis

A. Hazard Analysis Table

Hazard	Cause/Scenario	Consequence/Effect	Controls and Verification	Status
Structure				
Thermal	Overheating of System	Raspberry Pi shuts down, preventing AMSAR’s further movement, delaying mission until cooled down.	A custom heat sink shall be implemented to dissipate heat from the Raspberry Pi to the external maritime environment through the use of intake water applied on the heat sink.	Controls in Place
		Motor no longer performs in optimal conditions, leading to vibrations affecting stability and adds heat to electrical components.	A heat sink shall be implemented to dissipate heat from the motor to the external maritime environment through the use of intake water applied on the heat sink.	Controls in Place
Waterproofing	Hull Cavities-Openings	Water enters the inner vehicle affecting circuitry.	The hull of the system will be two halves bolted together and sealed with a waterproofed NBL-approved Hi-Solids Catalyzed Epoxy connection. Testing shall be conducted to ensure that the system is buoyant and sealed properly. The electrical components do have some water resistance as they are in a watertight case.	Controls in Place

	Water Entering Propulsion Motor	Water damages the motor resulting in loss of the propulsion system.	The motor shall be connected to the propellers via a drive shaft and waterproofed through the use of a watertight ball bearing.	Controls in Place
	Nozzle Servo Motor	Water damages the motor, resulting in loss of direction control.	A watertight ball bearing shall be used to waterproof the servo motor to the nozzle connection in the same manner in which the drive shaft is waterproofed . The servo motor will be bolted to the exterior above the nozzle, and is built as waterproof.	Controls in Place
Impact-Resistant Structural Integrity	Lower Hull cracks due to impact	Renders vehicle defective. Mission no longer achievable.	The hull will be printed in ABS-Like “Tough Resin” using stereolithography. The structure has integrated supports to prevent fracture. The design has been validated through FEA with a minimum factor of safety of 1.99.	Controls in Place
	Internal Circuitry & Systems shift out of place.	Possible damage and disconnection of electrical components.	Electrical components will be firmly connected to the inside of a waterproof case.	Controls in Place
	Camera is damaged upon drop impact.	Loss of a close-range sensor.	The visual equipment shall be in a sealed and bolted case mounted to the front of the vehicle.	Controls in Place
Software/Sensors				

Software Operation	Software Timeout	System stops and the mission is delayed.	A watchdog timer will be implemented in the case of software timeout. If the system fails to reset the timer, the system will reinitialize, excluding the accelerometer.	Controls in Place
	Inaccurate Human Detection in Maritime Environment With Raspberry Pi Camera	Astronauts are not recognized, at close range.	Human detection in a maritime environment shall be implemented using TensorFlow software. A model has been trained in order to detect people in a maritime environment. As an additional redundancy the model will be trained to detect the personnels suit color. Additionally, ultrasonic sensors are in place as an alternate close-range sensor.	Controls in Place
Sensor System Operation	Ultrasonic Sensor damaged due to water.	No longer have multiple close-range detection sensors.	A waterproof sensor has been purchased and the connection interfaces will be sealed with NBL-approved Hi-Solids Catalyzed epoxy.	Controls in Place
Electrical				
Power Connection	Unsecured Electrical Power Connection	Vehicle shuts off due to lack of power, water becomes a conductor.	1) Umbilical cord shall be wired through the rear of the hull and permanently fastened to the interior. 2) Fuse in place between power source and vehicle to prevent the system from over drawing power.	Controls in Place

Waterproofing	Internal Circuitry & Systems Brought into Contact with Water	System short circuits.	AMSAR has been designed to be constructed in two separate halves. By means of bolt connections and NBL approved Hi-Solids Catalyzed epoxy, it shall prevent water from reaching internal electrical components. The components themselves (except for certain sensors and the motors) will be placed in a watertight case.	Controls in Place
Operational Hazards				
Potential Hazards to User	Exposed Propeller	Incised Wound inflicted onto user (who has touched a running propeller)	1) The propeller shall be placed within internal piping running through the hull's bottom to prevent contact with the external environment. 2) The generated flow of water will prevent the entry of materials into the pump outlet.	Controls in Place
	Shape Design featuring sharp edges	Possible incised wounds inflicted onto astronauts.	The vehicle shape shall be manufactured to have rounded edges, as to mitigate sharp corners.	Controls in Place
	Users unaware of vehicle functions.	User interacts unexpectedly with the vehicle incurring self-harm.	Warning tags for hazardous areas and operation shall be used. Operational directions shall be labeled on the capsule prior to testing.	Controls in Place

	Vehicle does not decelerate and runs at dangerous velocity.	User is collided by vehicle incurring harm.	Full stop time and distance required from cutoff to power (upon target detection) and target collision shall be found via deceleration testing. This testing will determine ideal reduced throttle, and ultrasonic sensor trigger distance.	Controls in Place
Potential Hazards during run	Water Obstructs Camera during mission	Inaccurate visual detection.	1) A protective case will act as a waterproof protectant for the visual equipment. 2) Additional close-range sensor in place.	Controls in Place
	Collision with pool extremities or objects.	Vehicle or objects damaged upon impact.	Close range sensors in place to prevent object collision.	Controls in Place
	Premature Motor Activation	UAV drone stability compromised prior to drop	Accelerometer is implemented for impact detection, which will subsequently initialize both motors and the SDR.	Controls in Place

B. Supplemental Description

There were many hazards to be taken into consideration for the safety of this design. NBL Engineering and Safety Requirements for Micro-G NExT were followed to help ensure the safety of this design. Hazards were considered from all different aspects and areas in regards to this project. This included considering hazards in structural, software, and electrical areas.

Hazards such as overheating, waterproofing, and structural integrity were considered with the hardware design. Overheating of the system can potentially affect the Pi's, as well as the motor. If either Pi shuts down, it would prevent AMSAR from moving until it has cooled down. Overheating of the motor could potentially render it unable to propel the vessel. This could then affect other components of the design. For the Pi's, a custom heat sink will be implemented to dissipate heat to the external maritime environment through the use of intake water applied on the heat sink. For the motor, a heat sink will be implemented to dissipate heat to the external maritime environment through the use of intake water applied on the heat sink. Waterproofing of components also needed to be considered in the hardware design. This included any hull cavities or openings, as well as the primary and servo motors. This could cause water to enter the inner vehicle, thus compromising the circuitry. Water would damage the motor, which would result in the loss of the propulsion system. Water damaging the servo could cause the loss of direction control. Multiple measures have been taken with the design to address these potential problems. The hull of the system will be two halves bolted together. They will be sealed with a waterproofed NBL-approved Hi-Solids Catalyzed Epoxy connection. Testing will be conducted to ensure that the system is buoyant and sealed properly. Electronic components will be housed in a waterproof case that is bolted to the interior of the vehicle. The motor will be connected to the propellers using a drive shaft, and will be waterproofed through the use of a watertight ball bearing. The servo motor will be bolted to the exterior above the nozzle, and is waterproof (as stated by the manufacturer). The structural integrity of the design could potentially be affected by lower hull cracks from impact, the shifting of internal systems and circuitry, and the camera being damaged on impact. A crack in the hull could render the vehicle defective, no longer allowing for a successful mission. If any internal components are shifted, this could cause possible damage as well as potential disconnections of electrical circuitry. If the camera is damaged, there would be a loss of a close-range sensor. To address these concerns, the hull will be made of 3D printed SLA resin, including a frame-like structure. The hull has a minimum factor of safety of 1.99 under the expected impact loads. The inner components will be secured in a waterproof case bolted to the interior of the hull.In order to protect the visual equipment, it will be sealed and bolted in a case mounted to the front of the vehicle.

Hazards such as software operation, as well as sensor system operations were also considered. Software operation can be affected by the software timing out, as well as inaccurate human detection. This can result in systems stopping, mission delay, as well as the astronaut not being detected at close range. To help make sure these issues are avoided, a watchdog timer will be implemented in the case of software timeout. If the system fails to reset the timer, the system will reinitialize, excluding the accelerometer. Human detection in a maritime environment will be implemented using TensorFlow software. A model has been trained in order to detect people in a maritime environment. As an additional redundancy the model will be trained to detect the personnels suit color.

Hazards such as power connections and waterproofing can also affect electrical systems. This could cause a non-secured electrical power connection, and internal circuitry and systems coming in contact with water. This could cause the vehicle to shut off due to lack of power, with water becoming a conductor, and the systems to short circuit. These problems will be avoided by using an umbilical cord to connect to AMSAR through an opening in the vehicle cover that will be sealed using an NBL approved epoxy. The required 25A fuse will make sure the components do not overdraw and damage themselves. AMSAR is designed to be constructed in two separate halves. The bolted hull halves and NBL approved Hi-Solids Catalyzed epoxy will prevent water from reaching internal electrical components. There are also close range sensors put in place to help prevent object collision.

C. Testing Phase Hazard Analysis

Operational hazards were also considered, specifically in regards to the testing at NBL, and for the safety of the divers conducting tests. This includes potential hazards to users, as well as potential hazards during a testing run.

In regards to the user, potential hazards considered include an exposed propeller, a shape design featuring sharp edges, a user unfamiliar with the vehicle and its functions, as well as the vehicle not decelerating. Negative outcomes include: blunt trauma, incised cuts/lacerations, electrocution, and burns to the user. To avoid these outcomes, many safety precautions have been taken. The propellers shall be placed within the internal piping running through the hull's bottom to prevent contact with the external environment. The vehicle shape will be manufactured to have rounded edges, as to minimize sharp corners that could be harmful. Warning labels for hazardous areas will also be used. Operational directions will be labeled on the capsule before testing. Waterproof connections will be used with all electronic components. All electronic components will be stored in a watertight case to keep both the components and divers safe.

In regards to potential hazards during a run, issues include visual obstruction of the camera during the mission (by water droplets), collision with maritime objects, and premature motor activation. The consequences of these issues include inaccurate visual detection, damage to the vehicle or objects, and compromisation of UAV drone stability. To avoid these issues, a protective case will act as a waterproof protectant for the visual equipment, and an additional close-range sensor is in place. The accelerometer will detect initial impact with the water. This will subsequently initialize the rest of the system.

VIII. Forward Plan

A. Gantt Chart

As COVID-19 resulted in the closing of our institution AMSAR's production has been delayed due to funding loss, virtual environment, as well as new vendors. The following below is the updated project Gantt chart, with the final step as the proof of concept video and testing. However, this is dependent on AMSAR's structure print (estimated to arrive within the week of July 13th, 2020). An updated Gantt Chart is provided below:

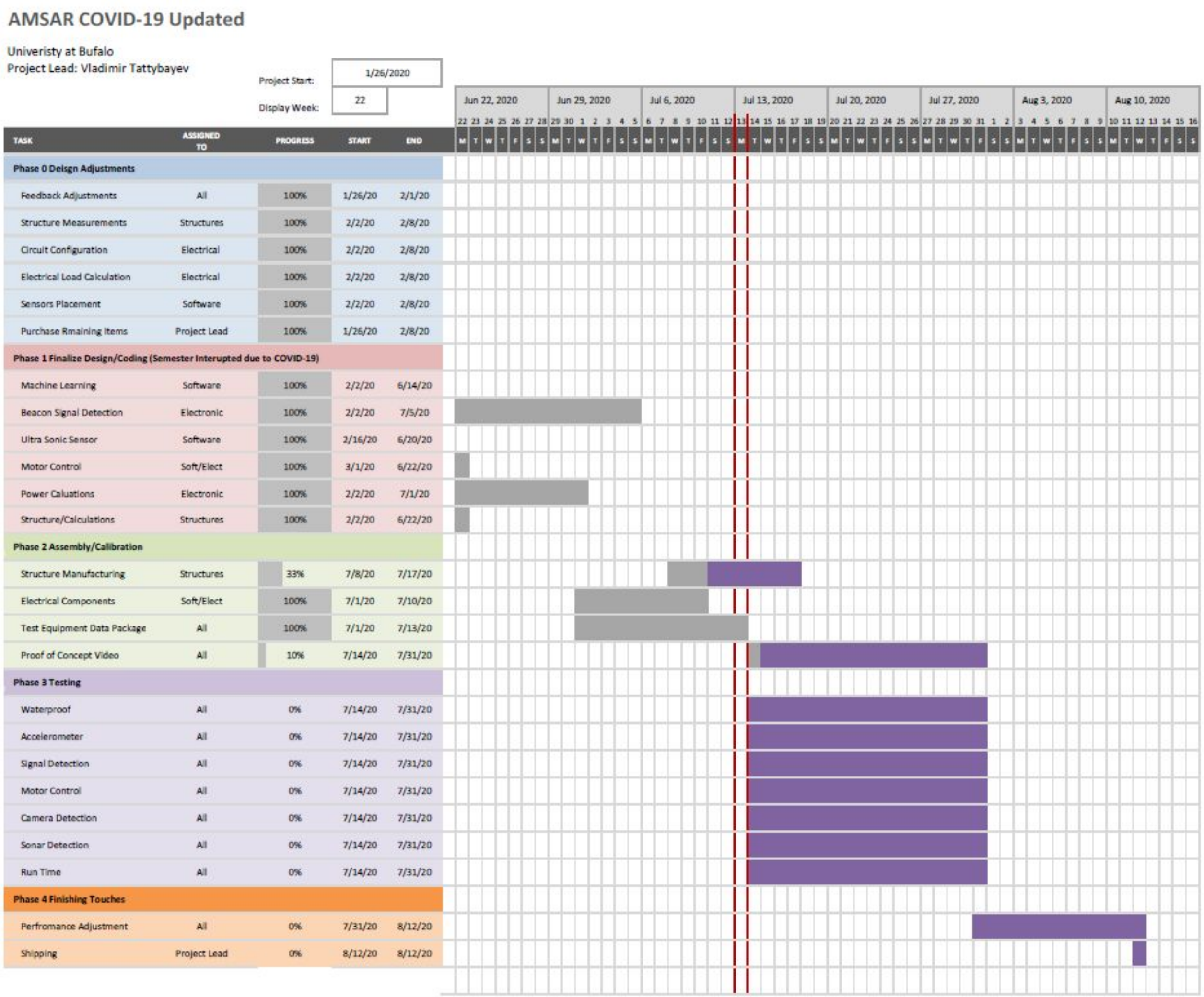


Figure 13: Gantt Chart describing future plans.

Electronics Testing

1. **Individual PDB Branch Testing**: Each branch of the electrical circuit in conjunction with the PDB and DCC will be tested where applicable (see **Figure 6**) to ensure proper powering to the individual parts of the circuit.
    a. Testing whether the Motor & ESC can be interfaced with and achieve variable spin.
    b. Test the functionality of Pi 1 and the attached sensor components.
    c. Verify SDR is functional when powered.

d. Verify Pi 2 is functional when powered.

2. **Integrated Circuit Testing:** All branches of the circuit through the PDB will be tested for the correct draw, its purpose being to ensure that the components are properly powered within safety regulations. Power consumption of all components except for the primary motor and ESC will be determined from a sub-test.

3. **Power Consumption Testing of Brushless Motor in Conjunction with Propulsion System:** A separate test of the motor's ability to function with the propulsion system will be completed using varied loads. Further, power consumption for heating and cooling purposes will be determined by maxing out the motor.

4. **Waterproof Testing:** Verify the waterproofing capabilities of our assumed waterproof components (servo motor, ultrasonic sensor, etc.) and sealant materials through submergence while disconnected from power.

B. Shipping & Transfer

AMSAR will be shipped via a local shipping company in a reinforced container. The container itself will have labels indicating fragility and top orientation. AMSAR's interior will be protected with foam sheets to prevent movement and bubble wrap to protect against impact. Regardless of travel conditions, all components will be secured prior to transportation.

C. Supplemental Materials

As Micro-G NExT has shifted toward virtual facility testing, only AMSAR itself will be shipped ready for operation.

Appendix

III. Hardware Design

A. Technical Description

Table 1. Components Description

Contains component names, what they are referred to as, as well as a brief description of the function of each.

Component Name	Common Name	Brief Description
Raspberry Pi4 Model B	Pi	The design requires 2 Pi's to meet its processing requirements. The Pi's take data from the ultrasonic sensors, accelerometer, SDR, and PiCam, then actuate the motors after processing the data. These are central to the function of AMSAR.
KerberosSDR- 4 Channel Coherent RTL-SDR	SDR	A software defined radio used in conjunction with an antenna array to find the direction of the homing beacon.
LIS3DH "nano" Accelerometer	accelerometer	Small, low power accelerometer which can detect from 0 to 16g's. Used to detect impact and initiate AMSAR primary functions.
Kerberos Antennas (Including Base and Wires)	Antenna, antenna array	Intercepts 121.5 MHz signal from the ANGEL beacon and feeds this to the KerberosSDR. Organized in a circular array for direction finding with a spacing factor of .15 as suggested by Kerberos.
JSN-SR0T4-2.0 Ultrasonic Waterproof Range Finder	USS	Used to detect objects in the path of the AMSAR to avoid collisions. Placed on the front end of the AMSAR.
DSSERVO DS3225 Digital Servo	Servo	Used for control of the nozzle, allowing direction changes.
Matek FCHUB-6S Power Distribution Board	PDB	Power distribution board which splits power between the Pi's, KerberosSDR, and motor.

LED Light	LED	Used for personnel understanding of system phase.
Google Coral USB Accelerator	Coral	Tensor processing unit which speeds up TensorFlow, allowing the object detection through the PiCam to be faster.
Raspberry Pi Camera B01	PiCam	Small camera which allows the detection of the astronaut in water. Placed on the nose of the vehicle.
Typhoon Brushless Motor 600-42	Motor	Primary propulsion device, drives the propeller inside the water jet.
EFLA1080B 80-A Brushless ESC	ESC	Interfaces with the Pi and motor, allowing the Pi to change the speed of the motor.

Table 2. Electrical-Components Specifications

Main electrical components, including their weights, quantities, and volumes.

Component	Weight (lbs)	Quantity	Total Weight (lbs)	Length (inches)	Width (inches)	Height (inches)	Volume (in^3)
Typhoon Brushless Motor 600-42	0.67	1	0.67	3.35	1.42	1.42	5.31
EFLA1080B 80-A Brushless ESC	0.25	1	0.25	3.03	1.61	0.61	2.99
DSSERVO DS3225 Digital Servo	0.15	1	0.15	1.57	0.79	1.59	1.98
Raspberry Pi Camera B01	0.03	1	0.03	0.90	0.90	0.40	0.32
JSN-SR0T4-2.0 Ultrasonic Waterproof Range Finder	0.10	2	0.20	1.65	1.14	0.47	1.78
Google Coral USB Accelerator	0.07	1	0.07	1.18	2.56	0.31	0.95
Kerberos SDR- 4	0.60	1	0.60	4.75	3.50	1.50	24.94

Channel Coherent RTL-SDR							
Kerberos Antennas (Including Base and Wires)	0.43	4	1.73	2.50	2.50	41.97	5.27
LIS3DH "nano" Accelerometer	0.00	1	0.00	0.12	0.12	0.04	0.00
Raspberry Pi 4 Model B	0.52	2	1.04	3.35	2.20	0.53	7.84
LED Light	0.00	2	0.00	0.00	0.00	0.00	0.00
Matek FCHUB-6S Power Distribution Board	0.02	1	0.02	1.42	1.42	0.10	0.20
		Total Component Weight (lbs)	***4.77***			**Total Component Volume (in^3)**	***51.6***

Table 3. Electrical subcomponents Chart

Electrical Subcomponents	**Weight (lbs)**	**Quantity**	**Total Weight (lbs)**	**Length (inches)**	**Width (inches)**	**Height (inches)**	**Volume (in^3)**
D-Planet 5A DC-DC Adjustable Buck Converter	0.035	3	0.106	2.130	0.910	0.710	1.376
Bussmann 25A ATC Blade Fuses	0.001	1	0.001	0.875	0.875	0.125	0.096
Bussmann easyID 3A ATC Fuse	0.001	3	0.003	0.875	0.875	0.125	0.287
MAXX Products 10 ft Fut. HD Servo Wire	0.101	1	0.101	0.021	0.021	120.000	0.114
MAXX Products 12 AWG Silicone Wire, 3 ft	0.128	2	0.256	0.081	0.081	36.000	0.742
Gardner Bender Polyolefin Heat Shrink Tube	0.013	8	0.013	0.125	0.250	4.000	0.982
PLA 3-D Printed Waterproof Hard Case	TBD	1	TBD	TBD	TBD	TBD	TBD
		Total Subcomponent	***0.48***			***Total Subcomponent***	***3.60***

		Weight (lbs)				Volume (in^3)	
		Weight (lbs)				***Volume (in^3)***	

Table 4. Structural Components

Structural Components	**Material**	**Weight (lbs)**	**Quantity**	**Total Weight (lbs)**	**Length (in)**	**Width (in)**	**Height (in)**	**Material Volume (in^3)**
Propeller	PLA	0.001	2	0.002	0.2	0.75	0.75	0.027
Hull Front Section	ABS like “Tough Resin”	0.872	1	0.872	12.49	14	3.704	22.78
Hull Rear Section	ABS like “Tough Resin”	1.259	1	1.259	12.61	14	4	32.889
Cover Front Section	ABS like “Tough Resin”	0.872	1	0.872	12.9	14.25	2.963	22.781
Cover Rear Section	ABS like “Tough Resin”	1.413	1	1.413	13.04	14.25	3	36.9
Hatch Upper Cover	ABS like “Tough Resin”	0.395	1	0.395	8.402	9.343	2.261	10.31
Hatch Lower Cover	Polycarbonate	0.253	1	0.253	8.369	9.338	0.125	5.828
Handle	PLA	0.171	1	0.171	2.812	3.007	3.007	3.067
Rear Latch Pin	PLA	0.006	1	0.006	2.036	0.5	0.375	0.159
Side Latch Pin	PLA	0.006	2	0.012	1.87	0.5	0.375	0.151
Latch Link	PLA	0.004	3	0.012	1.976	0.5	0.125	0.106
Latch Hub	PLA	0.007	1	0.007	0.25	2	2	0.186
Latch Hub Cover	PLA	0.006	1	0.006	0.125	2	2	0.168
PiCam Front Plate	Polycarbonate	0.004	1	0.004	0.063	1.199	1.244	0.089
PiCam Housing	PLA	0.008	1	0.008	0.262	1.199	1.244	0.219
PiCam Housing Back	PLA	0.013	1	0.013	1.018	1.199	1.854	0.337
Servo Mounting Bracket	PLA	0.071	1	0.071	0.968	4.337	1.824	1.278
Nozzle	PLA	0.02	1	0.02	1.5	1.39	1.898	0.527
Outlet Tube	PLA	0.038	1	0.038	2	1.5	1.5	0.992
Cooling Block	Aluminium	0.2	1	0.2	1.181	1.5	1.5	2.052

	6061							
Propeller Casing	PLA	0.023	1	0.023	0.75	1.5	1.5	0.609
Elbow	PLA	0.065	1	0.065	4.469	1.5	2.043	1.688
Propeller Shaft	Aluminium 6061	0.028	1	0.028	7.93	0.125	0.125	0.097
Permanently Lubricated Ball Bearing	Steel	0.004	1	0.004	0.156	0.375	0.375	0.015
Inlet	PLA	0.145	1	0.145	5.25	2.25	1.27	3.781
Motor Clamping Bracket	PLA	0.019	1	0.019	0.927	2.25	1.25	0.341
5/8 Inch 1/4-20 Socket Head Screw	Aluminium 6061	0.005	24	0.12	0.875	0.188	0.188	0.046
1 Inch 1/4-20 Socket Head Screw	Aluminium 6061	0.006	3	0.018	1.25	0.188	0.188	0.06
3/4 Inch 1/4-20 Socket Head Screw	Aluminium 6061	0.005	2	0.01	1	0.188	0.188	0.051
1/4-20 Hex Nut	Steel	0.008	29	0.232	0.219	0.438	0.438	0.028
1/4 inch x 2-1/2 inch Screw Eye	Stainless Steel	0.044	3	0.132	2.5	1.187	0.141	0.153
			Total Structural Weight (lbs)	6.43	**Total Weight With Electronics**	11.2		

Note: PLA and “Tough Resin” weight estimates calculated using similar material ABS plastic in Autodesk Inventor as solid parts. Actual PLA parts will be lighter, due to being 3D printed at between 20 to 40% infill. The weight estimates for the PLA parts is a worst case scenario maximum possible weight for that geometry.

Table 5. NBL approved materials

Coatings	3M Adhesive Sealant, Plasite 7122

B. Functional Description

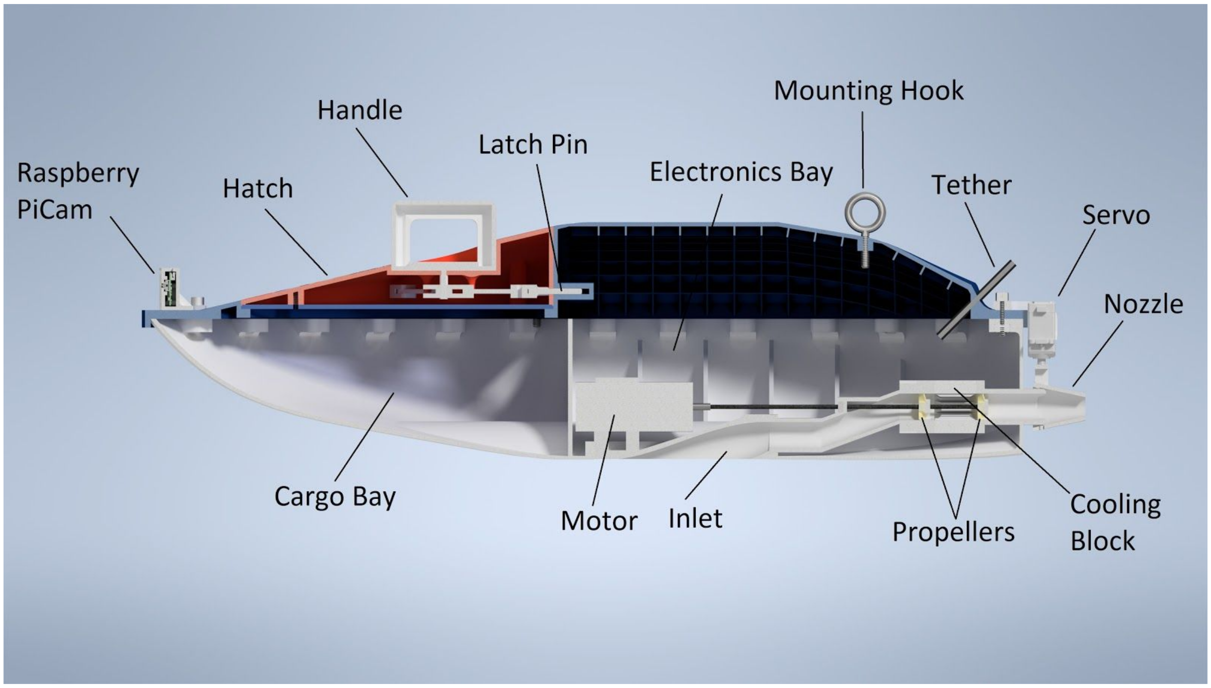


Figure 14: Cross Sectional View of AMSAR

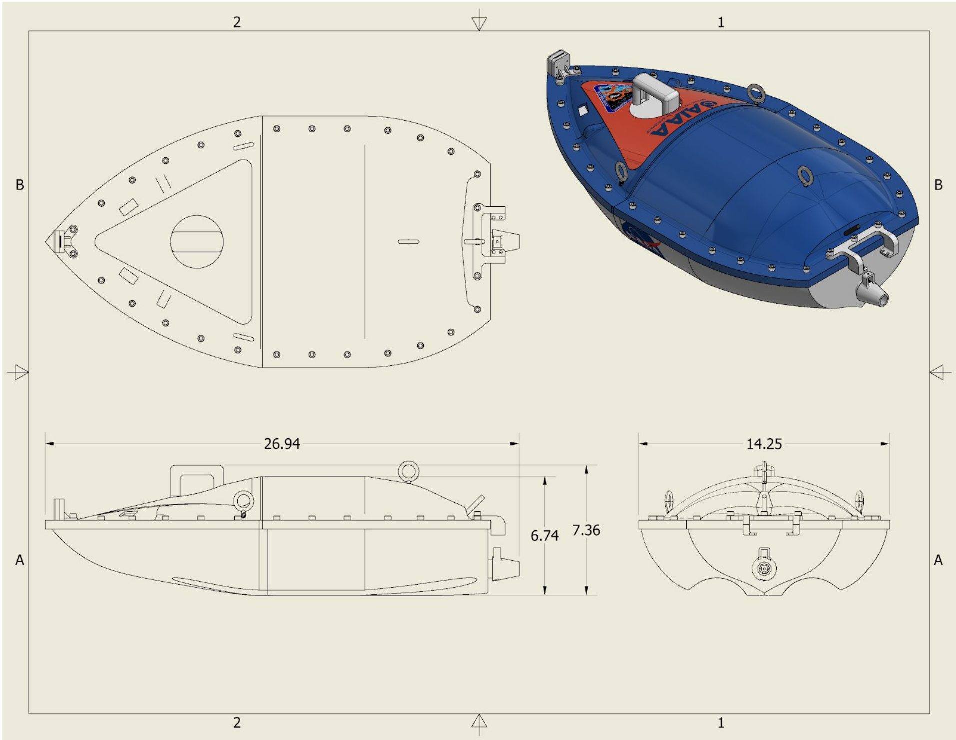


Figure 15: Overall Dimensions of AMSAR

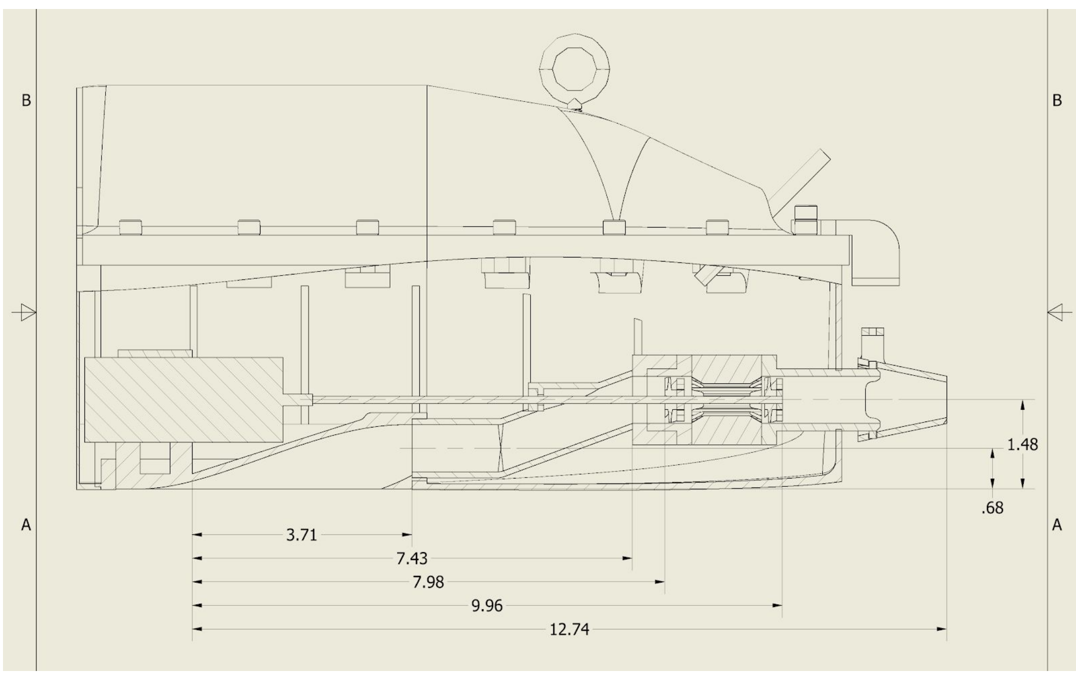


Figure 16: General dimensions of the propulsion system

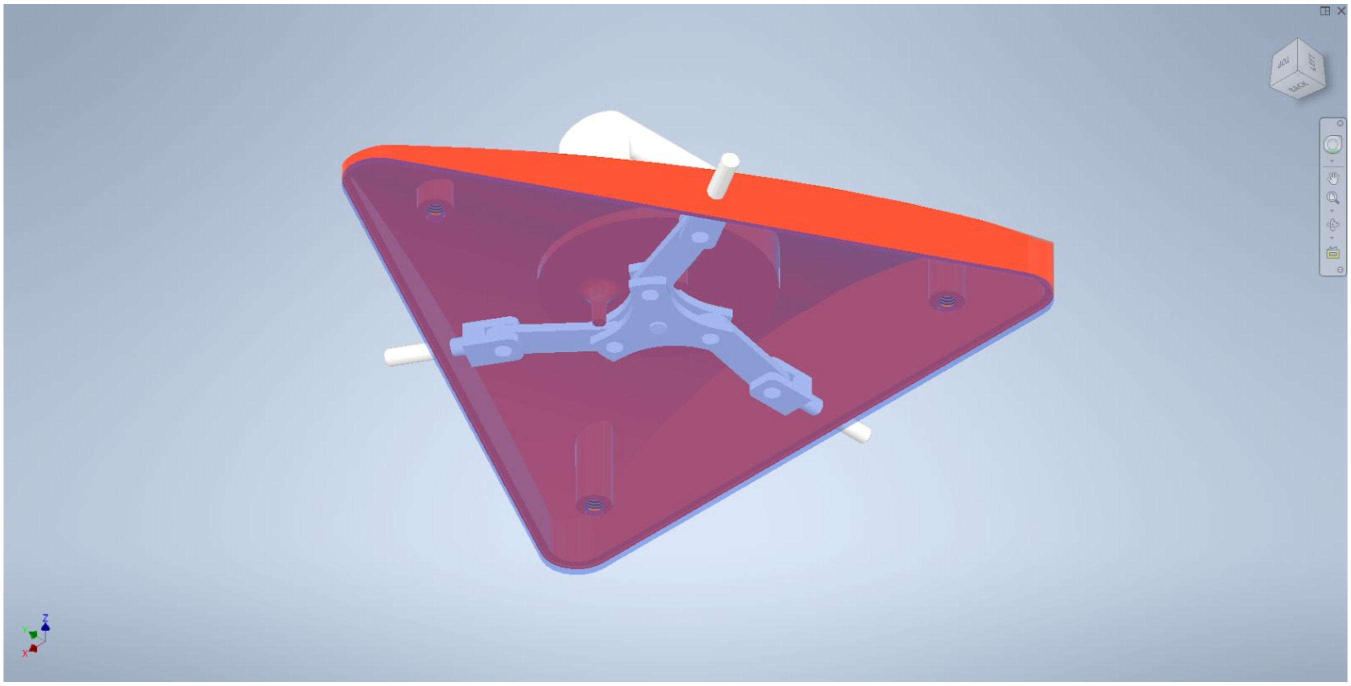


Figure 17: Hatch Removed From Vehicle