Hall and Boats
Roboboat 2017 - Georgia Tech

Vinayak Ruia, James Chen, Henry Chen,
Austin Spalding, Avanti Joshi, Arsene Lakpa
Sam Seifert

***Abstract*—This paper details the design and development of a new autonomous surface vehicle that will compete in the 2017 AUVSI RoboBoat competition. The new platform was built to be robust, modular, and support the Georgia Tech team for years to come. The autonomy and simulation environment developed and used for Roboboat 2016 has been expanded to include this years vehicle and competition elements. This simulation environment has helped the team develop the hardware and software in parallel. With a matured software stack and a more reliable vehicle (that hopefully won't need to be rebuilt the night before finals), the team is excited to see the fruits of their labor at this year's competition.**

I. Acknowledgements

This team was made possible by generous contributions from both the Georgia Tech Student Foundation (A Georgia Tech Alumni Association Affiliate), and the Aerospace Systems Design Lab (a Georgia Tech aerospace lab). Without their help, none of this would be possible. Our team would like to thank them for their contributions!

II. Introduction

This team picked up right where last year's left off: with a great software stack, and a rickety old boat in need of replacement. It was immediately evident to this year's team that a new boat needed to be designed and fabricated to facilitate us participating in Roboboat 2017. Over the course of the last year we've done just that, while simultaneously continuing to develop the software stack and simulation environment (called the Adept Autonomous Vehicle Simulator or AAVS) used to control our vehicles. At Georgia Tech, the nearest suitable testing site is a 40 minute car ride away, making it difficult for this team to do real world tests. AAVS has been invaluable helping maximize the efficiency of the time we spend at the lake, and minimizing the number of trips needed!

The majority of the paper will outline and describe the development of the software and the hardware that constitutes our entry to the 2017 RoboBoat competition. The paper first describes lessons learned at past competitions with past vehicles in III, End of an Era. Next, the design and fabrication of the new vehicle is detailed in Sections IV - VI. Finally the sensor list is detailed, and concluding remarks are made about where we think we stand.

III. End of an Era

Last year's vehicle (Fig. 1) helped this team attend multiple Roboboat competitions. It is being retired for several reasons, including:

Figure 1: Trimaran vehicle that is being retired.

- Deteriorating structural integrity
- Failure of 1 of the 4 motors (remaining 3 are near end of life)
- Too small and wrong form factor for landing platform
- Not enough buoyancy

The main pontoon of the trimaran was built in a way that provides little flexibility to address any of the above issues easily. There isn't an easy way to change the thrusters on the existing hull; they are epoxied to the side of the hollow fiberglass hull. Removing them could damage the pontoon, and adding new ones only increases the number of holes / failure points on the main pontoon. Similarly, increasing the buoyancy means enlarging the hull, which also can't easily be done.

One goal for the new vehicle is derived from these observations: the new vehicle will be larger from the start, and new thrusters will be installed. In addition to meeting our current operational requirements, the system will be modular. That way, when the new thrusters eventually need replacement, they can be swapped out without significant effort. Similarly, if larger pontoons were required, they could be swapped out without modification to the chassis or thrusters.

The 2016 vehicle also suffered from several design flaws. The light weight trimaran design caused the thrusters rest two inches below the surface of the water. Under full power, the motors would pull enough flow to actually suck in air from the surface. This kills the efficiency and the power of the motor, and throws off the dynamics (if only one motor sucks in air, the boat will turn in that direction). The new vehicle design should allow the motors to sit in deep enough water where this isn't an issue.

The 2016 vehicle wasn't all bad! There were several things that vehicle did well. The vehicle's center of mass was low to the water, providing great pitch and roll stability. It also had a top speed of 1.5 meters per second (middle of the pack), and a turning rate of 75 degrees per second. The 2016 vehicle weighed in at around 60 pounds (depending on configuration) and had a one hour battery life. The goal for the new vehicle is to surpass the old vehicle in straight line speed, turning speed, and battery life.

A. *Objectives*

The objectives that have already been outlined are:

- Modularity (ability to swap in hulls / motors / chassis)
- Motor placement $\geq$ 6 inches below water surface
- Straight line speed $\geq$ 1.6 meters/s
- Turning speed $\geq$ 75 degrees/s
- Battery life $\geq$ 1 hour

The process used to meet these objectives is more of a hazy nebulous cloud than a concrete systematic approach. Last year's vehicle had a total of 8 kg of thrust. The thruster configuration for this years vehicle (Blue Robotics T200's) provide 14 kg of thrust. These thrusters were chosen due to convenience, they are used on other projects in our group and our high level objectives include using similar hardware across platforms. The T200's have met expectations and are available at a very competitive price point, so this desire to be cross platform isn't a handcuff, just a justification of our decision making. The increase in thrust (14 kg over last year's 8 kg) allows this year's vehicle to have more drag while still meeting the old top speed.

Previously the vehicle used a small LIPO battery (150 watt hour) to power all systems. A much larger LIPO (2800 watt hour) was selected for this year's vehicle. The selection process was again largely influenced by our desire to be cross platform. The WAM-V that is used by the ASDL is powered by three Torqeedo 26-104, which were all available for use on this project. With the massive increase in storage capacity comes a dramatic increase in battery weight (1.5 lbs to 54 lbs)! The battery for this years vehicle will almost outweigh last year's vehicle on it's own!

IV. Hull Shape

A. *Design*

The decisions to use the T200 thrusters and the Power 26-104 battery were made early on in the design process. The hull shape had to provide enough room and buoyancy to facilitate the size and weight of the new battery. Our design criteria for hull shape were, ordered by importance:

1) Stability
2) Turning speed
3) Straight line speed

Stability was desired because the sensor package works better when it's not being rocked around. Turning speed is more important to us than straight line speed because most of the competition tasks involve the boat making decisions to avoid or approach obstacles at low speed. After discussions with Troy Keipper (thanks Troy!), a naval architect at Navatek, a catamaran hull shape was selected. The catamaran design provides more stability for the sensors when compared to a monohull. The catamaran design will also allow the thrusters to be placed far away from the center of the vehicle, providing a larger moment arm to facilitate faster turning. A trimaran hull could meet the same criteria, but was avoided due to the need to construct an additional hull! Additionally, mounting thrusters on the side hulls of a trimaran would not provide the thrusters with enough depth to avoid sucking in air from the surface, and mounting them to the central hull sacrifices the moment arm of each thruster.

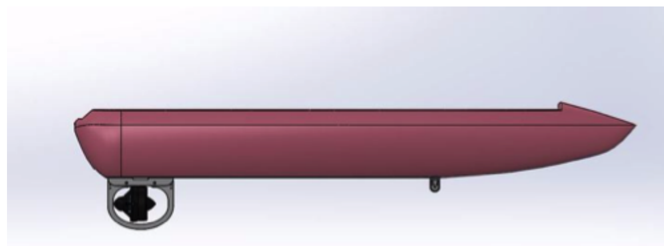

Figure 2: Side view of catamaran pontoon, with thruster.

Flow dynamics are not the team's expertise, therefore little time was spent modeling, simulating, and iterating upon the design of the pontoons. The final pontoon design, shown in Fig. 2, was a hybrid between a hull shape given to us by Troy Keipper, and design for a vehicle that was found online. Each pontoon was designed to displace 90 pounds of water, giving the catamaran a combined theoretical weight of 180 lbs. The vehicle was estimated to weigh around 100 lbs, indicating a pontoon waterline of a little over half the height of the pontoon.

Each pontoon is sandwiched by two aluminum rails. These slotted rails (80/20) run lengthwise through the pontoon, and allow thrusters or the chassis to be added or removed from the pontoons in an ad-hoc fashion.

B. *Fabrication*

Fabrication of the pontoons was challenging due to lack of experience. There was a very steep learning curve associated with the CNC routing of foam and application of fiberglass. We are proud of the first attempt, but if we had to do it again, we could do a significantly better job just based off of what was learned the first time around. The team will try it's best to pass this knowledge onto future members to help make future fabrication attempts more successful.

The pontoon internal pontoon structure was created using four layers of 2 inch thick Owens Corning Foamular (pink). Each layer of foam was cut to shape with a CNC router. There was a significant learning curve associated with operation of the machine, and the team spent a total of 14 hours simply cutting three foam pontoon cores (one of which was scrapped, as it did not match the dimensions of the others). The layers were then glued together, sanded, and painted. The motivation behind the painting at this stage (with latex paint) was to ensure the epoxy resin adhesion as well as provide a smoother surface to fiberglass. The painting process was deemed unnecessary in hindsight, specifically because and the paint made it difficult to see where fiberglass was applied. On later iterations, the team skipped the painting step. Next, the team applied three layers of epoxy and fiberglass to the pontoon. Due to the inaccessibility to a composites lab, the team was forced to fiberglass by hand. However, to improve the wrapping of fiberglass, the sheets were cut into pie/pizza slice shapes to better contour a 2-D shape to a 3-D surface. For future pontoon designs, the team may consider simplifying the curvature of the pontoon to aid in the fiberglassing, sanding, and patching process. After repetitions of sanding and patching, the pontoons were finally covered in a paint finish to protect the epoxy from UV damage.

V. Chassis & Waterproof Enclosure

Last year's vehicle used a Pelican Case to house the computer and other electronics. This year the decision was made to move away from the Pelican Cases. They are expensive, don't efficiently use the space they occupy, and are never available in the size you want. Instead of using a Pelican Case, the team built an electronics case out of laser cut plywood, which was later coated in polyurethane to make it water resistant. Building a custom case allowed the team to make it exactly the right form factor, and also provide spaces for the appropriate sensors and plugs. The camera and the LIDAR are mounted directly onto the case, away from the rest of the boat deck, to maximize visibility. The case also offers protection from the camera and LIDAR from potential damage associated with a UAV.

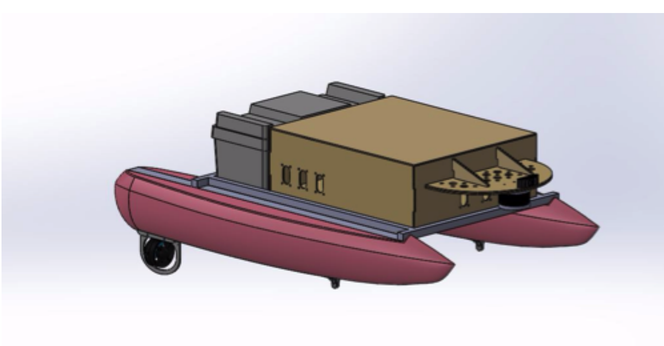

Figure 3: An overall view of the boat, electronics case, and battery design and layout.

The electronics box and battery are housed on a very minimal chassis, that was made out of 80/20 (extruded aluminum). The mating between chassis and pontoon is a standard 80/20 insert, which helps achieve the goal of modularity. The entire chassis can be removed if a replacement is needed, or slid back and forth to adjust the weight distribution on the vehicle. The entire vehicle design, including pontoons, is shown in Fig. 3, and the first manufactured version capable of floatation is shown in Fig. 4.

Figure 4: The vehicle on the water!

A. Thrusters

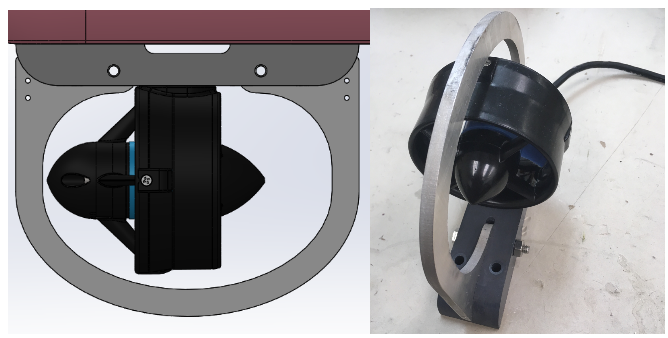

Figure 5: T200 with weight bearing fin.

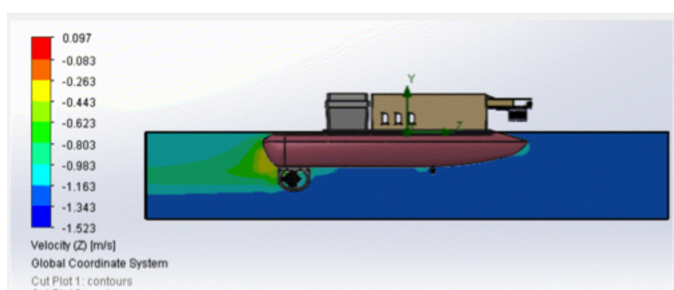

Figure 6: Solidworks flow simulation at 1.5 m/s.

The boat is equipped with two Blue Robotics T200 thrusters that are mounted on the extruded aluminum rails on the underside of either pontoon. An additional shroud was added to each motor to carry the weight of the vehicle when it's being dragged into and out of the water, and when it's sitting on a flat surface as shown in Fig. 5. Using the Solidworks flow simulation, we tried to optimize the shape and size of the thruster mounts and shroud (Fig. 6). It was difficult for us to draw conclusions, as Solidworks flow simulation didn't allow us to rotate the prop and provide thrust estimates.

While testing it became apparent that having the thrusters *on* caused the vehicle to pitch *up*. In an attempt to alleviate this, the thruster mounts will be remade with a slight upward pitch. This way, the thruster force will be acting closer inline with the vehicle center of mass, minimizing the moment the thrusters induce.

VI. Testing Observations

We have been able to softly determine if our vehicle meets the original goal specifications. Hard numbers aren't in yet, but the vehicle is faster than last year's, and turns at around the same rate. The motors are deep enough below the surface to not suck in air, and the modular design has been effective so far. The largest area of improvement over last year's vehicle is, not surprisingly, battery life. One hour of consistent driving drains only 15% of the battery life. This extrapolates to roughly 7 hours of battery life at half speed. We're hoping that valuable on site testing time during competition week will be saved by us never having to come out of the water. We'd like to only use the crane at the beginning and end of the day, maximizing our teams testing time.

VII. Sensor Package

The vehicle is equipped with an RGB Camera (same as last year's) and a VLP-16 LIDAR (purchased with winnings from 2016 Roboboat). The VLP-16 is a significant improvement over last year's Hokuyo. The VLP-16 scans at 16 distinct vertical angles, as opposed to the Hokuyo's single scan, making the LIDAR actuation found on last year's vehicle unnecessary. The vehicle is equipped with two hydrophones, and this will hopefully be the first honest attempt at the pinger portion of the competition.

Our vehicles have traditionally struggled with noisy and bad magnetometer readings. This prevents us from getting an accurate heading measurement. We typically compensate for the poor magnetometer readings with great state estimation. The best way we've found to actually determine vehicle heading is by driving the vehicle forward and using the difference in GPS measurements as part of our heading calculation. In practice, the vehicle concludes and state that balances the vehicles predicted state with the actual measurements the sensors provide. This solution is functional, however it fails when the vehicle is stationary for longer than a few seconds. This year, we're trying a two GPS approach (one forward, one rear). Hopefully, the difference in GPS readings will provide us with accurate heading information even when the vehicle is stationary. This is still being tested. In an effort to address the bad magnetometer readings, the IMU was also moved as far away from high power electronics and lines as possible. Our current theory is that the IMU magnetometer is struggling because of noise associated with the magnetic fields induced by current. The vehicle is equipped with two Novatel 10 Hz GPS units, and one Microstrain 3DM-GX4-25 IMU.

VIII. Software

We are using the same software stack that was presented in last year's paper, demonstrated at last year's competition, and summarized in our own Roboboat Finals 2016 Recap Video (here: https://www.youtube.com/watch?v=fAYEVduLsGI). Much has changed in the software, but the high level overview remains the same: we will save testing time by simulating many of the course tasks, while continuously validating our results in the real world. A new dynamic model has been developed for this year's vehicle, and we've added the tasks for this years competition. The simulation does not at this point include anything for a UAV, and it is unlikely that that will be added before this years competition.

If you're interested in learning more about the software, we encourage you to check out last year's paper https://www.dropbox.com/s/tocirvnfh3myyb7/paper.submitted.pdf?dl=0 or talk to us at the competition!

IX. UAV

Our UAV and landing platform are still in development. We are testing the IR-Lock, a commercial target-landing product, however at this point it is unclear what we will be bringing to the competition.

X. Conclusion

We're excited for this year's competition. The challenges are a step up in difficulty from previous years, and we're trying to position ourselves in a way that gives us the best chance to succeed. We'd like to make minimal hardware changes during competition week, and maximize our testing time. With our large battery letting us stay on the water for hours, our capability to simulate several of the tasks in full, and our great team, we approach competition time with confidence.