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Solar Splash Watercraft Propulsion System

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MFET 491 - Senior Project, ENGR 491 - Senior Design
Spring 2024

ACKNOWLEDGEMENTS

We would like to acknowledge the following faculty: Dr. Susan Ely for the inspiration for this project and getting us connected to Solar Splash team members, Dr. Paul Kuban for guidance as our project advisor, Dr. Arthur Chlebowski for sourcing the material for 3D printing and setting up the Fortus 450mc 3D printer, and Dr. Jim Durbin from the Geology Department for allowing us to use their outboard motor for testing purposes. We would also like to acknowledge Mariah Fulton for walking us through the setup for the initial CFD simulations and Kyle Echert for providing a boat and assisting with the necessary tests for this project.

ABSTRACT

This report discusses and analyzes a new propulsion system for the USI Solar Splash watercraft. The Solar Splash team finished in third place in the last competition and the team seeks to improve their race results and overall standing. This project aims to assist in improving the team's placement by proposing and analyzing a design for a new propulsion system. Typically, a drive train includes an assembly of the motor, transmission, shaft, and propeller. The primary focus of the drivetrain was on the design of a new propeller. Two new propeller designs were created, one conventional and the other toroidal, and these propellers were compared using both CFD simulations and in-water testing to determine if the toroidal propeller would give the desired benefits, and if it is more effective than a traditional propeller.

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1 INTRODUCTION

The University of Southern Indiana (USI) has a team that competes with many other universities and colleges in the annual Solar Splash competition. This competition challenges students to not only create fast and efficient solar-powered boats, but also provide detailed technical reports, visual displays, and workmanship. Though the USI Solar Splash team has worked hard in past competitions, their performance has not yet earned first place. To accomplish this feat, the current propulsion system will be upgraded to maintain a competitive edge against other teams. This report will fully examine these upgrades.

1.1 BACKGROUND

Solar Splash is an interdisciplinary annual competition between various colleges and universities. This competition focuses on the design and races of solar panel-powered boats by engineering students. The University of Southern Indiana has a Solar Splash team that has placed last or near-last place in most of the years in which they participated. However, after a major overhaul to the design of their boat, USI won 3rd place overall and an award for “Most Improved Hull” in the most recent Solar Splash competition. A primary concern from the USI Solar Splash team is for their propulsion system, which is a semi-functional design that needs a complete overhaul in the long run. Within the timeframe for this project, the goal is to increase the functionality of the drivetrain system through upgrades to the propeller, in hopes of enabling USI to achieve 1st place in a Solar Splash competition.

1.2 STATEMENT OF PROBLEM

The existing propulsion system for the USI Solar Splash team has a suboptimal design and needs upgrades before the 2024 Solar Splash competition. The previous design has a number of issues, such as incorrect gearing, improper steering, excessive weight, and a propeller with an excessive pitch to compensate for performance. A new drivetrain design must be compatible with the available steering and motor designs and provide increased functionality to give the team a competitive advantage.

1.2.1 Discussion of Competition Events

The Solar Splash competition is designed to test each team's boat through three different races, which are scored as follows:

- Slalom Race: The score from the Slalom race is from the best time of the team's two attempts to complete the course shown in Figure 1. This event makes up 20% of the points for the competition [9].

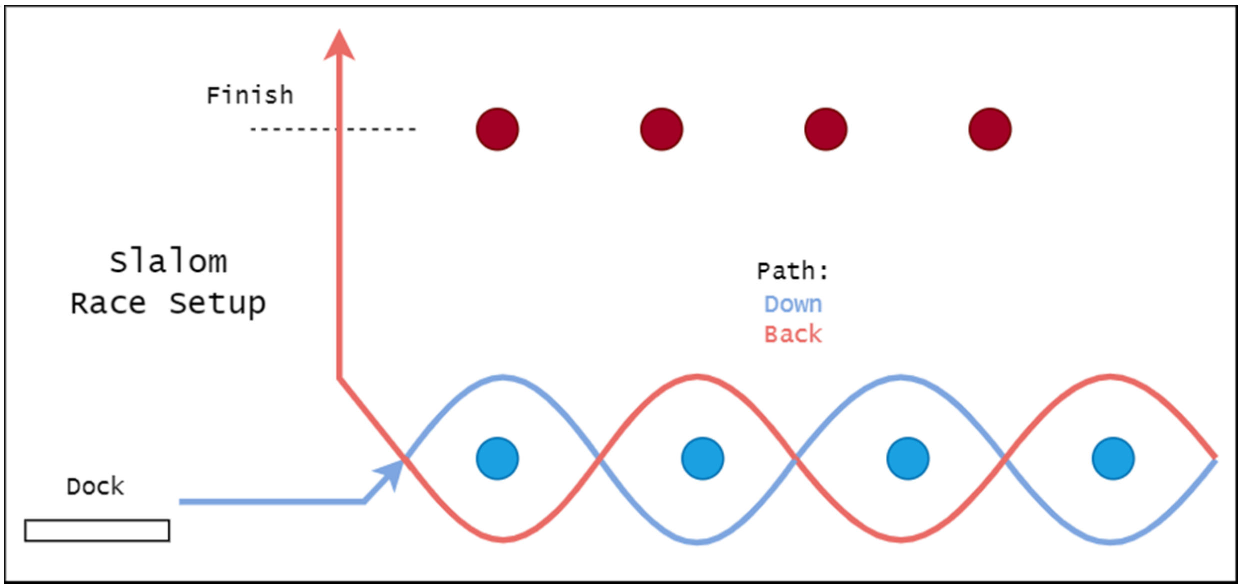

Figure 1: Slalom race diagram.

- Sprint Race: The score from the Sprint race is from the sum of the team's two best times over a 300-meter straight course, as seen in Figure 2. This event makes up 25% of the points for the competition [9].

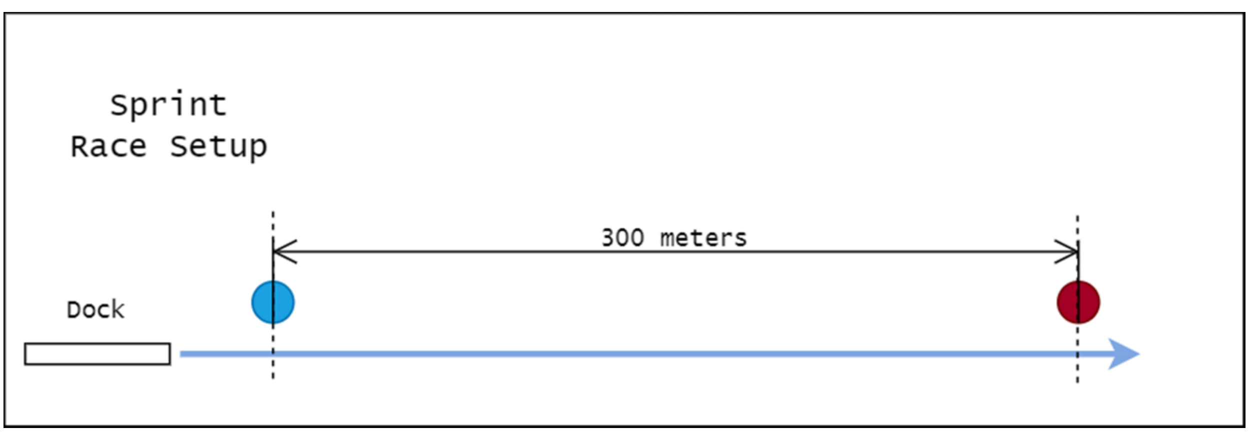

Figure 2: Sprint race diagram.

- Endurance Race: The score from the Endurance race is from the total number of laps traveled in two 2-hour heats. The total distance of 1 lap is 590 meters, and the score is rounded to the nearest ¼ lap. This event makes up 40% of the points for the competition [9].

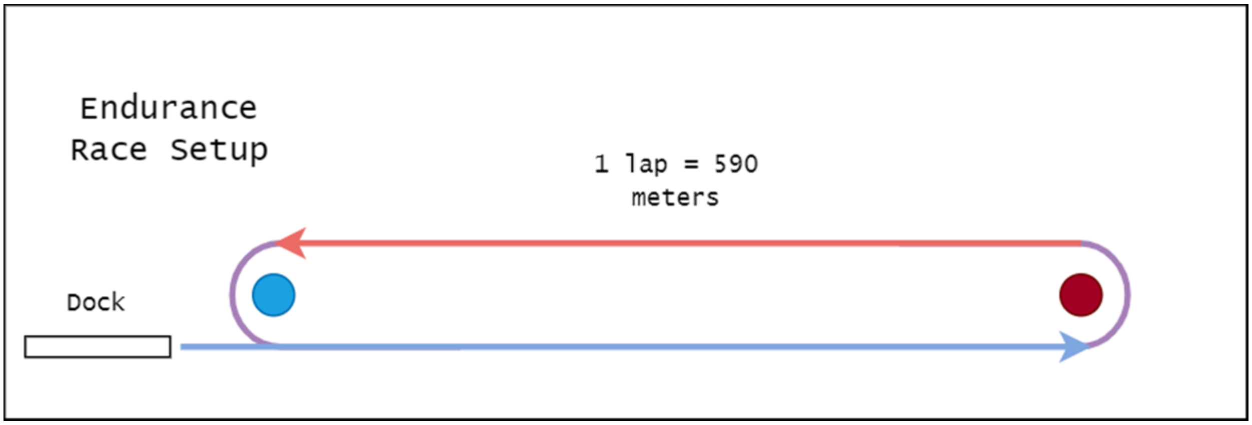

Figure 3: Endurance race diagram.

The remaining portion of the points come from the technical report, video presentation, and workmanship presented by the team.

The Slalom race requires that the team's boat is maneuverable and quick, as the course consists of weaving in between buoys in the minimum amount of time to earn a high score. This race places special focus on the ease-of-use of the steering system and a configuration of gears and propeller that prioritizes a balance between acceleration and speed. The Sprint race requires that the configuration of gears and propeller mostly provides a high maximum speed, as they will need to complete the 300-meter course as quickly as possible. If the number of configurations is limited, a Sprint configuration bears more importance than a Slalom configuration, as the Sprint race provides more points, and the same configuration should be used for both races. The Endurance race, however, would ideally be ran with a unique gear/propeller configuration that provides high output efficiency, as the boat must utilize onboard solar power to its full extent to travel the greatest distance.

1.3 *REVIEW OF PREVIOUS COMPETITION AND EXISTING SOLUTIONS*

The following table is a summary of results from the 2023 Solar Splash competition. The competition was between 9 teams, but the data for this table focuses on the top 3 teams, which includes USI, as well as the last 2 teams to serve as a point of reference for the ranks of each team.

Team Name	Overall Rank	Slalom (s)	Sprint (s) [Sum of Two Best Times]	Endurance (laps) [1 Lap = 590 meters]
University of Puerto Rico-Mayaguez	1	44.35	48.58	69.25
Cedarville University	2	49.87	56.66	77
University of Southern Indiana	3	54.97	86.87	39.25
…	…	…	…	…
Carnegie Mellon University	8	208.82	123.86	38.50
Wright State University	9	116.28	151.31	34

Table 1: 2023 Competition Results

The winning team of the 2023 Solar Splash competition was the team from the University of Puerto Rico at Mayaguez (UPRM), who decided to focus on their propeller setup for the Endurance races [7]. The UPRM team re-used and slightly modified their previous drivetrain to have fixed extensions that altered the depth of the propeller. The steering-wheel and pulley system received no major modifications, and both the steering and drivetrain systems met their requirements for weight, efficiency, and performance. However, four new propellers to be used in the Endurance race were designed to maximize the points gained from that event. The team utilized the MATLAB program OpenProp, which uses RPM, voltage, thrust, drag, and efficiency data to optimize the design of the propeller's geometry. The 2-blade, aluminum propellers were outsourced for CNC manufacturing and performed very well for the UPRM team in the Endurance race, having traveled a full 30 laps more than USI [8]. However, UPRM placed below Cedarville University for the Endurance race.

The Cedarville University (CU) team won second place, and their Solar Splash boat drivetrain consists of a drive motor, motor mount, down-shaft, driveshaft, gearbox, transom mount, tilt assembly, and propeller [6]. For the 2023 competition, CU chose to redesign various components of the steering system and their propellers. Like UPRM, they had also used OpenProp to assist in the design process of their propellers. CU had determined that a 12-inch, 2-blade propeller would provide the best solution to replace their previously low efficiency propeller for the Sprint and Slalom race. Their new custom-machined propeller was designed to provide better acceleration at lower speeds, but its performance did not beat UPRM in the Sprint and Slalom race.

Though the USI team won third place, there was a large gap in the scores for the sprint and endurance races compared to UPRM and CU (refer to Table 1). The drivetrain system for that competition had the electric motor in direct drive with salvaged components from an outboard motor. However, the original driveshaft and propeller were designed to be paired with the original outboard motor, which operates at double the RPM of the electric motor that USI used in competition. To compensate for this, a propeller with a higher pitch was chosen to make up the speed at the cost of acceleration. Though the boat overall performed far better than the boat before it, due to upgrades such as the hull design (which won "Most Improved Hull"), the continued use of the drivetrain in its current state would be an undesirable choice. This is because the components from the outboard motor make up a large portion of the weight of the boat, and the pairing of the propeller and motor could be optimized.

2 CONCEPTUAL DESIGN

2.1 System Hierarchy

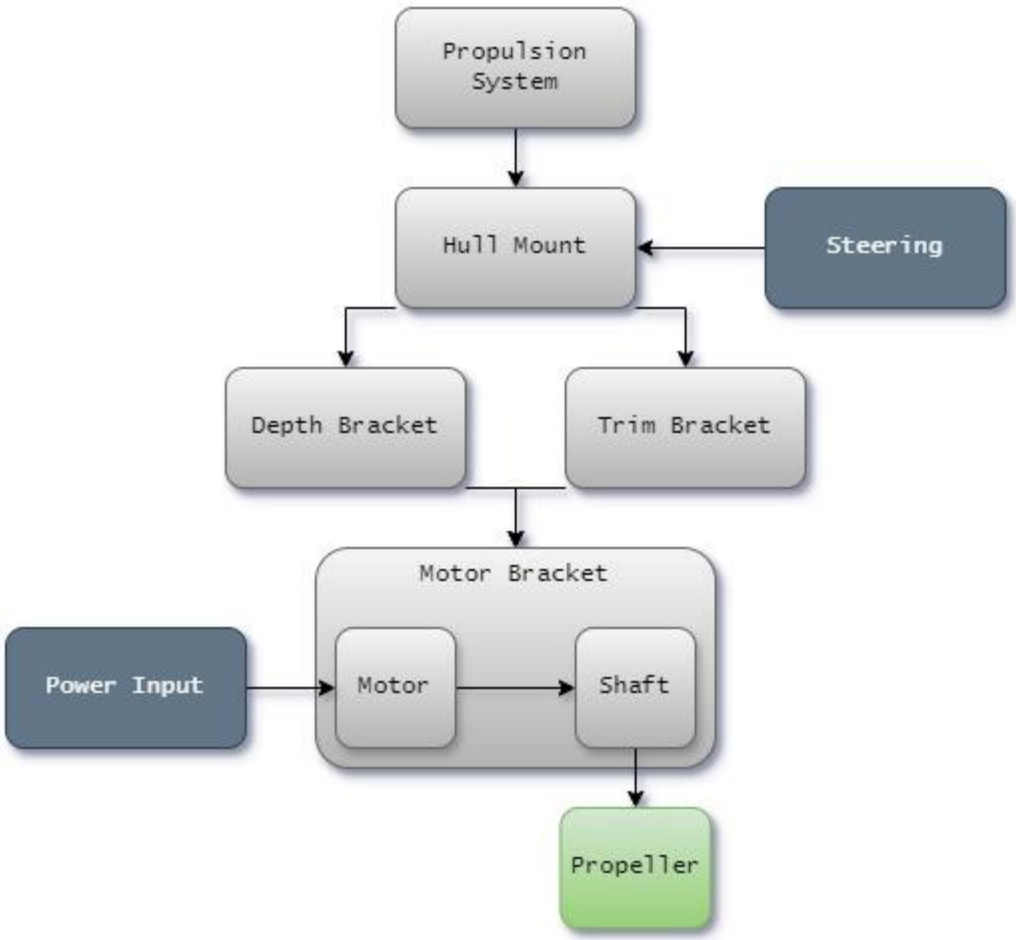

Figure 4: System block diagram for proposed concept.

The dark gray blocks on the system hierarchy diagram indicate external systems that interact with the propulsion system, the light gray blocks depict the system components that are necessary for the entire drivetrain, and the green block depicts the primary focus of this project. The diagram above is used as a visual aid to help understand how the entire system would be constructed. As seen in Figure 4, the entire propulsion system is connected to the hull of the boat. The depth and trim brackets attach to the hull mount where the system is attached and would allow the team to adjust the depth and trim for the entire drivetrain. Within those two brackets, there would be a motor bracket that holds the motor and the motor shaft at the proper operating distance. The propeller, which is the focus of this project, would then be attached to the motor shaft. The power input and the steering components would be connected to the motor and the hull mount, respectively.

2.2 *REQUIREMENT SPECIFICATIONS*

2.2.1 Safety

The drivetrain should be safe to operate and adjust, whether the boat is on the paddock or on the water. No additional hazards should be introduced with the addition of the proposed depth and trim adjustment mechanisms (this project does not focus on specific design considerations for these mechanisms). Solar Splash regulations 7.11 and 7.13.10 apply to this requirement of safety [9]. These regulations state the following:

- **7.11** - The skipper's cockpit must provide for the skipper's unassisted exit within 5 seconds in case of emergency.
- **7.13.10** - The boat's revolving parts must be suitably covered to prevent accidental contact. All steering linkage must be shielded from contact with the skipper.

It is crucial that the introduction of new mechanisms for the drivetrain does not interfere with these rules. Additionally, it is important in this project that students remain safe when testing the newly designed propellers. For this requirement, testing needs to be done in compliance with the following Coast Guard standard:

46 CFR 177.800*: All passenger accommodations must be arranged and equipped to provide for the safety of the passengers in consideration of the route, modes of operation, and speed of the vessel.*

2.2.2 Weight Limitations

This requirement limits a few possible solutions that would increase performance, but only by utilizing excessively heavy components. The current drivetrain system weighs 109lbs, so even if new upgrades have a minimal effect on thrust, a decrease in weight would increase performance. For that reason, the new drivetrain will ideally reduce weight without sacrificing overall performance.

2.2.3 Water Resistance

As this vehicle will spend much of its time in water, it is crucial to ensure that water exposure will not inhibit the performance of the drivetrain in any way. Since the motor and most rotating components above the waterline need to be covered for safety reasons, they should be safe from repeated splashing of water. However, extra precautions should be taken in the design so that the operation and maintenance in the long run account for this exposure to water. This includes material selection and engineering controls to avoid water hazards.

2.3 TOROIDAL PROPELLER CONCEPT

The MIT Lincoln Laboratory and marine propulsion manufacturing company Sharrow Marine have recently explored a new type of propeller. This propeller is called a toroidal propeller, and based on research and experimentation, the toroidal propeller has many advantages over a standard propeller. A toroidal propeller is a propeller in which the tip of each blade is joined at the tip or into the base of another blade. This forms the “toroid,” which is the term in geometry that describes a ring. This unique geometry effectively removes the tip of the propeller, and by doing so, less tip vortices are created. The reduction of these vortices creates a reduction in cavitation and turbulence around the propeller tip, which increases efficiency.

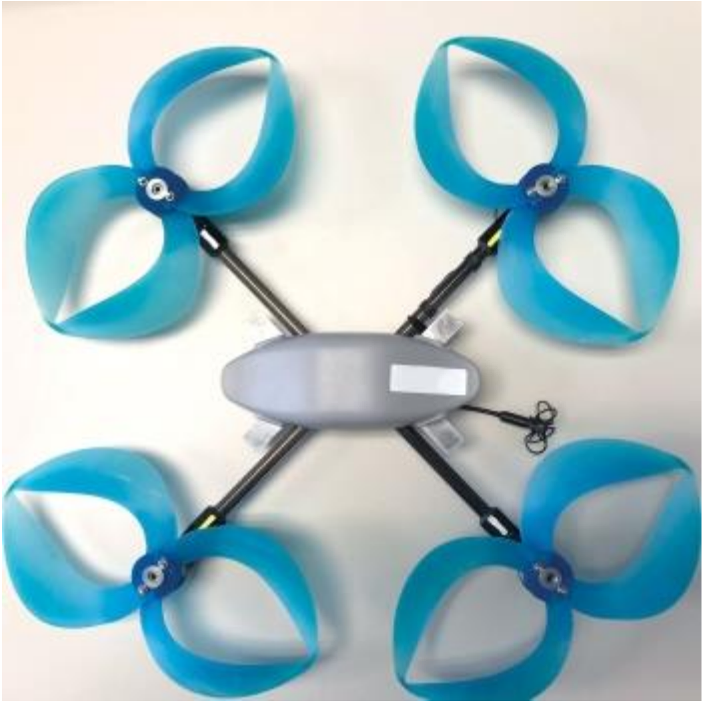

Figure 5: MIT toroidal propeller.

MIT Lincoln Lab's version of the toroidal propeller can be seen in Figure 5. Their challenge was to create a propeller that would reduce the amount of noise created by drones so that they can be used for many daily applications [15]. According to the MIT Lincoln Lab, the reduction of tip vortices will reduce the sound of the propeller for drones while increasing efficiency. This toroid shape also increases the overall stiffness of the propeller [15].

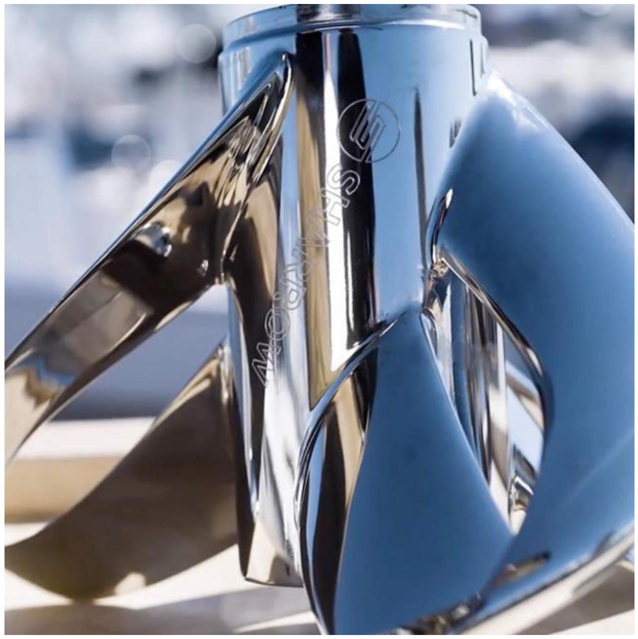

Figure 6: Sharrow Marine toroidal propeller.

Sharrow Marine manufactured the toroidal propeller in a similar way, as the founder, Gregory Sharrow, was attempting to create a video production using drones, and started modifying the drone propellers to reduce the noise that was being created [5]. After testing and modeling the toroidal propellers, Gregory Sharrow decided that the propeller would be better suited for marine applications. Extensive research has been performed, and the Sharrow Marine propellers have determined that toroidal propellers are much more efficient, create less noise, increase maneuverability of the craft, achieve higher speeds, and have more applications [10]. As seen in Figure 7, the flow of the toroidal propeller is far more concentrated than the flow of the standard propeller. This indicates that the toroidal propeller will have a higher efficiency as it is generating less turbulent flow around it. Similarly, as seen in Figure 8, there is virtually no tip vortices on the toroidal propeller, but the standard propeller consistently generates tip vortices which is a form induced drag.

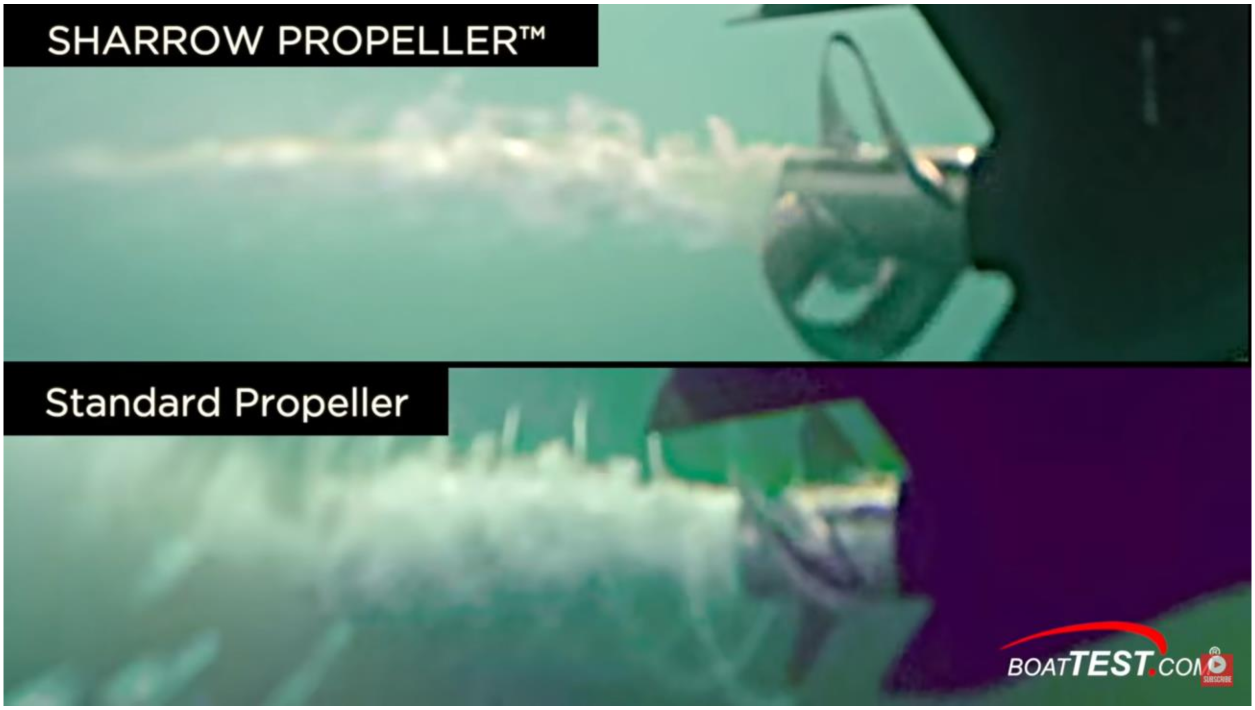

Figure 7: Comparison of propeller flow from BoatTest.com.

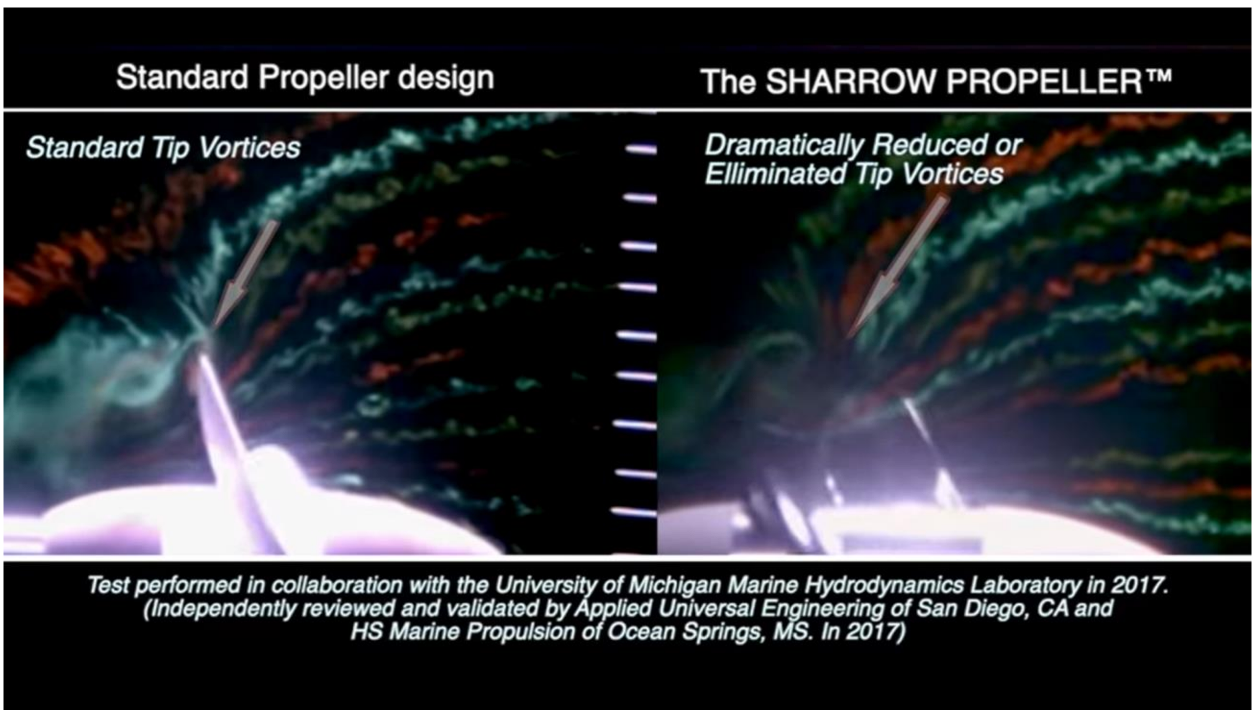

Figure 8: Comparison of propeller tip flow from Sharrow Marine.

For this project, it was decided that a toroidal propeller would be designed and tested to try to improve the performance of the USI Solar Splash propulsion system. The experimental concept was based on the style of toroidal propeller that MIT Lincoln Laboratory created, but adapted for marine use. The goal was to determine how well a custom toroidal propeller would compare to a custom designed standard propeller with similar cross-sectional geometry.

3 SYSTEM DESIGN

3.1 STANDARD PROPELLER DESIGN

Two designs were created to be analyzed for this project. Firstly, the conventional propeller was designed using a MatLab program called OpenProp. After running the program, an input interface opens and parameters for the propeller can be entered. A photo of this interface can be seen below.

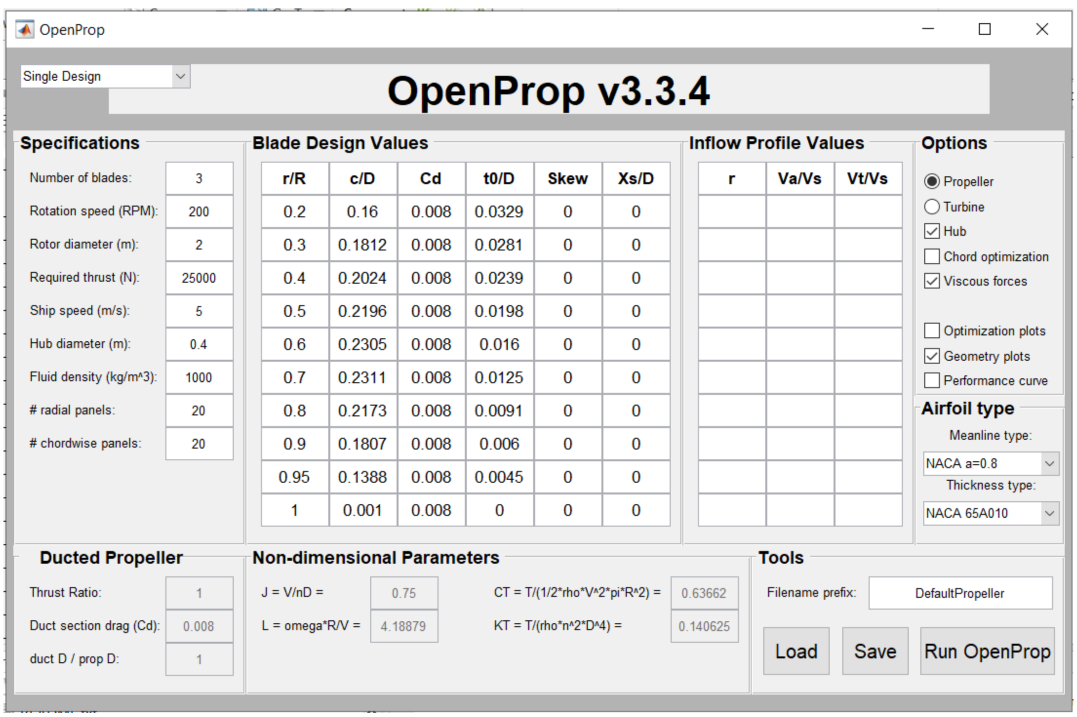

Figure 9: OpenProp inputs interface.

As seen in Figure 9 above, the user will input the following desired specifications:

- Number of blades
- Rotation speed (RPM)

- Rotor diameter
- Rotor thrust
- Ship speed
- Hub diameter

These parameters define how the propeller will perform and the geometry that will be generated. A four-blade propeller was chosen to manipulate the blades to create a toroidal shape. The USI Solar Splash team is currently using a motor that is being run at around 2916 rpm, so this number was kept consistent. The rotor diameter was chosen based on the size of the propeller that was used in last year's competition, and the hub diameter was decided based on the same metric. In the last competition, USI completed the sprint race with a speed of 7.01 m/s, while the top speed completed with a speed of 12.35 m/s. Because each team will be striving to improve their performance, a value of 14 m/s was chosen as the desired speed. There is one more section that the user must modify before running the program, which is the c/D section. This section determines the length of the blades from leading edge to trailing edge, as a function of the propeller diameter. These values should be around 0.1 or less for the best propeller shape [3]. After the specifications are entered and the program is executed, a propeller is designed by the

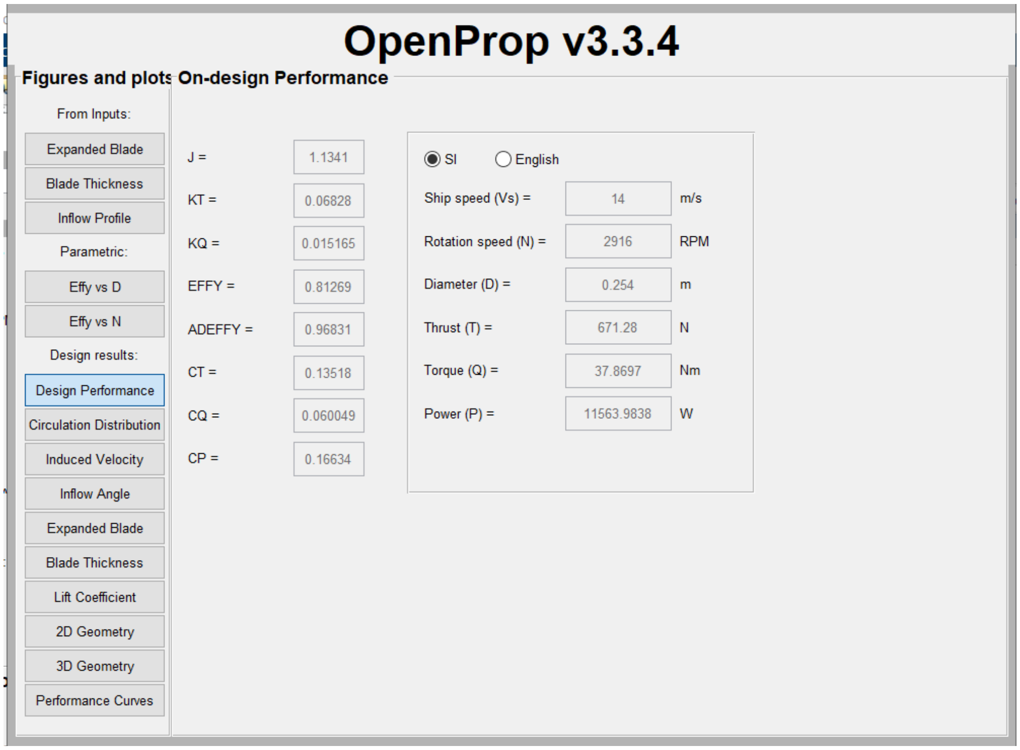

Figure 10: OpenProp output interface.

program and performance values are calculated. Figures 10 and 11 display the OpenProp outputs that were created after entering the design specifications that were required for this project.

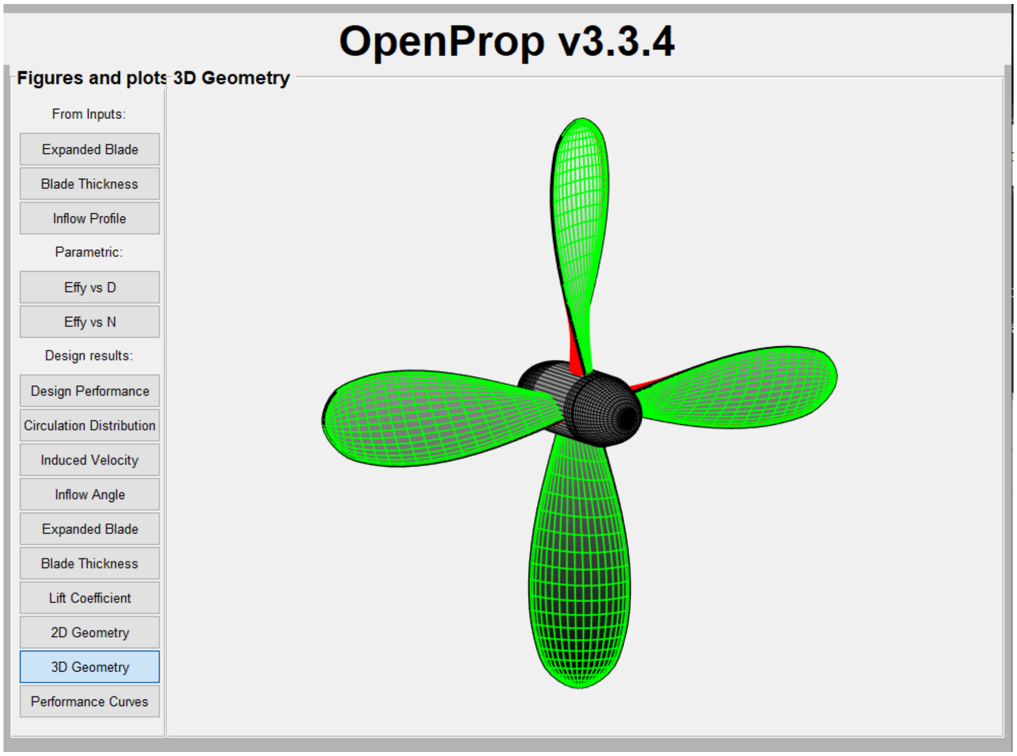

Figure 11: OpenProp geometry output.

Once OpenProp has generated the outputs based on user-input parameters, the geometry can then be exported as a series of comma-separated values of XYZ coordinates. These XYZ coordinates can be imported to SolidWorks as curve profiles. The number of curve profiles and the number of coordinates within each profile is dependent on the number of chordwise and radial panels (see Figure 9). For this project's purposes, the default value of 20 panels was used as it results in acceptable resolution. Once each profile is imported, the loft feature can be used, which connects two or more profiles with a solid body. Figure 12 shows the curve profiles before and after lofting. To make a standard 4-blade propeller, as shown in Figure 13, the lofted geometry of a single blade was duplicated in a curved pattern around the axis of rotation. A cylindrical hub was made to connect all 4 blades, with fillets to smooth the model at the points of contact.

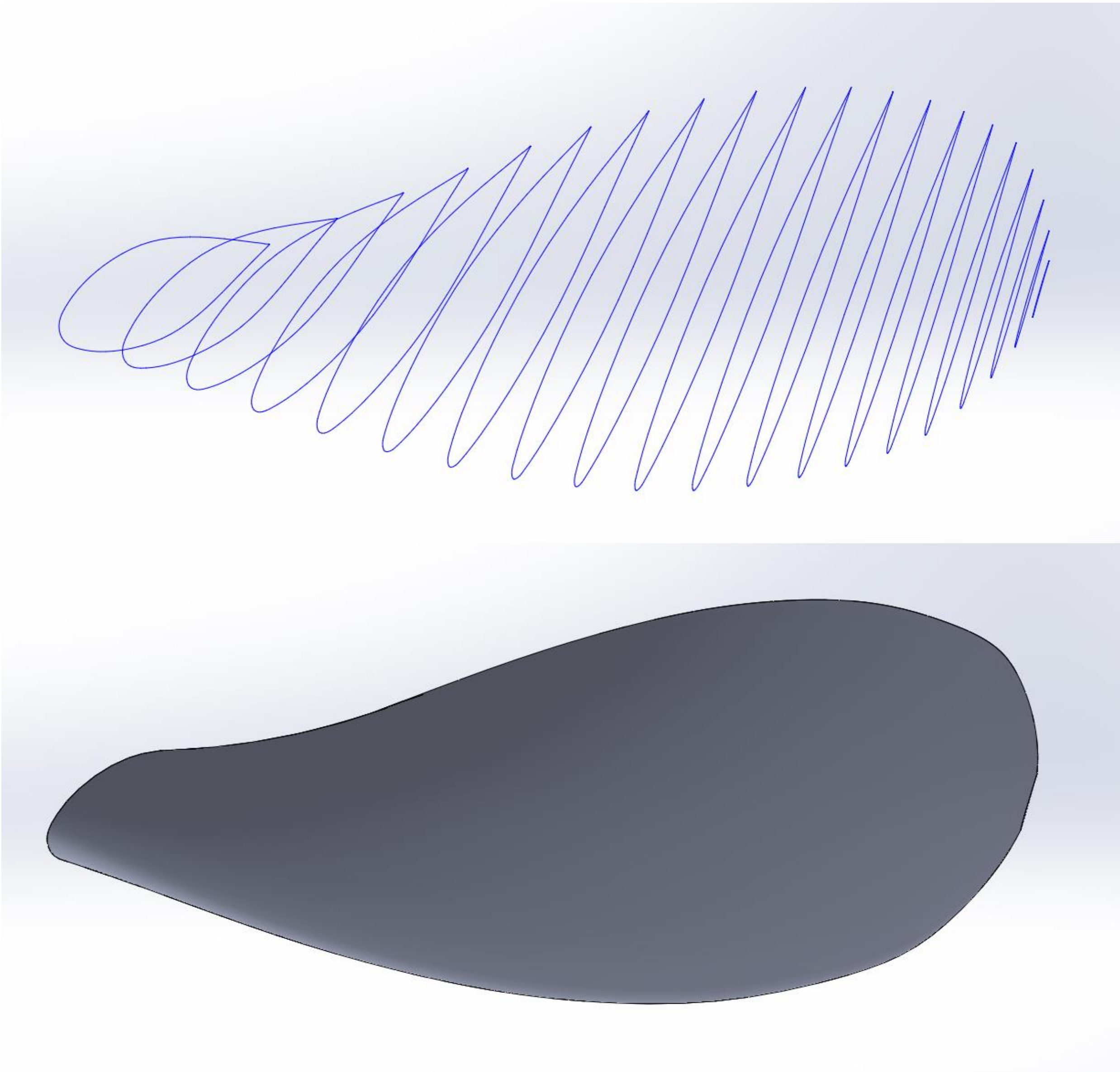

Figure 12: 3D sketch and model of standard propeller blade.

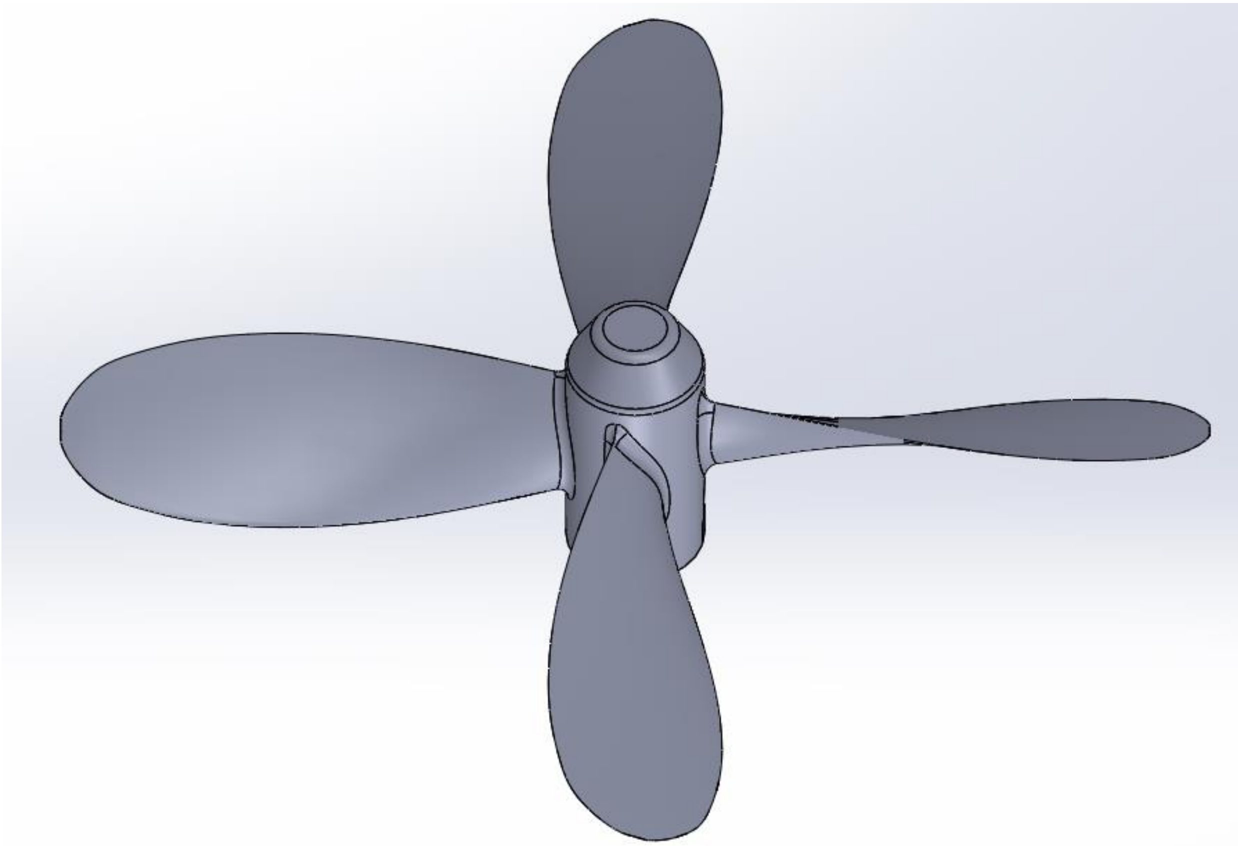

Figure 13: Standard propeller 3D model.

3.2 TOROIDAL PROPELLER DESIGN

To design a toroidal propeller, there is not software like OpenProp that will generate curve profiles for toroidal propellers automatically, as the concept of toroidal propellers is still very new. The approach taken for this project was to use a majority of the curve profiles generated by OpenProp for the standard propeller, then manipulate the shape of the model to create a propeller that is similar to the design of MIT's patented toroidal propeller. The final model generated is seen in Figure 14. Since this type of propeller does not have the standard characteristics of a propeller, the performance cannot be analyzed through math equations under ideal conditions. Instead, its performance can only be verified through fluid simulations and in-water testing.

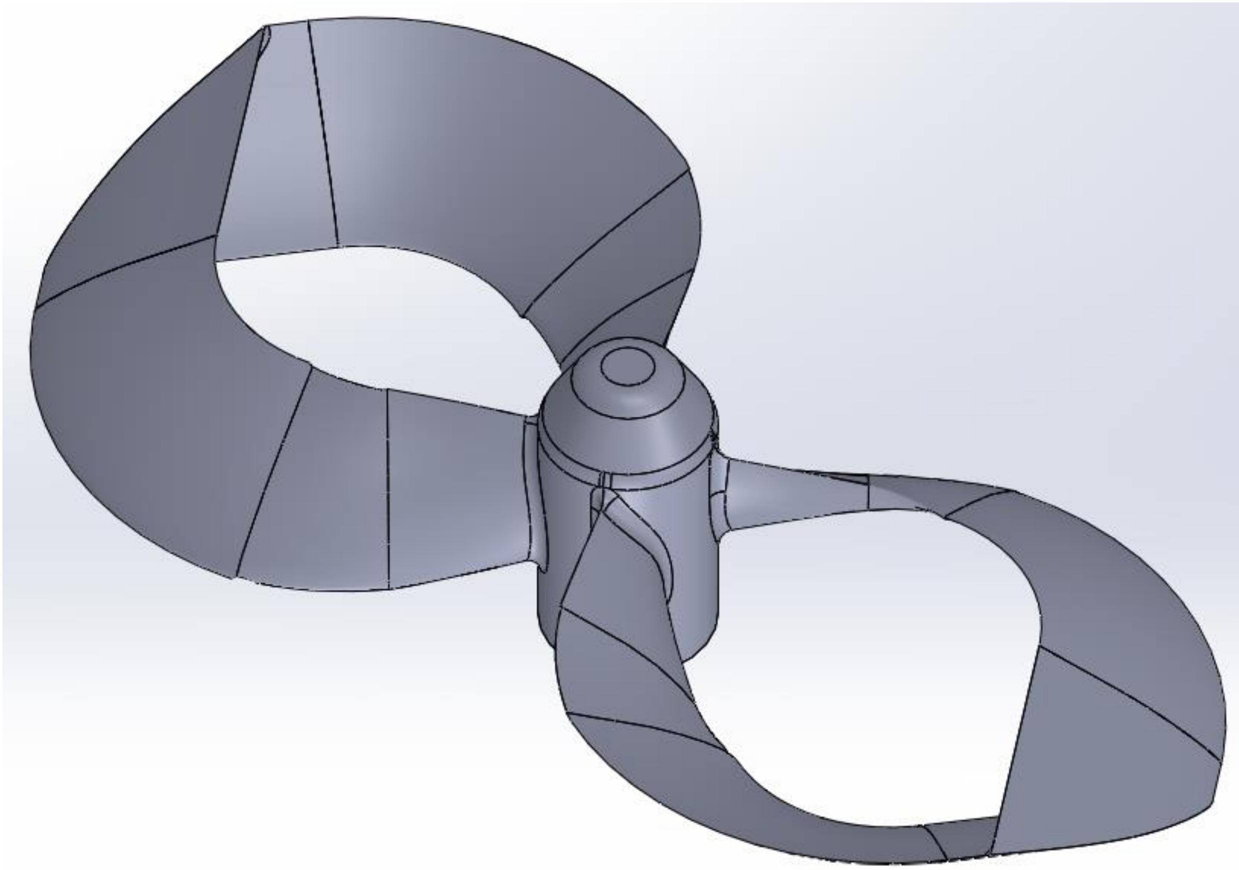

Figure 14: 3D model of a toroidal propeller.

3.3 MATERIAL CONSIDERATIONS

To ensure that the performance of the propeller was maximized, a material that could withstand the maximum RPMs, velocity, and forces needed to be selected. It was also necessary to identify a material that would not react or mix with the water. The material that was chosen to fit these criteria was Nylon-12CF from Stratasys. According to the Nylon-12CF safety datasheet provided by Stratasys, the Nylon-12CF is not categorized as a pollutant under the Clean Water Act:

> **40 CFR 122.2***: Pollutant means dredged spoil, solid waste, incinerator residue, filter backwash, sewage, garbage, sewage sludge, munitions, chemical wastes, biological materials, radioactive materials (except those regulated under the Atomic Energy Act of 1954, as amended*

(42 U.S.C. 2011 et seq.)), heat, wrecked or discarded equipment, rock, sand, cellar dirt and industrial, municipal, and agricultural waste discharged into water. [13]

This material would be compatible with the university's new Fortus 450mc 3D printer, which is ideal for producing a prototype propeller. Two other materials were also considered as alternatives to the Nylon-12CF, these materials being ABS-M30 from Stratasys and Aluminum. ABS-M30 is a viable alternative as it is decently strong, insoluble in water, and is much cheaper than the Nylon-12CF. It is compatible with the Fortus 450mc as well, which would allow for on-campus production. Aluminum is another viable material to be considered. It is much stronger than either the ABS-M30 and the Nylon-12CF which would allow for much more strenuous performance, it does not rust, and is relatively cheap and light compared to metals. Aluminum should be considered as the UPRM team used it in manufacturing their custom propeller blades.

In order to properly choose the appropriate material, datasheets for each were researched and material properties were compared. The following table displays the material properties [1] [2] [4].

Material	Elastic Modulus (GPa)	Density (g/cm^3)	Strength to Weight Ratio (kN*m/kg)
ABS-M30	2.40	1.05	26.8
Nylon-12CF	12.7	1.07	101.6
Aluminum	68	2.70	33.3

Table 2: Material comparisons.

When comparing the properties of each of the considered materials, Nylon-12CF was the most beneficial. While Nylon-12CF and the ABS-M30 had similar densities, their elastic modulus and strength to weight ratio were vastly different. While the ABS-M30 is an option for the propeller, it should only be used in testing situations to determine how the propeller would behave. When comparing the Nylon-12CF to the aluminum, it can be noted that the aluminum was much stronger, but also twice as dense. The aluminum would be able to withstand much more stress than the Nylon-12CF, but the Nylon-12CF would cut down on the weight of the propeller without sacrificing much performance.

4 SYSTEM EVALUATION

4.1 CALCULATIONS

In order to know what parameters to input into the OpenProp software, calculations needed to be completed to determine ship speed. The following calculations determine USI's speed from last year's race, as well as the first-place team's speed:

$$\frac{300m}{42.80s} = 7.01\ m/s$$

$$\frac{300m}{24.29s} = 12.35\ m/s$$

These calculations helped determine how fast the ship needed to be, which was faster than 12.35 m/s. A design choice of 14 m/s was picked to give the USI team a competitive speed for the sprint race.

OpenProp takes an input parameter of thrust, and this value needed to be calculated. Initially, the horsepower that was output by the motor was converted into Watts. This was recorded as brake shaft power (BSP). After the BSP was calculated, with a value of 12,000, the BSP was multiplied by an efficiency value of 0.75. This parameter was chosen based on the motor datasheet. This value was recorded as the effective power (PE). The last input for the thrust calculation was the speed in meters per second (Vp), which was determined in the previous calculations. Once these values had been determined, the thrust could be calculated using the following formula:

$$T = \frac{PE}{Vp}$$

$$T = \frac{8925W}{14m/s}$$

$$T = 637.5\ N$$

4.2 SIMULATIONS

Simulations were initially to be performed using a Computational Fluid Dynamics (CFD) software called ANSYS Fluent. However, due to the complexity of the software, and in the interest of time, a simpler CFD software was used. SolidWorks CFD was chosen as the simulation software as it is much simpler and more user friendly, and in theory would yield similar results as ANSYS Fluent. Multiple iterations of the flow through each propeller were performed.

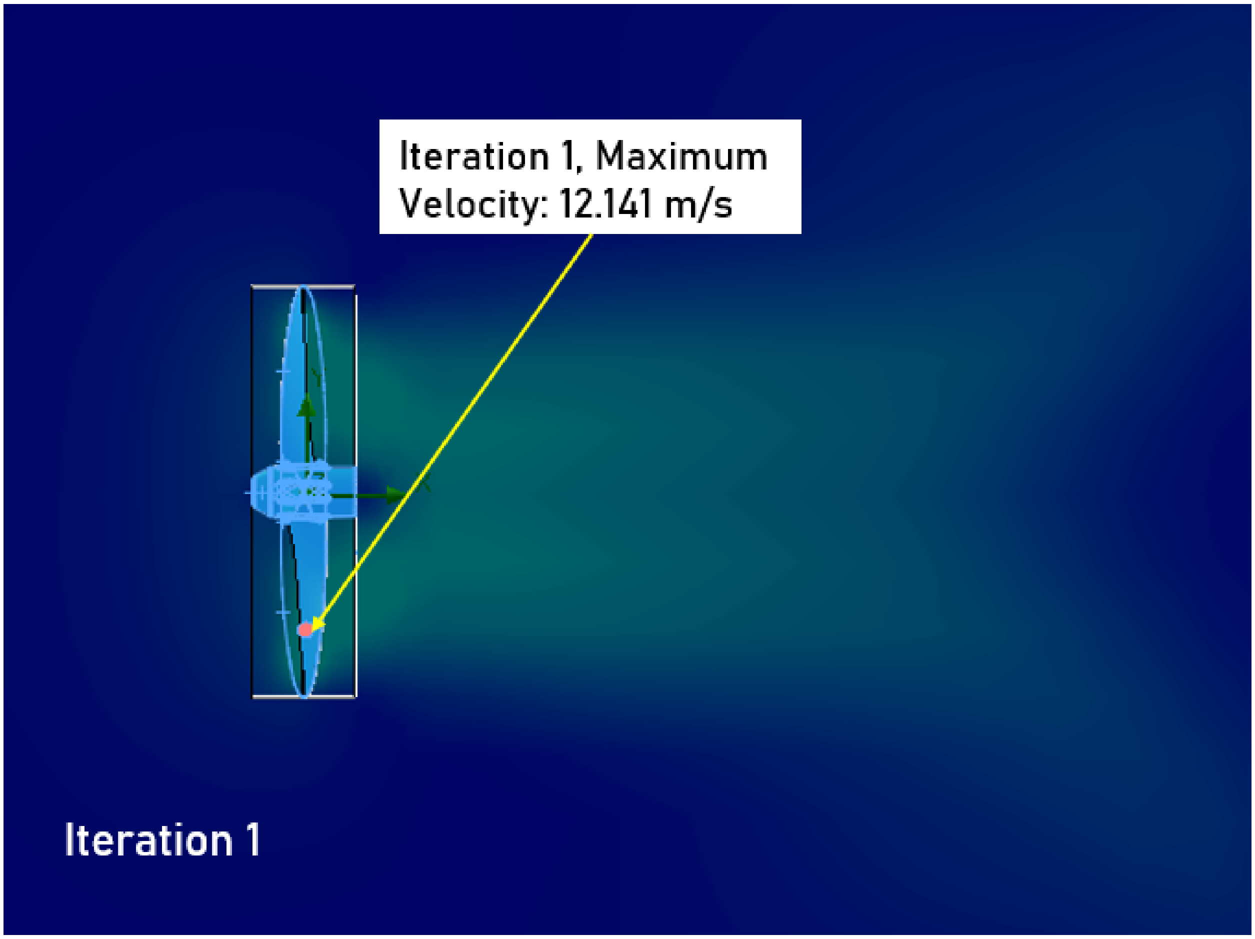

Figure 15: Standard propeller simulation iteration 1.

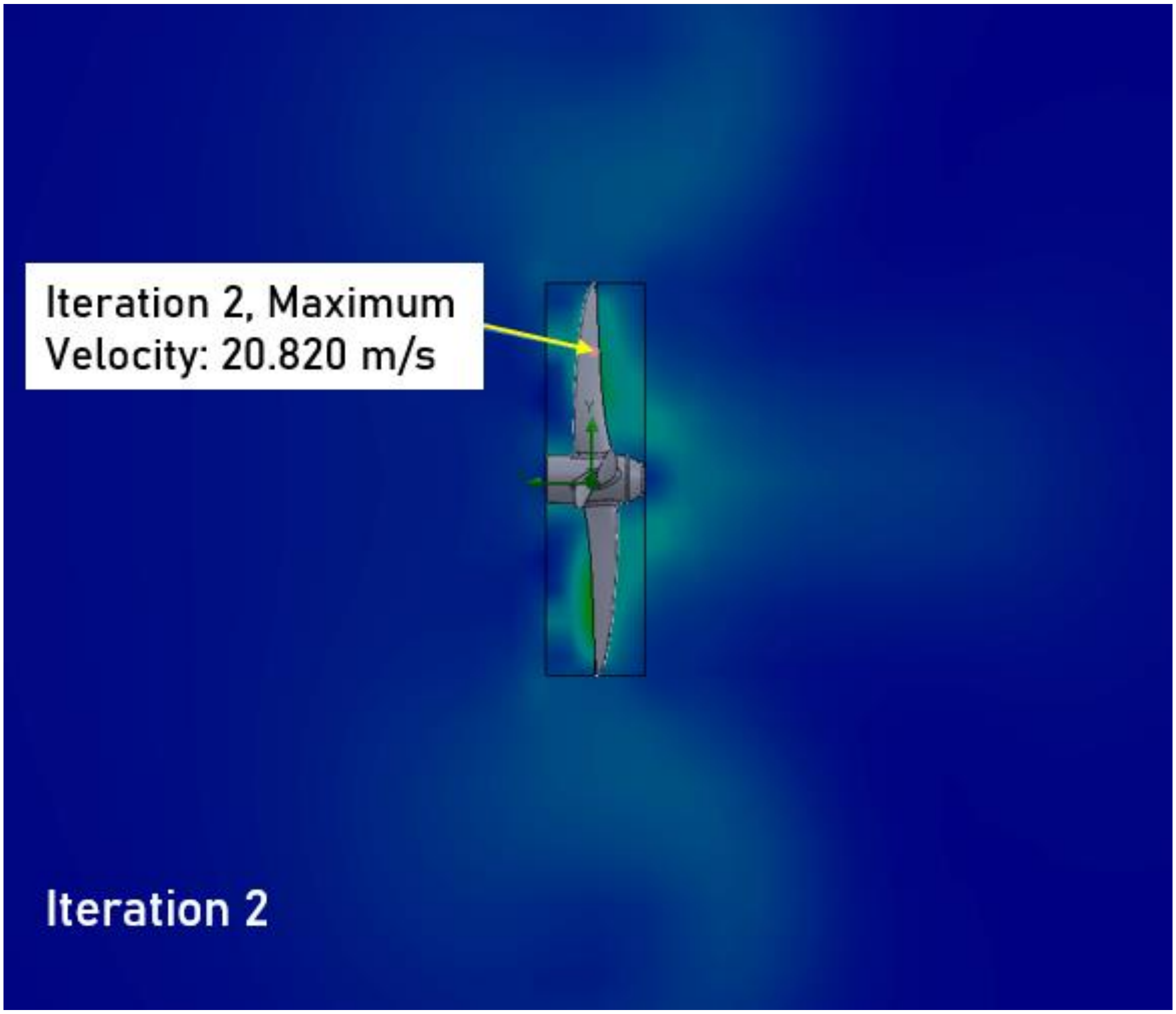

Figure 16: Standard propeller simulation iteration 2.

The standard propeller design was analyzed first as it is a simpler geometry and would allow for learning of the CFD software. As shown in Figure 15, the flow profile through the propeller looks exactly as it should. The water passes through the propeller, and fans out the farther away it gets. In this iteration, the velocity was 12.141 m/s which was slightly lower than anticipated, as OpenProp output a propeller design that would reach a speed of 14 m/s. In Figure 16, the flow profile does not follow the same pattern as in the first iteration. The flow is concentrated around the propeller's blades, and the fluid flows out from the tips of the blades. Very little fluid passes through the propeller, but the little that does is very concentrated. The maximum velocity for the second iteration was 20.820 m/s, which was much higher than expected, and much higher than the first iteration.

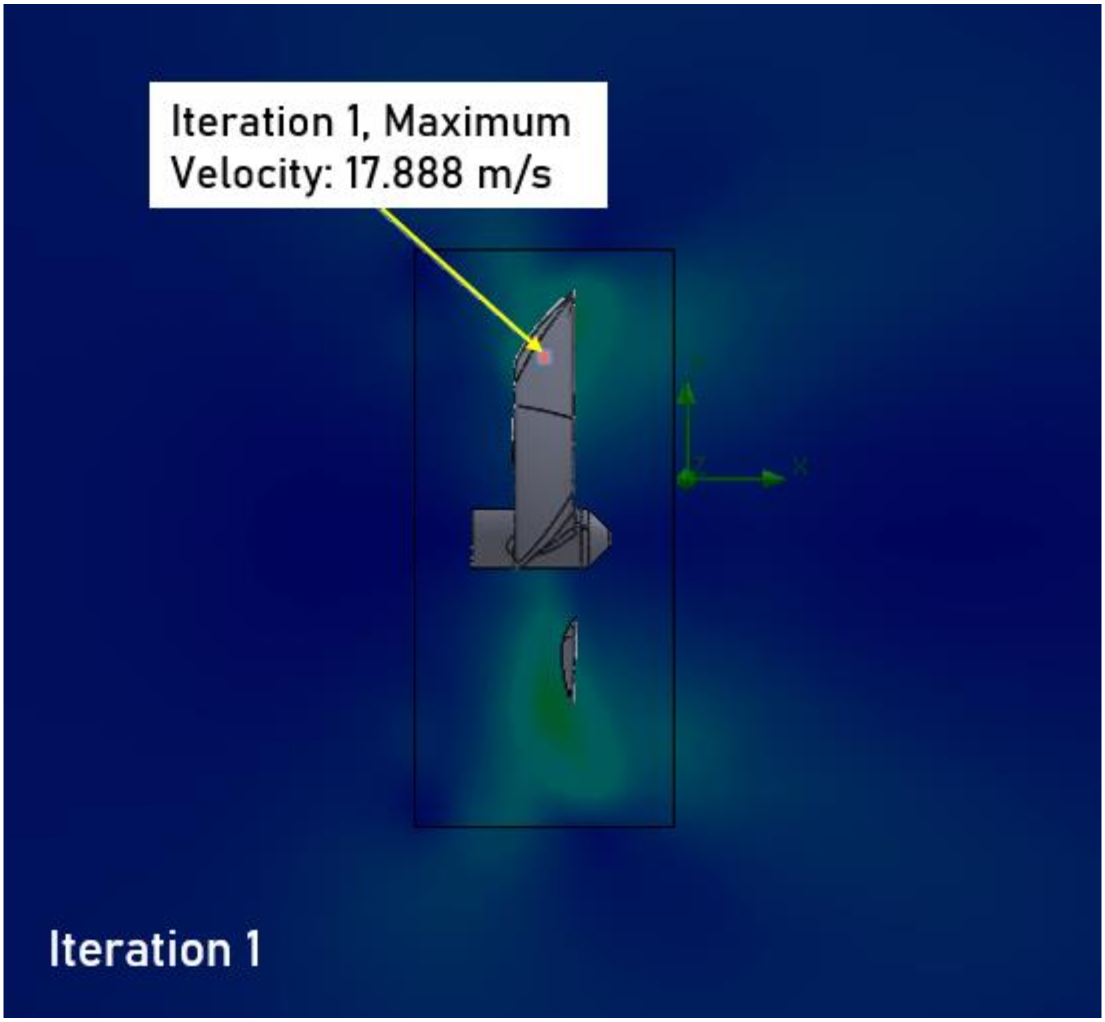

Figure 17: Toroidal propeller simulation iteration 1.

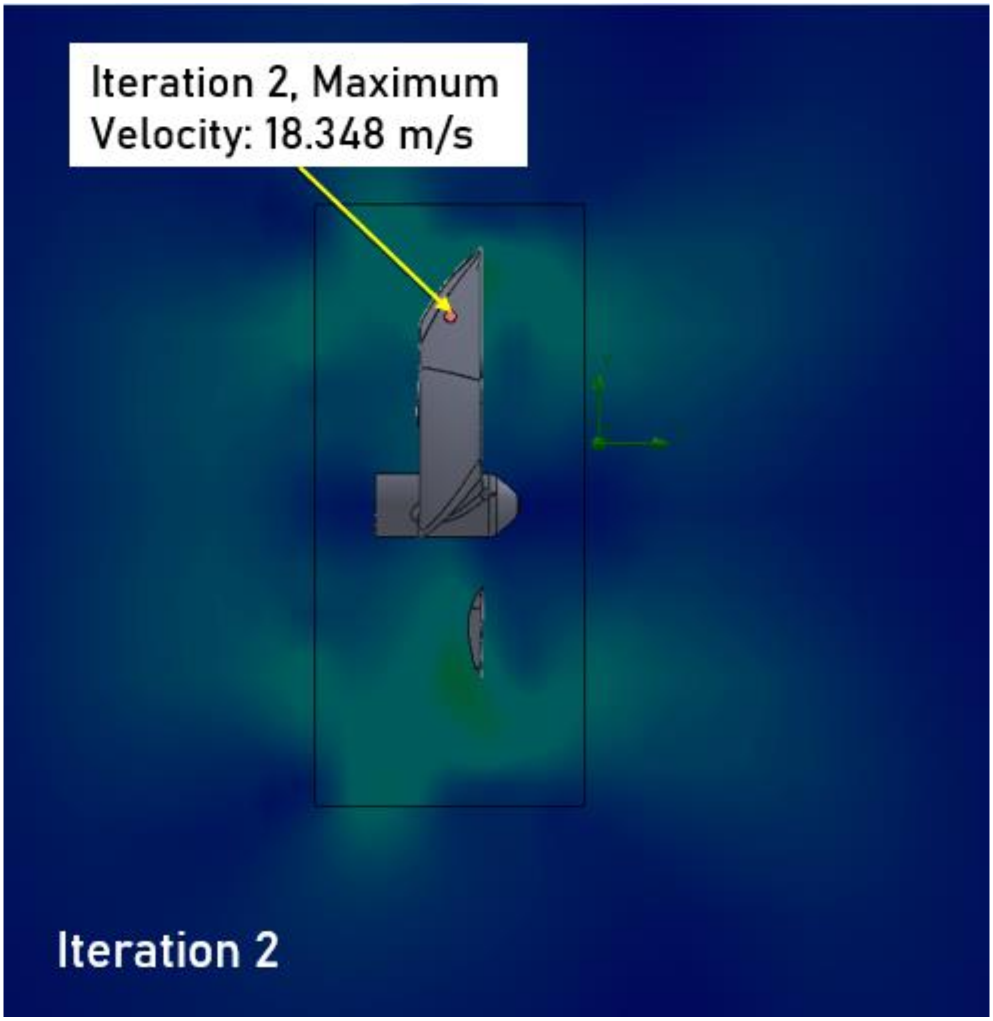

Figure 18: Toroidal propeller simulation iteration 2.

Once the standard propeller's flow had been simulated, the toroidal propeller was simulated under the same parameters. As seen in both Figure 17 and Figure 18, the flow profile for the toroidal propeller is very similar to the second iteration of the flow for the standard propeller. The flow is concentrated around the blades, and almost none passes through the propeller. Most of the fluid passes around the outside of the propeller, with a very high concentration on the blade tips. In the toroidal simulations, the velocity was more consistent across iterations than the standard propeller, but due to the flow profile, it cannot be confirmed if the propeller will perform better.

Due to the erratic flow profiles and the inconsistencies across iterations, the simulation results provided no real conclusions. Simulations were performed multiple times, and in each iteration, a dramatically different result was produced. Because of the discrepancies identified across the simulations, the results were determined to be inconclusive and unreliable.

4.3 PHYSICAL TESTING

Physical testing was completed using a small fishing boat along with a motor provided by the USI Geology department. The testing was done at Hovey Lake using three propellers. During testing, each propeller's max speed and average sprint time were collected. The first test was completed using the original propeller that belonged to the motor that was being used. This was to determine if the designed propellers would be comparable to the original propeller. The only baseline data that was collected during the trial for this propeller was a max speed, which was 10.8 mph.

Figure 19: Mounted printed standard propeller.

After collecting the speed for the original propeller, the standard propeller design was attached and tested. Figure 19 shows the standard propeller on the base of the motor. This propeller was able to reach a max speed of 6.3 mph and completed the sprint in a time of 28.05s. It was determined after this testing phase that the printed propellers would not warrant results comparable to the original propeller. The baseline measurement of 10.8 mph was much higher and confirmed that the printed propellers may be better suited for USI’s boat and motor that they were designed for.

Figure 20: Mounted printed toroidal propeller.

In the last phase of testing, the performance of the toroidal propeller was tested and compared to the performance of the standard propeller. The propeller was attached to the motor, as shown in Figure 20. The toroidal propeller managed to reach a top speed of 5.9 mph, with a sprint time of 30.25 s. While this propeller's test statistics are close to that of the standard propeller, testing proved that there was no increase in performance. This could be caused by many reasons, such as poor print quality or the complexity of designing a toroidal propeller. It should be noted that due to incoming inclement weather, only one trial was able to be completed for each propeller.

5 ECONOMIC CONSIDERATIONS

When designing the propulsion system, cost estimates and considerations played an important role in choosing materials and components. The current propeller is a standard 3-blade, 10-inch propeller for a boat of this size. Since this propeller is a fairly common style, there are three options for alternatives, which would be to purchase a prefabricated propeller, 3D print a custom propeller, or machine a custom propeller. When considering these alternatives in the technical reports from other Solar Splash teams, there were some teams using prefabricated propellers and other teams that used custom machined propellers in the previous competition. To replace the propeller with another off-the-shelf propeller, it would cost approximately $200-300. While the propellers would be ready to mount immediately if purchased that way, it can be costly, especially if the propeller does not perform as desired. The cost of 3D printing a propeller can vary greatly depending on the slicer software and material used for printing. When 3D printing the toroidal propeller designed in this project, the Fortus 450mc printed the model with a wasteful amount of Nylon 12CF model and support material, which increases the total cost of the print. Despite this waste of material, the cost was only $79 of model material, and $19 of support material, resulting in a total cost of about $98. This means that the cost to 3D print the propeller is still lower than the cost of buying a propeller from the store with the additional benefit of having the ability to make modifications and reprint at any time. If an aluminum propeller was to be used at any point, modeling could be done at the USI campus, but the fabrication of the propeller would need to be outsourced. This would result in a very high price point for the aluminum propeller, as the machining would have to performed within very tight tolerances, and the material would need to be purchased beforehand as well.

6 CONCLUSIONS AND RECOMMENDATIONS

6.1 Lessons Learned

This project proved to be a very challenging experience. Throughout this semester, we gained increased understanding of SolidWorks in which we designed, modeled, and simulated our propeller concepts. We also gained some experience with OpenProp, which could assist the Solar Splash team if they choose to design custom propellers for their future drivetrain designs. This project also provided extensive information about the design and capabilities of toroidal propellers. From our testing, we learned that the design of our custom toroidal propeller had very comparable thrust to the custom standard propeller. This aligns with the conclusion that MIT found with their drone propellers, as they learned that the toroidal propeller drastically reduced sensitive noise profiles without sacrificing thrust. However, we also learned that the propellers we designed had a more similar geometry to airplane propellers than marine propellers. Marine propellers typically have a much greater chord length than airplane propellers, which has a great effect on overall speed as seen in our testing.

6.2 Future Recommendations

Though much effort went into the design and creation of these propellers, there are many projects that could be done in the future to contribute to the Solar Splash drivetrain system and ultimately lead the team to 1st place. Future senior design projects could include a testing apparatus for evaluating motor-propeller output, a drivetrain mount with adjustable trim and depth, a “hot swap” gearing system for quick changes between races, or even a continuation of this project with a more finely designed toroidal propeller. If this project were to be continued in the future, more in-depth simulations and a more thorough physical testing plan would provide more accurate results for the propeller comparisons. It would also be good practice to test the propellers with the drivetrain and hull that the Solar Splash team will be using in competition for a more accurate display of expected performance. For the purposes of this project, this was not an option, and another boat had to be used for the physical testing. One specific recommendation for the design of the propeller would be to adjust the input parameters so that the chord length is increased, as seen in typical marine propeller geometry. Another recommendation would be to use a different plastic than Nylon 12CF, as the printed propeller was very rough and heavy, which decreases its efficiency. The use of a plastic like ABS could be viable if an aluminum shaft insert/adapter is machined for it. Lastly, since the 3D printed propellers are plastic, it may be necessary to adjust the OpenProp parameters for a moderately thicker propeller blade as well, so that the propeller blade doesn't deflect under load.

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