RoboBoat 2020 - Technical Design Report "Phantom II"

Embry-Riddle Aeronautical University

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Abstract

The Robotics Association at Embry-Riddle's (RAER) strategy this year surrounded the optimization of the Phantom II Autonomous Surface Vehicle (ASV) platform. Building upon last year's successes and setbacks, Phantom II's inline thrusters along with trimaran design provided a platform with pinpoint maneuverability, high speed, and stability. The mechanical sub-team focused on creating permanent amas and a modular aft deck. The control systems sub-team worked on reconfiguring sensors and rebuilding electronics while testing old and new competition tasks. Due to the onset of COVID-19 suspending all further physical process, the team was forced to transition our efforts online. Additional prototypes for other mechanical components including a modular aft deck, hydrophone and quad implementation were designed and prototyped. The team however, had no effective way to push a final product we felt was up to presentable standards. The control systems team made new developments with sensors and electronics but suffered from lack of important testing time due to the pandemic. Although the team was unable to make use of the most critical time leading up to competition, which are dedicated to developing final products and testing competition tasks, we feel confident that we have developed an intuitive framework that can be flexible to the challenges in future years.

I. Competition Strategy

This year, the Embry-Riddle team continued to develop and optimize the Phantom II. The mechanical team worked to prepare for the new tasks this year, along with tasks that the platform was unable to attempt last year. While mechanical team worked on new designs, the control systems team helmed the testing to ensure old tasks still performed comparable to our competition performance. Many of last year's members have grown with the Phantom II platform and continue to develop new features of the vehicle while also assisting new members learn about the complexities of autonomous systems and contribute to the team. Given the modular design choices implemented into Phantom II last year, it set the team up for success as we approached our new ideas and designs with rapid prototyping and testing.

When deciding what to prioritize, after basics like weight, thrust, and basic navigation were addressed, the team turned to identify tasks we already had the configuration to accomplish with minimal vehicle modifications to our existing vehicle configuration. After these easier tasks were addressed, we moved on to tasks that could be implemented easily and without any major changes to the ASV. If time permitted, which this year it did not, attention would turn towards those far reaching goals that would require a new vehicle configuration or rebuild to accomplish.

The challenges we had categorized from least to most challenging to complete can be found as part of our Software Architecture Outline found in Appendix C.

Starting out, the tasks that the team identified as simple to complete with no significant vehicle change was the mandatory navigation channel, speed gate, and return to dock. Last year, Phantom II had success in completing all the above therefore, with no major changes, these tasks would theoretically be possible to complete this year. The next task on the team's radar was the find the path (obstacle field) and the obstacle channel. These two tasks presented very similar problems and solutions involving obstacle detection and avoidance, so success with one would inherently lead to success in the other. Basic obstacle detection was implemented last year and was refined over the last year to now implement obstacle avoidance into the control system. With these vehicle developments, everything necessary to complete these tasks is in place and the mechanical team can begin developing new pieces of the platform while the control systems team continues to refine and tests these tasks.

Our far-reaching goals for this year was the UAV object delivery and acoustic docking. Last year, we showed promise with the UAV integration, however, a major issue we encountered was landing the quadcopter on Phantom II, due to limited deck space and deck obstacles. A hydrophone deployment system was also a much-needed component of Phantom II that had yet to be developed to truly attempt a successful acoustic docking. Both designs would have to be designed, prototyped and developed from the ground up and were hence planned as stretch goals for mechanical to work on towards the end of the semester, as the control systems team would be testing with a stable platform.

II. Design Creativity

One of the first major design changes from last year's platform was with the ama design. The motivation for this change was to reduce listing experienced by Phantom II when she decided to turn suddenly. This can be problematic both for the sensors and the UAV on the deck. The first major changes to improve the stability was to widen the amas, increasing submerged volume, as well as widening the ama's mountings, to increase the restoring rolling moment. Change in the amas along with an improved and expandable top deck would facilitate increased surface area, improving the odds of a successful landing. As a final potential design change, a hydrophone deployment mechanism was considered & prototyped. However, due to time constraints, could not be fully implemented. The control systems team had a major overhaul to the vehicle's control system while continuing to develop and improve the software base.

A. Ama and Mount Redesign

In order to reduce in-water testing time and fine-tune ASV performance, the use of flow-simulation software was used. By using Autodesk CFD, various designs could not only be tested, but also put up to a more consistent standard of performance of both roll performance as well as quick drag calculations. Through CFD tools, we were able to perform in-depth analysis on several ama designs, in the time of less than one physical test, as well as avoiding unnecessary manufacturing time and cost. Another major benefit of using CFD tools is that the results are available for future years, allowing for easy access to the data if the decision is made to re-design the amas in the future. As shown in Figure 2, the new wider amas have improved water displacements (as shown by the light blue ‘clouds’) which would relate to restoring forces, especially on the side being pushed into the water.

In conjunction with the redesign of the buoyancy of the amas, the mounts that support them were also modified. In order to improve stability even further, the mounts were made wider, which increases the stability of the ASV, as well as providing a wider base onto which the UAV deck can be placed. Due to the new challenges associated with wider amas structurally, they were designed from marine wood like the rest of the ASV. By designing with manufacturing in mind, the parts were made easy to laser cut and put together, in a jigsaw like fashion. This allowed for quick fabrication and assembly of the ASV’s new mounts allowing additional time to be spent on other tasks that required the ASV, such as the rebuild of the control systems and any water testing time. Figure 1 shows the comparison between the old set of amas (grey) with the new wider mounts and amas, and in conjunction with figure 2 show the improved buoyancy of the ASV platform.

B. Unmanned Aerial Vehicle Recovery

While we did launch and land a Unmanned Aerial Vehicle (UAV) successfully from Phantom II last year, the RAER RoboBoat team strived to improve, and planned modifications that could allow reliable autonomous landing of the UAV on the rear deck of the vessel. The method for landing the UAV on the ASV was pioneered by RAER's National Science Foundation (NSF) Cyber Physical Challenge team. Our fellow Embry-Riddle team developed a reliable precision landing system for autonomous landing of similar UAVs on hard ground. This system utilized an infrared beacon that emitted high intensity Infrared (IR) light and was placed on the center of the desired landing zone. A sensor was added to the UAV which could detect this infrared light and its intensity. The UAV was then able to use onboard software and data from its IR sensor to center itself over the IR beacon as it descended to the landing beacon to accomplish consistent and reliable autonomous landings. Of course, per competition rules, the UAV was also capable of a manual override of the autonomous landing, transferring control to a Part 107 certified remote pilot should anything go awry.

While the RAER RoboBoat team had high confidence in the precision landing system developed by the RAER NSF Team, it was noted that there was a significant degree of uncertainty in such landings. The NSF Team had observed in practice that the system was only precise within a minimum area, and as such, they recommended that minimum back deck of Phantom II be increased to 36 x 36”. Since the aft deck of the Phantom II (measuring 19 x 19”) was significantly smaller than the landing zones on which the IR homing system had been previously developed on, it caused significant concern for the safety of the UAV. Additionally, this aft deck space would almost unavoidably experience lateral, pitching, and rolling motions while on the water. Consequently, the UAV was deemed unable to safely land in the small non-stationary space on the aft deck of the Phantom II using the current IR-homing technique. Therefore, beyond the increased aft deck size, a significant amount of design work went into creating solutions that would allow an autonomous landing on Phantom II using the IR-homing system available to us.

The most obvious modification that could allow the Phantom II to recover the UAV would be to simply increase the size of the aft deck. The aft deck of the Phantom II is a removable panel that allows for access to the control systems of the vessel, and as such, exchanging this component for a larger deck that could overhang edge of the hull would be a comparatively easy alteration to the platform. However, this presented a number of problems. One such anticipated problem with pursuing this solution, was there was no apparent way to support an extension of the deck, and therefore, warping of the extreme edges of the panel could be expected without further support. The deck could perhaps be structurally extended to port and starboard if supported from below by specially modified ama mounts (as outlined above in section II A). However, there was no way to support an extension to the rear without drilling into the hull and jeopardizing the ASV's watertight gel coat seal. Another potential problem which the RAER RoboBoat team recognized were the new forces and weight offset caused by the quadcopter landing at a position removed from the center of gravity of the ASV. Which if extreme, could potentially cause instability of the Phantom II's navigation, creating a pitching moment possibly throwing the UAV overboard, or even inflicting serious damage to either the UAV or ASV. Finally, it was recognized that any expansion of the vessel's outer dimensions to the side or rear could hinder the platform's ability to avoid obstacles and remain maneuverable during each challenge. Therefore, while an upscaling of the aft deck of the Phantom II was likely needed for safe and reliable quadcopter recovery on the water, other innovations were needed to retain other areas of functionality of the platform and minimize risks to the Phantom II and the quadcopter during the drone's recovery.

Recognizing that additional deck space necessary, but not attainable, to safely land the UAV, a more complicated but clever option was required to develop a mechanism that could unfold the aft section of the ASV at a designated time in the competition just before an attempted recovery landing of the UAV. From the start of the competition the expandable section could be folded with the quadcopter resting on top of the foldable section(s). While quadcopter would be released to complete its mission, the deck could remain folded for obstacle avoidance challenges and general navigation of the ASV, as the UAV completed its task and is ready to return to the ASV, the deck could be fully unfolded for the recovery of the UAV near the end of the competition run. Simply put, an expanding deck could provide the additional space on the aft deck of the ASV needed for recovering the UAV, while also retaining the Phantom II's small profile, agility, and weight distribution during obstacle avoidance and navigation challenges. The team envisioned using pipes pivoted about the edge of the deck by high torque servo motors, which would extend over the edge of the wooden deck. Netting could be strung between the pipes, creating a lightweight, strong, and foldable additional landing space for recovery of the UAV. These pipes could also be angled around the wooden deck space creating a funnel shape (see Appendix F Figure 5). It was intended that this shape, once unfolded would be 36 x 36", as recommended, but force the UAV to land and arrest itself to a relatively centered position on the wooden deck of the ASV. Yet relying solely on an expanding deck system for the recovery could prove to be unnecessarily complicated and could take several iterations to make reliable and effective. There were also apparent spatial problems with getting multiple sets of arms to fold on the same 19 x 19" deck without interfering with vents, instruments, sensors, or the footprint of the UAV when resting on the deck at the start of the competition.

Ultimately, the RAER RoboBoat team set a plan for implementing both a larger fixed plate as well as a folding mechanism to replace the current aft deck (see Appendix F Figures 6 and 7). This was, in theory, to maximize rear deck space and ensure an effective UAV recovery capability while also retaining ASV stability and minimizing the invasiveness of modifications to the existing Phantom II platform. Additionally, pursuing both platforms would give us experience with both techniques, and allow us to shift our design focus should either the larger fixed deck or expanding mechanism prove infeasible. A final design was not finalized, but it was decided that the new deck panel would span the full recommended 36” from port to starboard, and the foldable deck element would project from the aft edge of the deck as much as possible while maintaining structural stability and weight distribution.

C. Hydrophone Implementation

As an additional goal, a hydrophone arm concept was prototyped but has yet to be implemented. The current design has the hydrophone array attached to an extended carbon fiber arm that sits comfortably underneath the aka, the space between the main hull and the amas. This is to protect the hydrophone array from collisions and potential damage, and to allows it to be retracted when not in use, minimizing hydrodynamic drag. The arm rotates using a high torque servo about its axis and is long enough to suspend the hydrophone underneath the thrusters, so they are not affected by the water displacement of the propulsion. In addition, a system was also developed using neodymium magnets to hold the arm in position when either the arm is not in use, or the servo is unpowered. As this was a stretch goal, the software portion for this sub-project has yet to be developed.

D. Software

Following our team’s successful implementation of software in the previous year's competition, we decided to continue development of our custom software suite known as Minion Core. The software, built in the LabVIEW language, is modularized into multiple independent programs, and uses the publisher/subscriber architecture commonly found with other software packages such as ROS. The Minion Core publisher/subscriber architecture was originally written by ERAU’s Maritime RobotX team, with the Roboboat control systems team developing a custom branch to meet our unique propulsion and sensor suite needs. We also took it upon ourselves to improve the existing code base used in the 2019 competition, in particular the areas of thruster control and obstacle avoidance, both of which we encountered various bugs and issues with. In addition to improving obstacle avoidance and thruster controls, we also started development on new aspects of the autonomous system such as object detection using the ASV’s LiDAR and object classification using TensorFlow, as well as improving our vehicles mapping and path planning algorithms.

E. Improved Control System

One of the biggest lessons the control systems team learned over the last year was the necessity of an improved and simplified control system. Over the months leading up to and following competition, we found ourselves battling with numerous electrical system bugs. Hence, following the end of the 2019 competition season, we started work on a complete overhaul of the electrical system of the vehicle. While we did still maintain our core functionality from last year, we also added many new safety and ease of use features. We accomplished this by designing a custom printed circuit board (PCB) that includes all of the major electrical and communications features on a single board. We added features such as the ability for batteries to be utilized in parallel (to double vehicle on location operations), worked on such a new safety features such a leak detection circuit, which will disconnect the batteries from the vehicle in the event of water being detected in the hull. We incorporated high quality MuRata voltage regulators to supply 5v, 12v, and 24v sources for the current electronics in the vehicle, with potential for expansion in future years. We added custom POE circuitry used by our radio to the board, not only to reduce the number of wires in the vehicle, but to reduce the number of potential failure points, In addition, we also added custom circuity to support our LiDAR and IMU, allowing them to seamlessly integrate into the board, providing an all in one elegant solution. A preview of the PCB can be found in Appendix G.

III. Experimental Results

As our original strategy had the majority of testing set in the spring semester, we did not accomplish nearly the amount of testing that we intended to. Our first major test of the vehicle post 2019 competition was done in the fall semester with the initial 'prototype' set of amas and mounts. This was to verify the CFD analysis that they would provide better vehicle stability. With these new modifications, we could easily compare the roll stability, as well as water movement around the amas, which were some concerns brought about at last year's competition. Once we had verified the ASV was more stable with the new design, we set about ensuring typical movement of the vehicle would not rock the UAV off the platform, as well as testing extreme and unlikely circumstances induced by the UAV, by using a heavy gearbox as a mass simulant in positions with extreme offset from the vehicles center of gravity. With satisfactory test results, we were able to verify the improved stability of the platform, as well as the ability of the ASV to keep the UAV on the deck without sacrificing maneuverability or speed in the worst potential conditions. The ama testing was the only major testing performed in the fall semester and the spring semester testing was set for the latter half, which was interrupted due to COVID.

The control systems team also had the opportunity to test out the previous year's challenges to confirm we were still capable of performing basic competition tasks with our new electrical system. While we still had success completing basic tasks such as GPS navigation, navigating through basic buoy gates, and completing tasks such as the speed challenge. Unfortunately, due to COVID, we were unable to achieve the level of testing the control systems team desired, but will continue to make progress in future semesters

If additional testing was able to be conducted, the next steps would have been to test the improved obstacle avoidance and control system. After this software was tested and implemented, we could begin fully constructing the logic to complete tasks such as the obstacle field and channel where the software improvements would be instrumental in completing the task successfully. Additionally, plans had been made to work closely with the aforementioned NSF team to test and implement the precision landing system mentioned in previous detail. Another student was working closely with one of our graduate students to research and develop the hydrophone localization system and begin to work on experimentation and testing on previous prototype platforms. While much of our expected testing did not come to fruition, we have laid out a truly great framework for next year's team to continue to improve and develop the platform, allowing them pick up right where we left off, and to continue to develop and test for the 2021 competition.

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References

[1] Roboboat 2020 Rules and Tasks Description, Robonation RoboBoat

Appendix A: Component specifications

Component	Vendor	Model/Type	Specs	Cost (If New)
ASV Hull	Developed	N/A	Marine plywood	$84
Amas	Developed	N/A	Foam Insulation boards and Marine Plywood	$42
Fiberglass Exterior	Fiberglass Plus	Marine Grade Gelcoat	http://www.fiberglassplusinc.com/gelcoats.html	Free (Sponsored)
Waterproof Connectors	McMaster-Carr	Various	All Screws, Bolts, Nuts, Washers, Inserts, and similar hardware was purchased here	$25
Propulsion	Blue Robotics	T200 Thruster	https://bluerobotics.com/store/thrusters/t100-t200-thrusters/t200-thruster/	$412
Power systems	Generic	6S LiPO	5000mAh	Free (Sponsored)
Motor controls	Generic	30A ESC	https://www.amazon.com/RC-Brushless-Electric-Controller-bullet/	Free (Sponsored)
CPU	Intel NUC	NUC8i7BEH1	https://www.amazon.com/Intel-NUC-Mainstream-Kit-NUC8i7BEH/dp/B07GX69JQP	$539
Teleoperation	FRSky	QX7	https://www.amazon.com/FrSky-Taranis-Channels-Transmitter-Controller/dp/B072559WH9	$150
LIDAR	Velodyne	Puck	https://velodynelidar.com/products/puck/	Free (Sponsored)
IMU and GPS	VectorNav	VN-300 Dual Antenna GNSS/INS	https://www.vectornav.com/products/vn-300/specifications	Free (Sponsored)
Camera	Point grey Research	Blackfly USB3 w/ 1920x1200 fixed focus lens	https://www.flir.com/products/blackfly-usb3?model=BFLY-U3-23S6C-C	$2,000
UAV Specification				
Aerial Vehicle Platform	Amazon	DJI Flame Wheel F450 ARF	4x E300 ESC (15A) 4x E300 Motor Integrated PCB Wiring	$31.99
Propellers	Amazon	O-XOXO Propellers	Self-tightening	$10.99
Camera	Amazon	GoPro Hero 7 Silver	4K30 Video Quality Stabilized Video 10 MP Waterproof	$249
Antenna	RobotShop	Here 2 GNSS for Pixhawk 2.1	https://www.robotshop.com/en/here-2-gnss-pixhawk-21.html	$95

LIDAR	lightware	LW20/B	https://lightwarelidar.com/collections/lidar-rangefinders/products/lw20-b-50-m	$259
Pixhawk	RobotShop	Pixhawk 2.1 Standard	https://www.robotshop.com/en/pixhawk-21-standard-set.html	$238
Landing Gear	Amazon	F450 F550 multicopter Landing Gear Kit	https://www.amazon.com/Xiangtat-multicopter-Anti-Vibration-Multicopter-Quadcopter/	$33
Raspberry Pi	Amazon	3 Model B Board	https://www.amazon.com/Raspberry-Pi-MS-004-00000024-Model-Board/dp/B01LPLPBS8?ref_=ast_bbp_dp	$42
IR-Cable	Ir-lock	IR-LOCK to Pixhawk2.1 Cable	https://irlock.com/collections/ir-markers/products/ir-lock-to-pixhawk2-1-cable	$6
IR-lock Sensor	Ir-lock	IR-LOCK Sensor	https://irlock.com/collections/ir-markers/products/ir-lock-sensor-precision-landing-kit	$120
IR Beacon	Ir-lock	MarkOne Beacon 3.0	https://irlock.com/collections/ir-markers/products/markone-beacon-v3-0-beta	$164
Power Management	Castle creations	CC BEC PRO SWITCHING REGULATOR	http://www.castlecreations.com/en/accessories-5/cc-bec-pro-010-0004-01	$40
Software				
Programming Languages	LabVIEW, Python, C++			
Vision	TensorFlow			
Inter-vehicle communication	Ubiquiti	Bullet M2	https://store.ui.com/collections/wireless/products/bullet2	$79
CFD Simulations	Autodesk CFD			
3D Modelling and Drafting	Autodesk Inventor			
Team Information				
Team Size	7			
Expertise Ratio	5 mechanical, 2 Controls systems			
Testing time: simulation	0			
Testing time: in-water	25 hours			

Appendix B: Outreach Activities

ERAU Club Activities Fair (September 19, 2019 and January 20, 2020)

Schoolwide fair to promote clubs, demonstrate projects, and acquire new members

Family Weekend (January 31, 2020 – February 2, 2020)

Opportunity for families and friends to see what the team works on and promote it schoolwide.

Appendix C: Software Architecture

Create mission blocks for each of the follow challenges. Use GPS along with indicating start positions to detect current challenge then run the corresponding mission block using prebuilt logic.

1) Mandatory navigation channel
    a) Obstacle detection (Lidar)
    b) Color Detection of objects from lidar (Camera)
    c) Gate identification
        i) Red and green buoys
    d) Create waypoints between gates and adjust as buoys move

2) Speed gate
    a) Recognize lone blue buoy as speed gate
    b) Go around buoy and return to start gate
    c) Speed important
3) Return to Dock
    a) Track starting position
    b) After mission ends, return to those gps waypoints
        i) Hitting stuff on return to dock point loss?
4) Obstacle channel
    a) Implement obstacle avoidance
    b) Go through identified green/red gates
    c) Avoid yellow buoys on path
5) Obstacle field
    a) Identify target (big buoy)
    b) Find way through cluster to main buoy
        i) Black buoys present new challenge
    c) Encircle the target (possibly create a set amount of evenly distributed points at certain radius)
6) Acoustic Docking
    a) Identify active pinger
    b) Determine location based on pinger
    c) Attempt to dock between bars directly above pingers
7) Obstacle delivery
    a) Implementation with help of NSF
    b) Launches at start of run
    c) Lands very end of run
    d) Does its challenge by itself while boat does other challenges
        (1) Check if we can do quad while doing other tasks

Appendix D: Optimized Amas

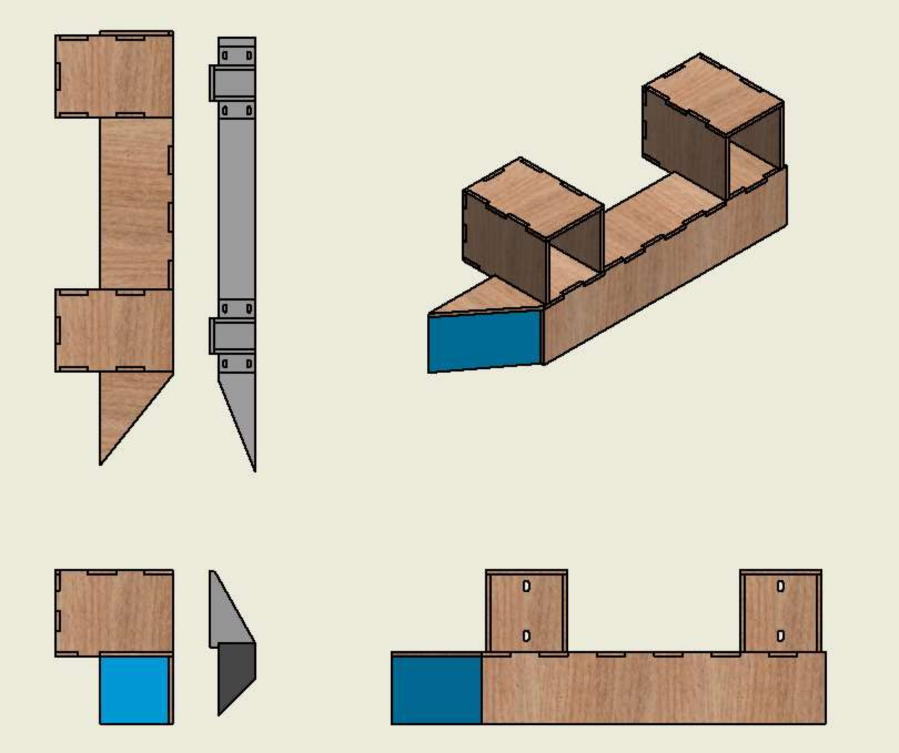

Figure 1 Redesigned Amas and Mounts next to old amas and mounts

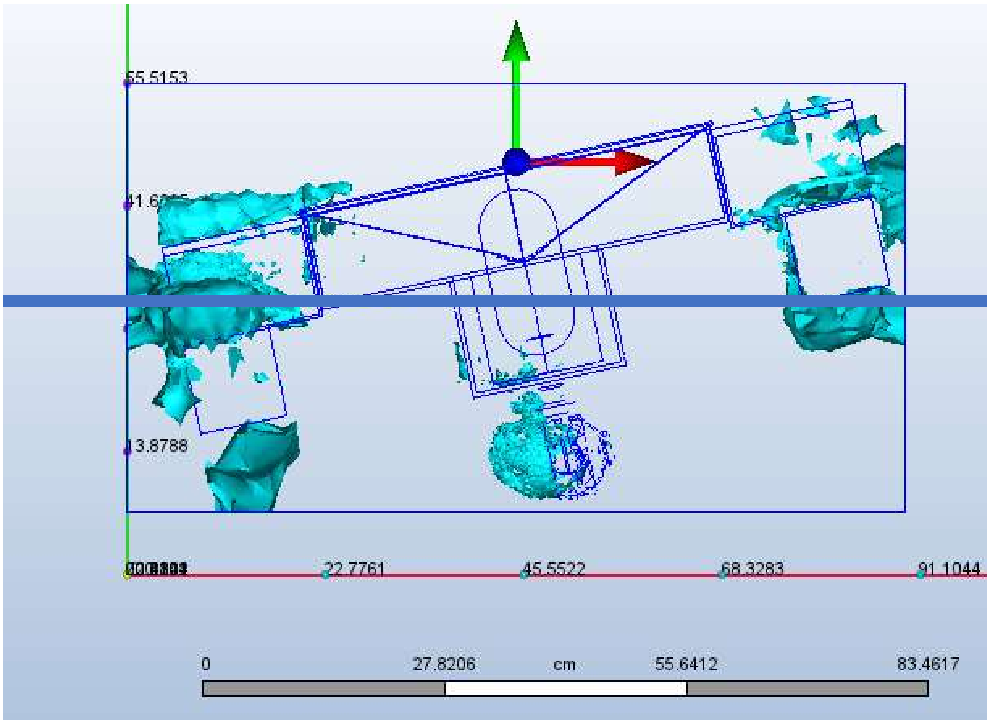

Figure 2 CFD Results for the modified Amas and mounts, showing increased fluid movement (buoyancy) when rolled

Appendix E: Hydrophone Deployment Arm

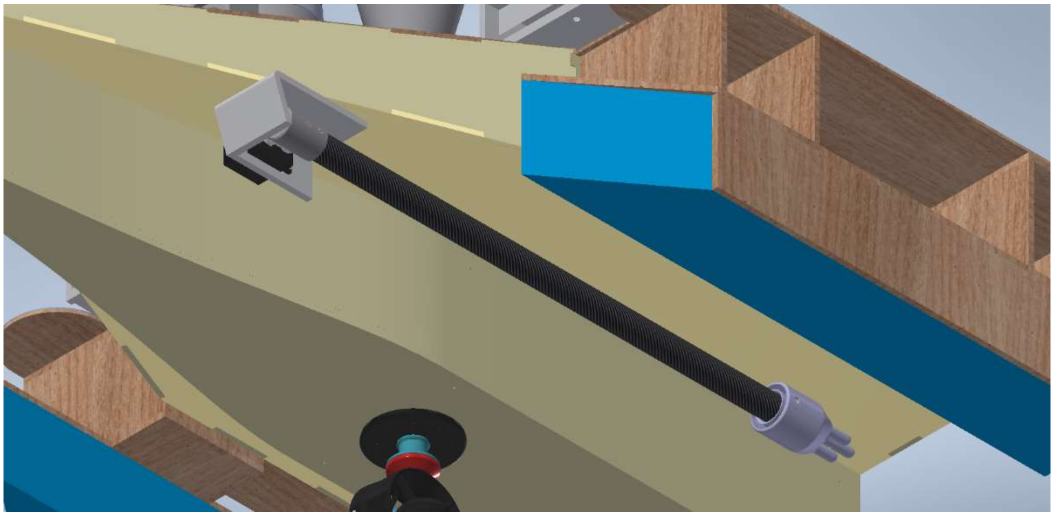

Figure 3 Hydrophone Arm Stowed

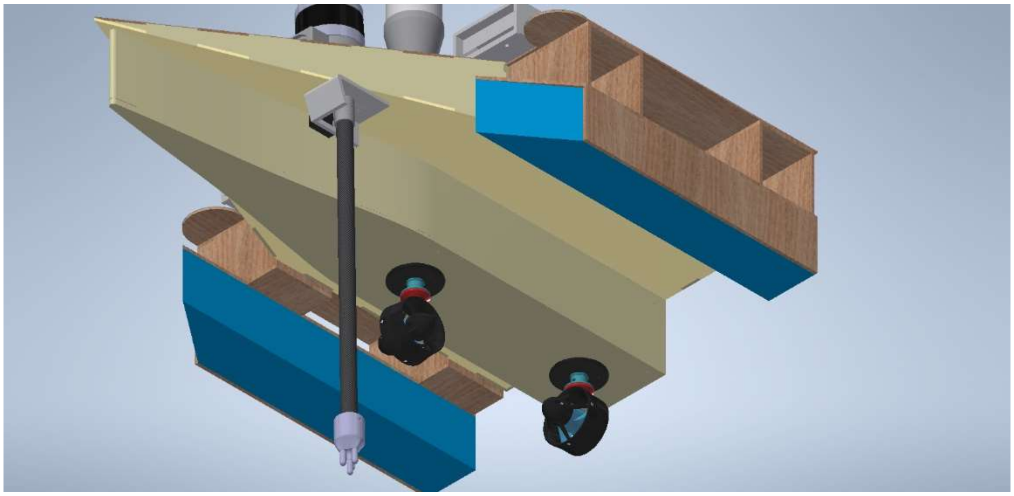

Figure 4 Hydrophone Arm Deployed

Appendix F: UAV Recovery

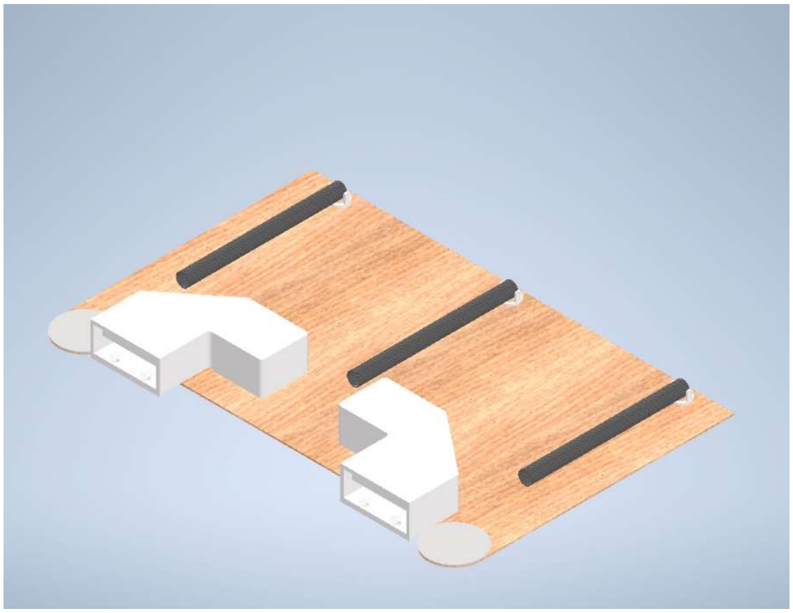

Figure 6 UAV Recovery net in the stowed position

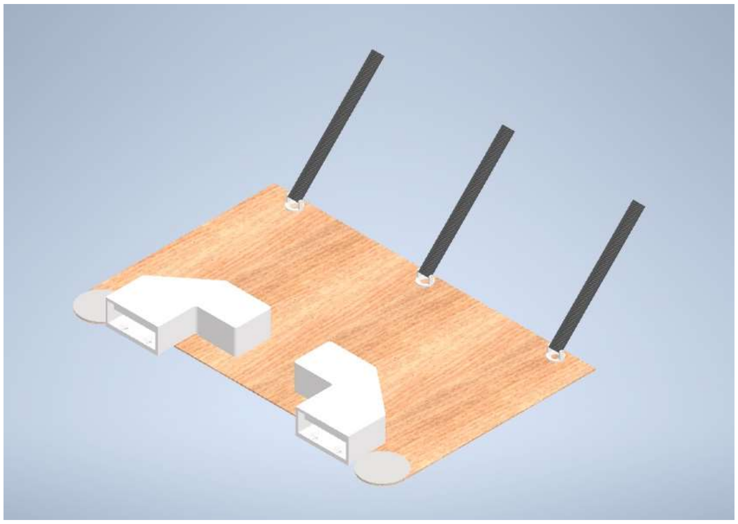

Figure 7 UAV Recovery Net in the expanded position

Appendix G: Power Distribution Board