MAY 1, 2023

BOAT #2

SOLAR SPLASH TECHNICAL REPORT

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Executive Summary

The purpose of the Solar Boat Project at UPRM is to develop an integrated multi-disciplinary design project applied to electric solar powered marine vehicles. Additionally, the UPRM Solar Boat team was created to enhance the students' educational experience developing their technical and non-technical skills. The goal for this year is to improve upon the 2022 results and reclaim first place overall in the Solar Splash competition.

After the 2022 Solar Splash event, the team revisited its performance and identified two major areas for improvement: the endurance event (-75pts) and the endurance qualifier (-18pts). The 2022 UPRM boat only exhibited maximum cruising speeds of approximately 3.2m/s compared to Cedarvilles's impressive speed of 3.7m/s. The results obtained from the newly designed propeller operating at 1,400 rpm were far from the projected 3.6m/s. It is hypothesized that the clearance of the propeller to the waterline along with the high rpm are inducing the propeller to cavitate. Hence, a drivetrain/axis extension was designed and incorporated to allow for better clearance of the propeller to the waterline. Additionally, the propeller was redesigned for 3.6m/s at lower rpm (700 and 900).

The endurance qualifier performance also suffered because of the propeller design. The voltage required by the motor at such high rpm (~1,400) is close to 20V, hence there is no room left for higher speeds as we operate at 24V in the endurance configuration. Although the lower rpm design should help, the team decided to incorporate a 24-to-36 voltage converter. The converter will allow for 36V operation at the endurance qualifier and 24V operation at the endurance event with the same boat/battery configuration as required by the Solar Splash Rules.

The Hull, Power Electronics System, Solar System and Drive Train System remained unaltered for the most part. Some updates were made to the Data Acquisition and Communication System, mainly focusing on expanding its sensing capabilities to include a drivetrain displacement sensor. The displacement sensor enables indirect measurement of the thrust developed by the propeller thus allowing for characterization of the design after fabrication.

The team has conducted a number of on-water tests at Lake Cerrillos in Ponce, Puerto Rico to validate the mentioned modifications and decide future implementations. Further tests still need to be conducted in the next few weeks in preparation for this year's competition.

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I. Overall Project Objectives

UPRM's Solar Boat Team earned second place overall in the 2022 Solar Splash competition, ranking first in Sprint and second in the Endurance event. The leaders of the competition had a 73.2-point advantage over our team in the Endurance event. Therefore, the main objective for this year's competition was to increase the Endurance Event top speed by 12% (from 3.2 m/s to 3.6m/s) without affecting slalom speed. The objectives established by the team for this year's boat are the following:

- **A.** Design, manufacture, and test four new endurance propellers matched to the motor efficiency and hull drag.
- **B.** Implementation of a thrust sensing and data acquisition system for hull drag measurements.
- **C.** Development of a 24V to 36V switching circuit to achieve a speed increase in endurance configuration events.
- **D.** Evaluate and update electrical systems, solar array, and panel frame.

II. Solar System Design

A. Solar Panels

1) ***Current Design:*** 2022's Solar Splash solar system design consisted of three OSFL160 Overland solar panels, with Genasun GVB-8-24V MPPT charge controllers. Given that they worked reliably during last year's competition, the same solar panel array and configuration will be used. The Overland solar panel array has a total weight of 8.16kg. These panels are lightweight, flexible, and sturdy enough for our boat, even at high speeds. The overland solar panel array configuration has a total power of 480W. A new frame was designed out of T-Slot extruded aluminum. The general properties of the Overland panel are displayed in **Table 1**, the general characteristics of the solar panel system array are given in **Table 2** and **Fig. 1** shows the electrical diagram for the solar array.

Table 1. *Overland Solar Panels*

Panel:	OSFL160(Overland)
Pm (W)	160
Vpm (V)	27.3
Imp (A)	5.86
Voc (V)	32.76
Isc (A)	6.27
Dimension (in)	58*22*0.16
Weight (lb)	6
Cell Efficiency (%)	Eff.>23.7
Vmax (V)	600
Area (m^2)	0.823

Weight/Area (lb/m^2)	7.29
Watts/Area (W/m^2)	194.41

Table 2. *2022 Solar Panel Array Characteristics*

Array:	**OSFL160 (2022)**
Power (W)	480
Area (m^2)	2.47
Weight (lb)	18

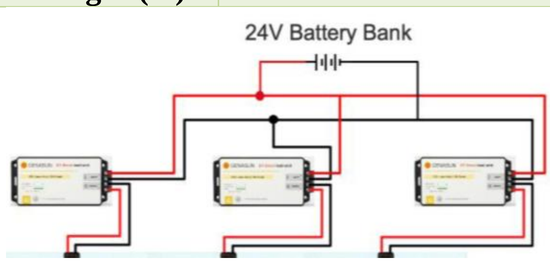


Fig. 1. *Solar Panel Array Wiring*

2) ***Analysis of Design Concepts:*** The arrangement of the components inside the boat, such as the solar panels, remains unchanged from what was used in 2022's competition. The team focused on keeping the resultant center of mass close to the center of buoyancy, so we would achieve a horizontally level ride during the endurance competition. For this reason, a spreadsheet was created to calculate where each of the components should be positioned. The preliminary resultant solar panel array position on the hull is shown in **Fig. 2**.

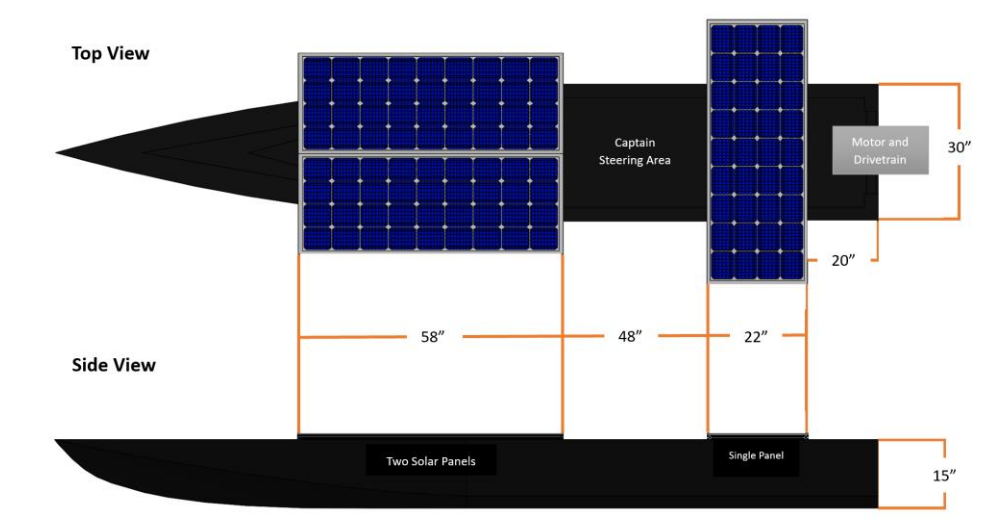


Fig. 2. *Solar Panel Positioning on the Hull*

Two frames were constructed using 53 ft of aluminum extrusion T-Slots cut to the exact measurements for a single and side by side OSFL160 arrangement. **Table 3** lists all the parts used to construct the new solar panel frame. The single panel frame resulted in a weight of 10 lb, while the double panel frame weights 20lb. The positioning on the hull of the frame can be observed in **Fig. 3**. Controller mounts and a bracket to secure the t-slot framing to the hull, shown in **Fig. 4**, were designed and 3D printed.

Table 3. *T-Slot Solar Panel Frame Parts*

Frame Piece	Quantity
Single 22 in.	8
Single 58 in.	4
Double 56 in.	1
Single 56 in.	2
3D Printed Mount	3
3D Printed Bracket	8
Connector Plates	22

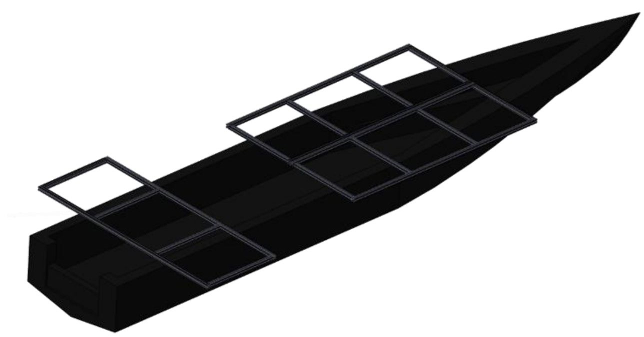


Fig. 3. *T-Slot Frame Positioning on the Hull*

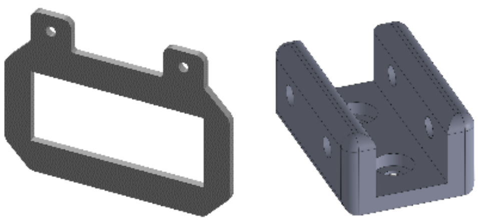


Fig. 4. *Controller Mount and Bracket for T-slot Framing*

B. Battery Bank

1) ***Current Design:*** Traditionally UPRM has used two identical battery banks composed of two Odyssey Extreme PC1100 and two Odyssey Extreme PC950. The bank is configured in a 24V array for the endurance event enabling maximum energy transfer from the battery at 31A, equivalent to approximately 1.5kWhr. For the sprint event the bank is configured in a 36V array for minimum series resistance of approximately 13mΩ.

2) ***Analysis of Design Concepts:*** N/A

3) ***Design Testing and Evaluation:*** N/A

III. Electrical System

A. Electrical System Block Diagram

1) ***Current Design:*** The electrical system used for previous competitions has worked well and met or exceeded the team's requirements for performance and efficiency. **Fig. 5** and **Fig. 6** show the power flow diagram of both the endurance and the sprint configurations. No changes to the electrical system have been made for the 2023 event.

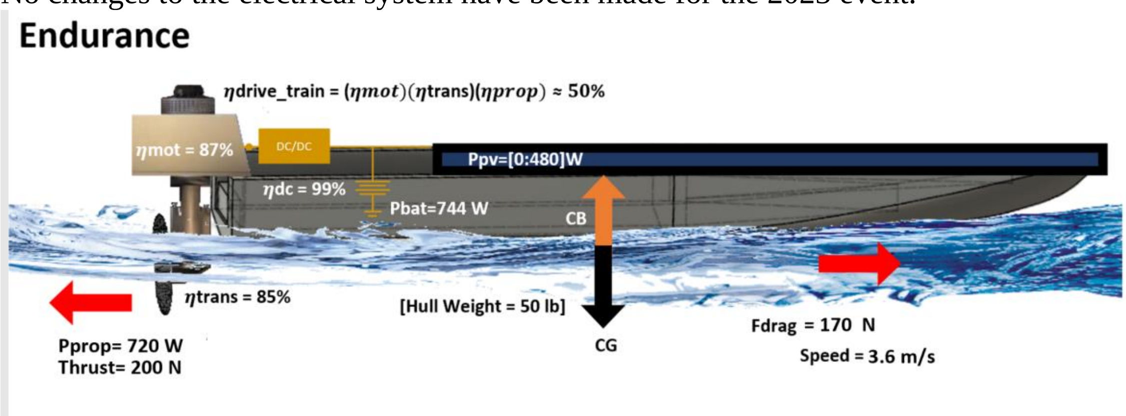


Fig. 5. *Endurance Power Flow Diagram*

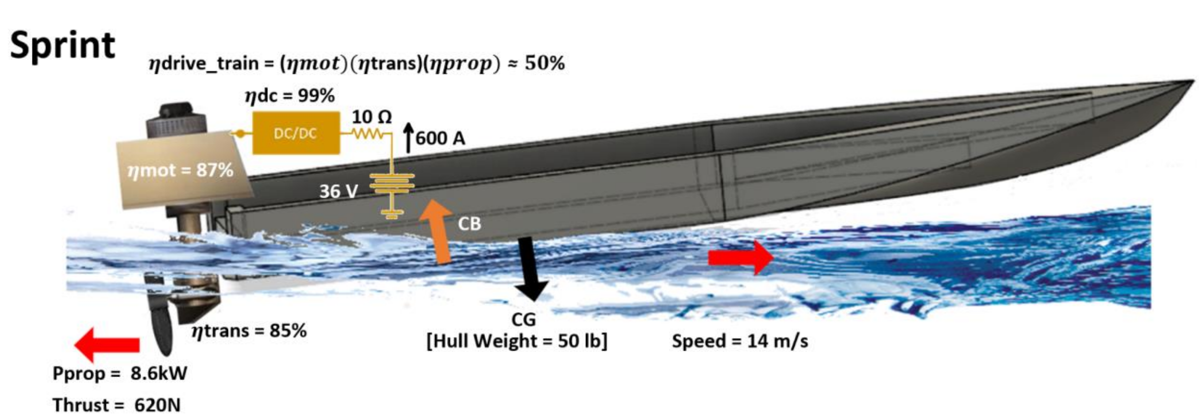


Fig. 6. *Sprint Power Flow Diagram*

2) *Analysis of Design Concepts:* N/A

3) *Design Testing and Evaluation:* N/A .

IV. Power Electronics System

1) Current Design:

The Kelly DC-DC controller used for previous competitions has worked well and met or exceeded the team's requirements for performance and efficiency. A single Lynch LEM 200-95 motor is used for both the sprint and the endurance events. **Fig. 7** shows the electrical system schematic for the sprint configuration at as system voltage of 36V; **Fig. 8** shows the electrical system schematic for the endurance configuration at a system voltage of 24V.

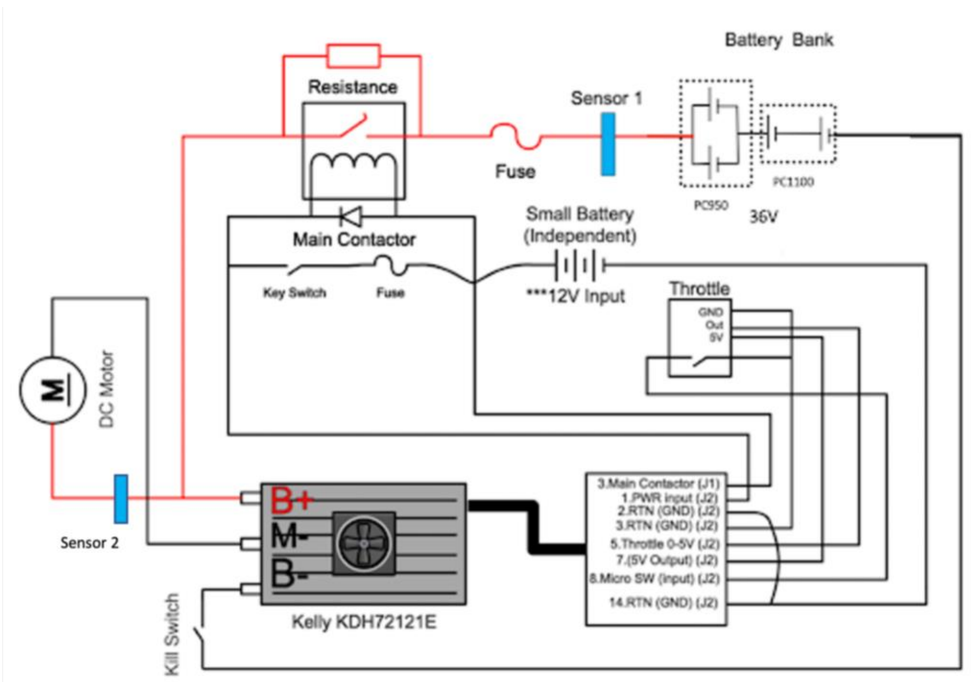


Fig. 7. *Electrical System Schematic for Sprint*

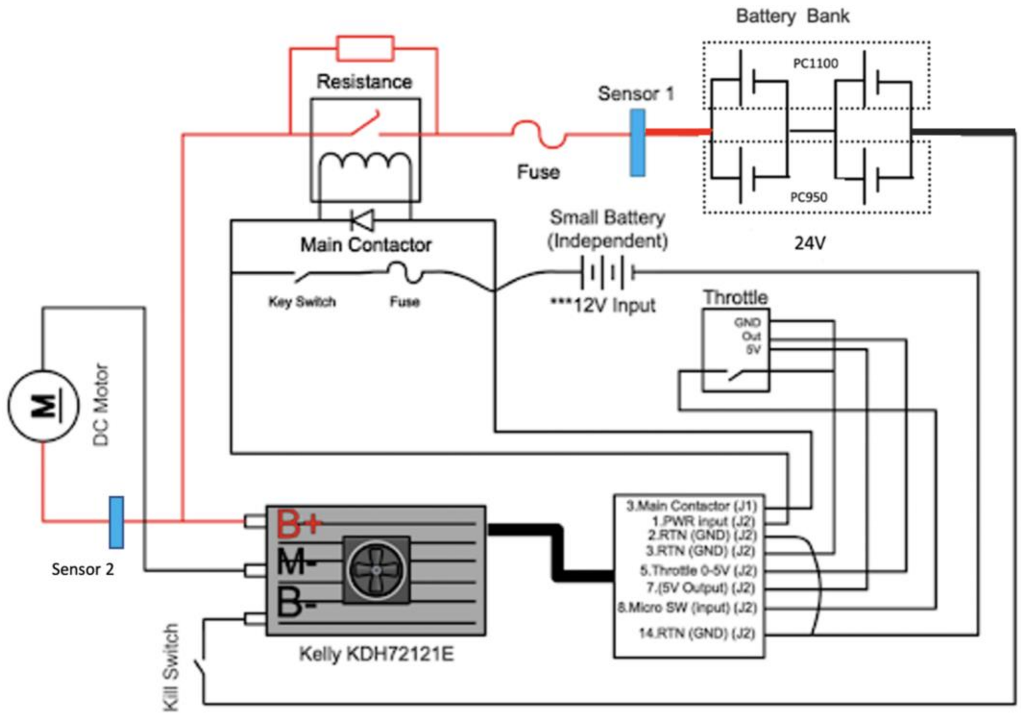


***Fig. 8.**. Electrical System Schematic for Endurance*

2) **Analysis of Design Concepts:** The motor voltage required for the 2022 propeller at 1400rpm was close to 20V. Since the system operated at 24V there was no room left for higher speeds in the endurance configuration, thus limiting a max speed in the endurance qualifier. The team decided to incorporate a 24-to-36 voltage converter that will allow for 36V operation at the endurance qualifier and 24V operation at the endurance event with the same boat/battery configuration as required by the Solar Splash Rules.

   Fig. 9 shows the circuit schematic of the proposed 24-to-36 V converter composed primarily by two Schottky diodes and a single relay. When the relay is open, the diodes allow for a 24V configuration obtained through the parallel combination 2 series connect PC950 and 2 series connected PC110. When the relay is closed, both diodes are reversed biased with a 36V configuration obtained through the series combination of 2 PC110 and a PC950.

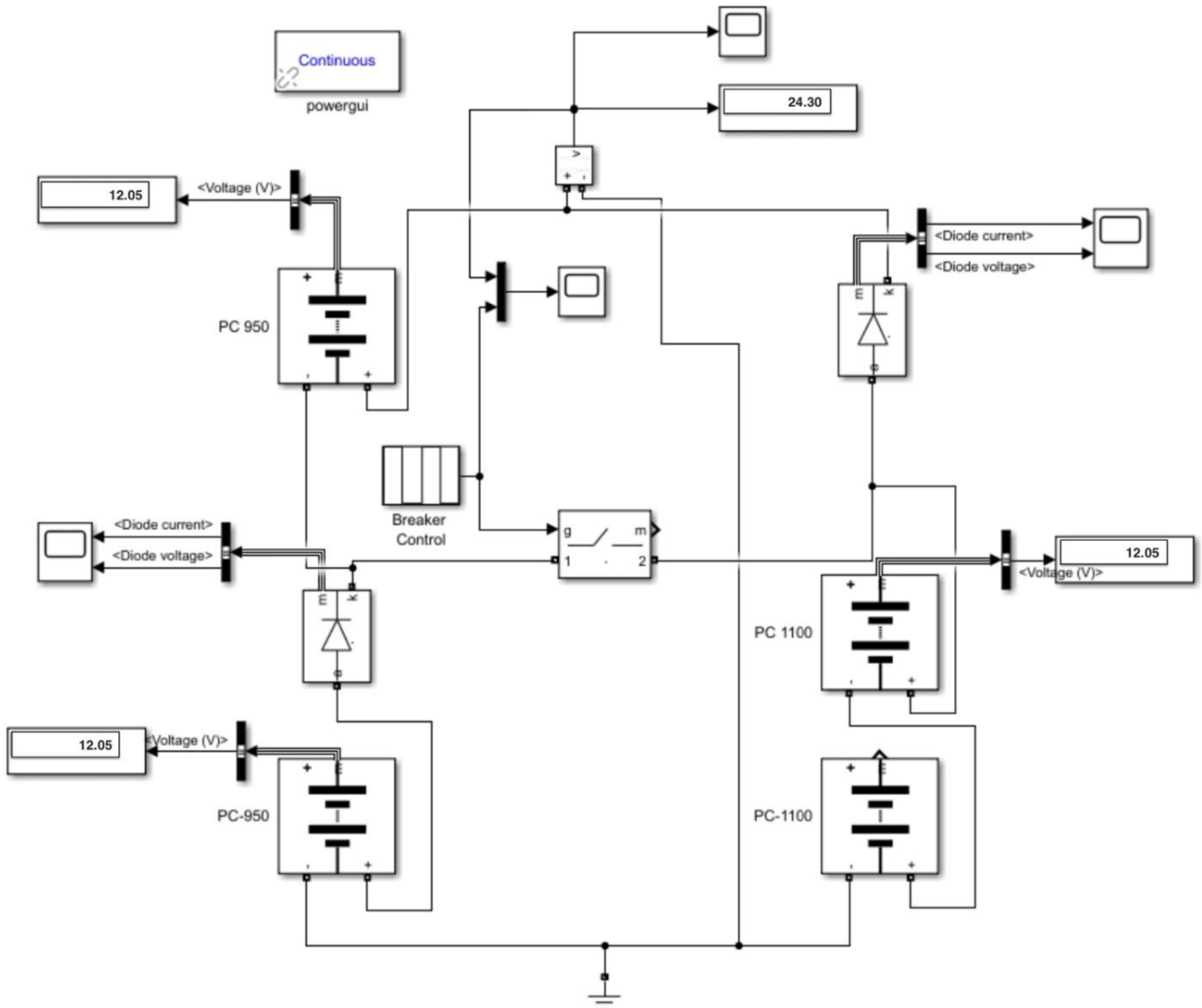


Fig. 9. 24 V to 36 V Switching Battery Bank Configuration

Fig.9 shows the new battery configuration that will be used for the events in the Solar Splash competition. To achieve the new configuration, while still complying with the competition rules, the switching action was decided to be done with a relay type switch Here, when the switch is in the open position the system will operate in the 24V range. This is because both sets of batteries will be in series, making them 24V, and from there set 1 will be in parallel with set 2. Then when the switch is closed, The PC-1100 set will be in series to make them 24 and that will be in parallel with the bottom left PC-950. From there the 24V will be in series with the Upper left PC-950 making the system reach 36V.

3) **Design testing and evaluation:**

To complete the work shown in the current design, a preliminary simulation was done utilizing Matlab Simulink. The first simulation was done with ideal components to ensure that the ideas was working as expected. Once that was confirmed the team was able to do the design already shown, where all the components have the real model.

This was to have more accurate values of the system functioning. For the Oddysey batteries all the values were obtained from their Datasheets and for the diode the team did a power loss calculation. To calculate the power loss from the two diodes, the total current from the Endurance Event (I) was multiplied by the forward voltage drop of the diodes (V_{FM}). This resulted in a power loss of 55.8W from the total power of the boat's electrical system. To achieve the state changes in the new configuration, while still complying with the competition rules, the switching action was decided to be done with a relay type switch.

V. Hull Design

1) ***Current Design*:** UPRM's hull was completely redesigned and manufactured for 2021's Solar Splash. After careful analysis of its performance in 2022's event, it was determined that no changes were needed for this year's event.

2) ***Analysis of Design Concepts:*** N/A

3) ***Design Testing and Evaluation:*** N/A

VI. Drivetrain and Steering

A. Drivetrain

1) ***Current Design:*** The aluminum drivetrain design fabricated for 2019's competition by the Mechanical Engineering group meets our criteria of efficiency, speed, and reliability, Therefore, the team determined that no major modifications were needed for this year's competition. That being said, the mechanical engineering team identified that the propeller used for the competition was underperforming. To determine if the propellers inefficiencies were due to an insufficient drivetrain length resulting in an inadequate propeller depth and cavitation, the team sought to extend the drivetrain to observe the performance of the propellers designed at greater depths.

2) ***Analysis of Design Concepts:*** The team determined that it would first be pertinent to evaluate 2022's competition propeller at greater depths of operation to establish if the loss in efficiency and performance was caused due to an improper submersion depth or a flawed design. To do so the drivetrain system must be evaluated at three different depths to calculate and compare results. The team first had to get the dimensions from both sides of

the shaft to make sure the extensions and the new couple design fit in place with, since a longer reach would result in an increase in stress. Three different extensions were designed ranging from 1 to 3 inches in increments of 1. The design for the drive train extension was developed using Solidworks. Two parts were created, an extension for the drivetrain body and an extended coupler for the shaft and transmission, as seen in **Figure 11**. Both parts were designed to match the exact shapes of the current system components to assure compatibility. The placement of the designed extension between the drivetrain body and transmission can be observed in **Figure 10.**

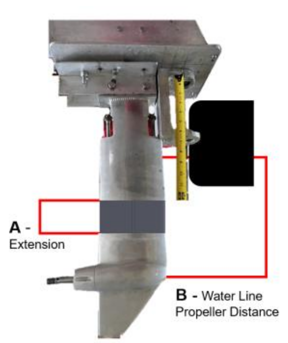


Fig. 10. *Drivetrain Extension Placement*

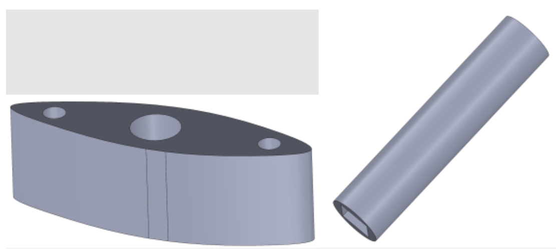


Fig. 11. *Coupler Extension CADs*

In **Table 4** below, the final extension lengths for the drivetrain extensions and couplers are shown. An increase in propeller submersion depth of 1, 2 and 3 inches has been achieved. Note, that the coupler currently used for the motor shaft and transmission has a total length of 56 inches. It was determined that the extensions and coupling would be CNC machined out of aluminum. Drawings of all the CADs developed can be found in **Appendix E-2**.

Table 4. *Coupler and Extension Part Lengths*

Drivetrain Extension Length	Extended Coupling Length
1 in.	2.56 in.
2 in.	3.56 in.
3 in.	4.56 in.

3) ***Design Testing and Evaluation:***

Further on-water testing of the drivetrain extensions will be conducted along each of the propellers designed, collecting data such as rpm, voltage, current, thrust, to establish a pattern in terms of performance efficiency and propeller depth. If no improvement is observed, an assumption of an incorrect selection of design parameters can be made and no drivetrain extension would be needed for competition.

B. Steering

1) ***Current Design:*** The steering system used for the previous competition worked well and met or exceeded the team's requirements for performance and weight efficiency. The steering system is composed of a pulley guided cable, connected to the steering wheel shaft and to a long bracket that is connected to the drivetrain. Since the steering system is easy to mount, it is moved to meet the desired steering position. Hence, no major modifications were made to the steering system. A schematic of the current steering schematic is shown in **Fig. 12**.

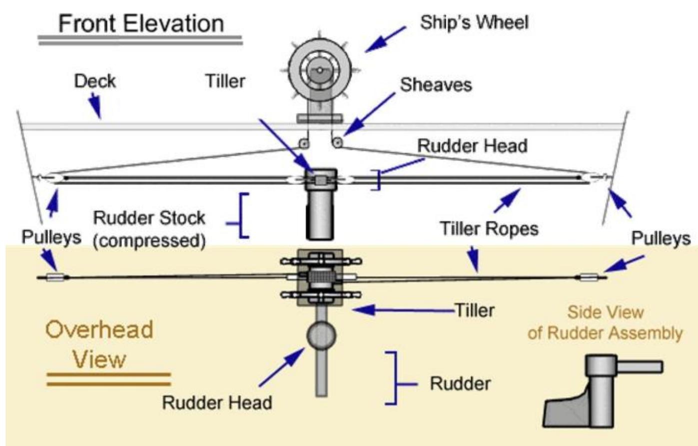


Fig. 12. *Diagram of Pulley Guided Cables*

C. Propeller

1) ***Current Design:*** The team currently uses two propellers, one for the Endurance configuration events and one for the high-speed events (Slalom and Sprint events). During the Endurance competition, the propeller performed at an average speed of 3.1 m/s for a total of 59.25 laps. In the Sprint competition, the propeller performed at an average speed of 12.6 m/s. This year the team decided to design four new endurance propellers. The endurance event is where greater improvement can be made, given that it is the most valuable event of the competition. 2022's propeller redesign matched at 1260 rpm failed to perform as expected. The four newly designed propellers would maximize the efficiency of the motor and hull design operating at lower rpms of 769N and 941N, to be able to reach a speed of 3.6 m/s without operating at the motor limit.

2) ***Analysis of design concepts:*** The propeller design and analysis process followed was the same as the one used for 2022's competition. The MATLAB programs previously developed, that automate the process of propeller design, were used. Two programs: one that calculated the motor efficiency curve at different rotational velocities (RPM) and different voltage; and a second one that calculated the thrust required at different speeds using polynomes that characterized the drag of the hull. For the endurance event, the program finds the optimal point for a propeller of greater efficiency. Both programs take as input a vector of the propeller diameter, then it calls a loop where it creates a single propeller for each diameter, when the loop is finished, it returns a graph with the given vector diameter. Two new lower rpm parameters of 769N-12V and 941N-14V were established for propeller design.

In **Figure 13**, the generated curves of efficiency at 14V of the propeller and motor in respect to RPM are plotted, as well as the overall system efficiency. From the overall system efficiency curve the new rpm design parameter of 941 rpm at 14V was set. **Figure 14** plots the curve for the optimal design system efficiency with the selected propeller design parameters. Likewise, **Figures 15** and **16** show the curves of efficiency of the propeller, motor, and overall system, in respect to RPM, and the optimal design system efficiency respectively for 769 RPM at 12V.

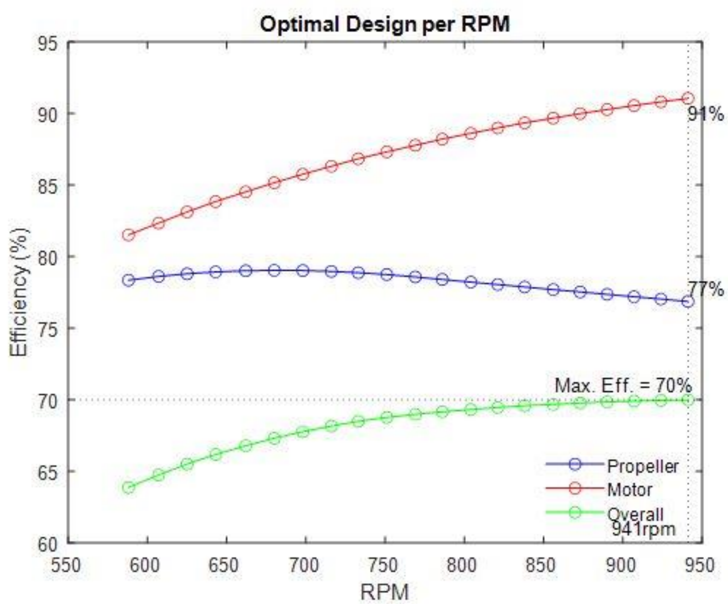


Fig. 13. *Propeller and Motor Efficiency in respect to RPM at 14V*

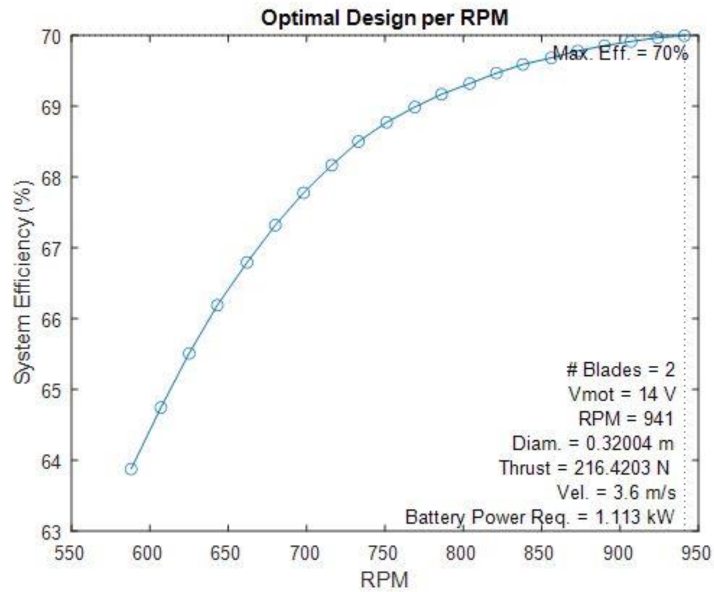


Fig. 14. *Optimal Design System Efficiency in respect to RPM at 14V*

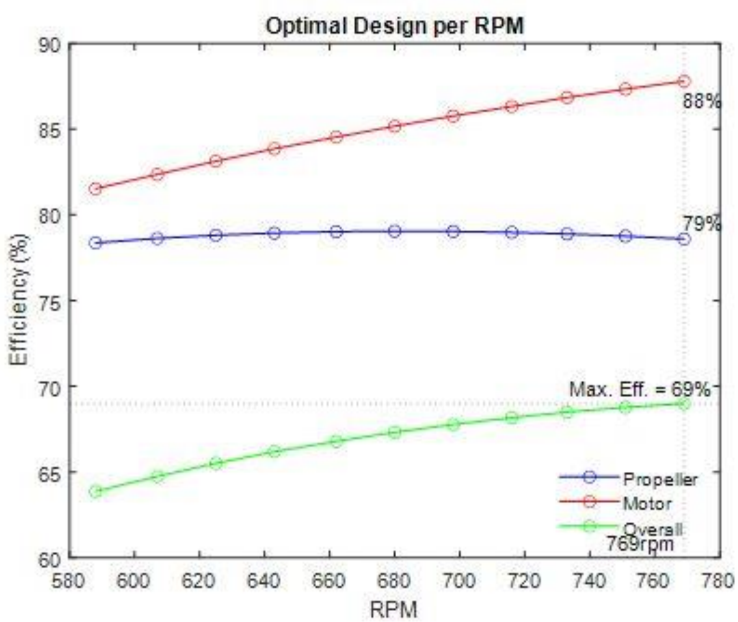


Fig. 15. *Propeller and Motor Efficiency in respect to RPM at 12V*

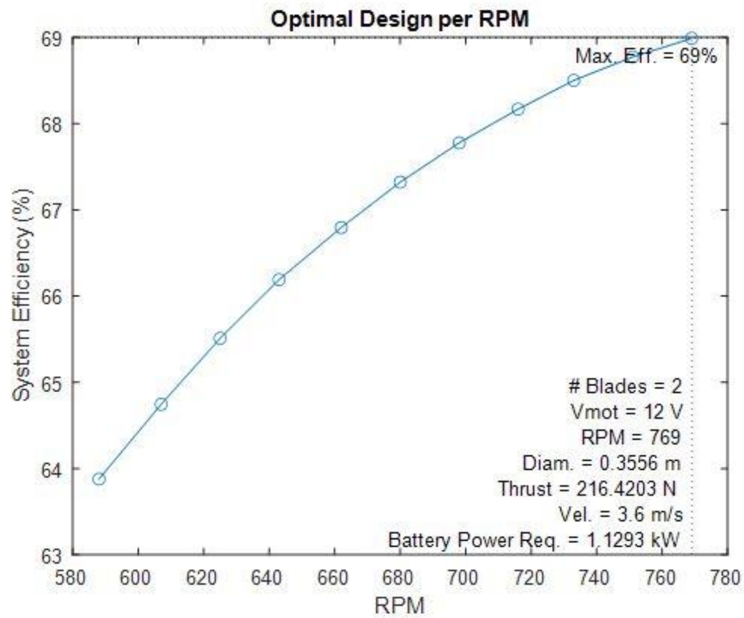


Fig. 16. *Optimal Design System Efficiency in respect to RPM at 12V*

Once the optimal points of design were selected, using Open prop for a single design, the values given by the results of the two optimization programs were copied into the inputs of open prop, and files of section curves were generated for the desired propellers. It was then exported to SolidWorks in the form of text files, to create the solid geometry of the blades, hub, and all additional design features. The designs parameters used to develop the endurance propellers are shown in **Table 5**, and the detailed drawings are included in appendix **E-1**.

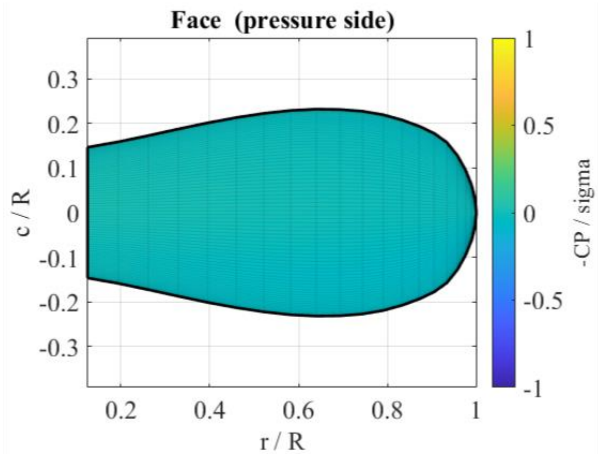
Table 5. *Theoretical performance of 4 propeller designs. Two blades with chord optimization on and the same two blades with chord optimization off.*

Constraints: D<14, V<12				
Chord. Opt.	***off***	***off***	***on***	***on***
PV Eff. (%)	*75*	*75*	*75*	*75*
# Blades	*2*	*2*	*2*	*2*
V_{mot} (V)	*12*	*14*	*12*	*14*
RPM	*769*	*941*	*769*	*941*
Diam. (m)	*0.3556*	*0.3200*	*0.3556*	*0.3556*

Thrust (N)	*216*	*216*	*216*	*228*
Speed (m/s)	*3.6*	*3.6*	*3.6*	*3.7*
Hub Diam. (m)	*0.04*	*0.04*	*0.04*	*0.04*
Mot. Eff. (%)	*88*	*91*	*88*	*91*
Prop. Eff (%)	*79*	*77*	*80*	*81*
Sys. Eff. (%)	*69*	*70*	*70*	*74*
P_{prop} ***(kW)***	*0.993*	*1.012*	*0.977*	*1.046*
P_{bat} ***(kW)***	*1.129*	*1.113*	*1.110*	*1.150*

3) ***Design Testing and Evaluation:*** Once the four propeller geometries were generated, the designs were analyzed using the cavitation analysis script provided by open prop. All four propellers resulted in a low likelihood of cavitation occurrence thus, the designs were validated for manufacturing. **Figures 18** to **25** show the front and back cavitation analysis results on each blade geometry. Since the University did not have the required tools for manufacturing the propellers, the process was outsourced to a CNC manufacturer. A picture of the machined propellers can be appreciated in **Figure 17.** Testing of the propellers so far has not been possible due to several limiting factors but are scheduled to occur in the upcoming days, since we send our boat to Ohio a month before the competition to make sure that it gets there on time.

Fig. 17. *CNC Machined Endurance propellers*



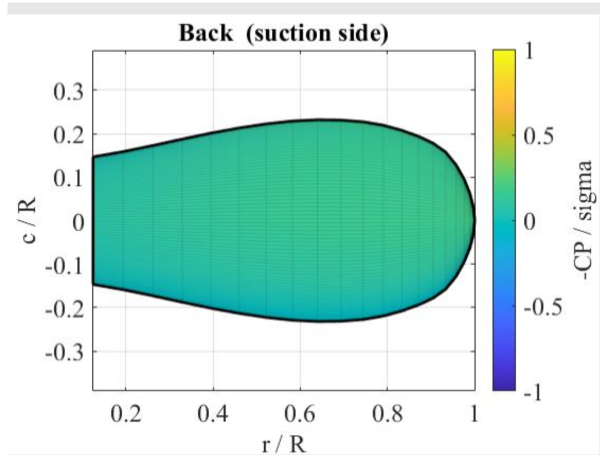
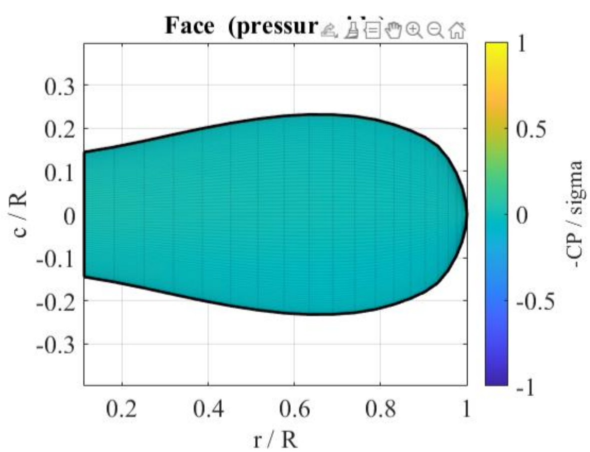


Fig. 18. *Endurance Propeller Face View (No Chord Opt. at 941 RPM, 14V and 216 N)*

Fig 19. *Endurance Propeller Back View (No Chord Opt. at 941 RPM, 14V and 216 N)*



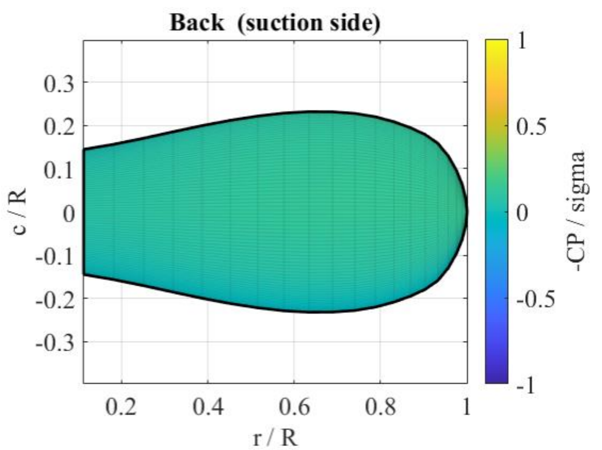
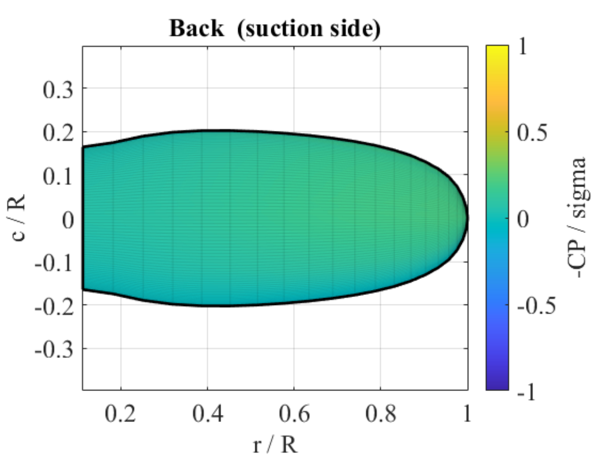


Fig. 20. *Endurance Propeller Face view (No Chord Opt. at 769 RPM, 12V and 216 N)*

Fig 21. *Endurance Propeller Back view (No Chord Opt. at 769 RPM, 12V and 216 N)*



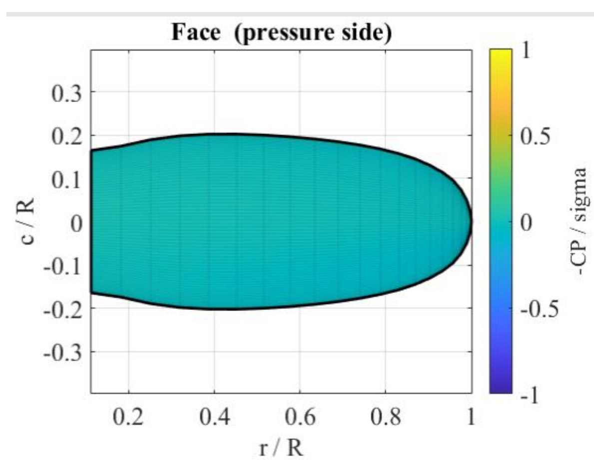


Fig. 22. *Endurance Propeller Face view (Chord Opt. at 769 RPM, 12V and 216 N)*

Fig 23. *Endurance Propeller Back view (Chord Opt. at 769 RPM, 12V and 216 N)*

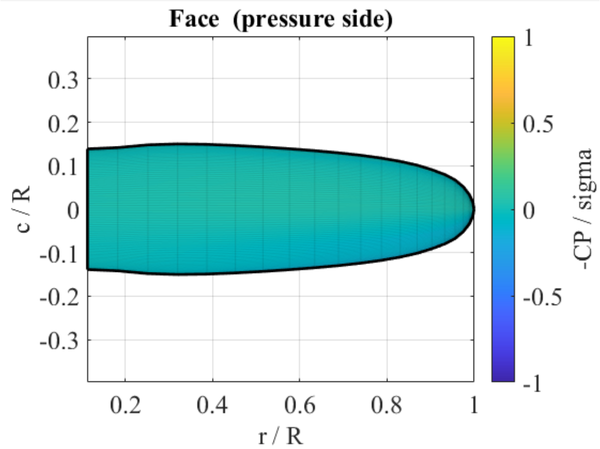


Fig. 24. *Endurance Propeller Face view (Chord Opt. at 941 RPM, 14V, and 228 N)*

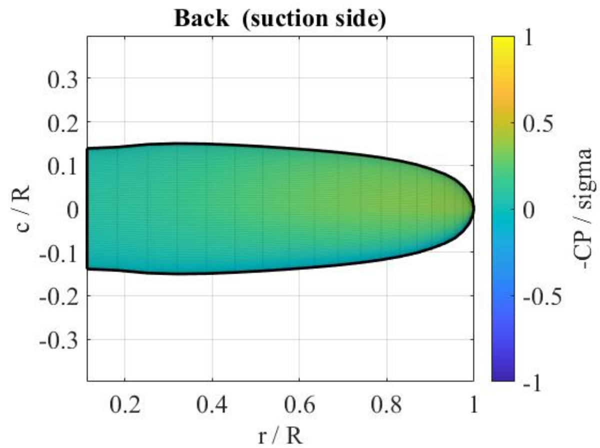


Fig.25. *Endurance Propeller Back view (Chord Opt. at 941 RPM, 14V and 228 N)*

VII. Data Acquisition and Communications

1) ***Current Design:*** Last year, the CR300 data logger was replaced by the GRAPHTEC GL240. This new system performed well during last year's competition and was able to correctly display the values of voltage, current speed, and RPM of the boat. This year the team decided to add a new sensor used for measuring the thrust of the boat. This will help us reach our design goals for the propeller.

2) ***Analysis of design and concepts:*** With the addition of a new thrust sensor, the electrical team decided to pair a second Monarch F2A1X to convert from frequency to analog voltage for the data logger to measure more efficiently and not placing too much load on only one converter. The fixed slide linear position sensor measures the thrust by measuring the difference in voltage with respect to distance. The sensor is hooked to the side of the transmission and measures the compressed distance between the transmission and the base of the mounting leg. The data acquisition box shown in **Fig. 26** was designed to be in different parts of the boat, and in case of technical difficulties, it can be removed from the boat with ease. With this idea in mind, the devices used for data acquisition were stored in a box capable of being moved and positioned in all parts of the boat. The box stores the data logger and 2 Monarch F2A1X. A 12V battery is used for powering the datalogger and all the sensors which requires an external voltage source. All devices are connected in parallel to the voltage source for equal voltage. For the current sensor, an Arduino is used to limit the voltage from 12V to 5V input of the current sensor.

Fig. 26. *Data acquisition box*

3) ***Design testing and evaluation****:* The thrust sensor was mounted between the transmission and the base of the transmission shown in **Fig. 27** Since the base was fixed, the thrust was able to measure the compressed distance and give out values in the form of voltage. To calibrate the sensor a land test was conducted; the base of the transmission was mounted to a fixed station. To properly position the transmission like it was on water, we made an aluminum frame and wooden base to attach at the end of the transmission and tied a rope around it connected to a hook scale.

Fig. 27. *Fixed Station to Calibrate Thrust Sensor*

The team then graphed the values of voltage with respect to the force applied and were able to calibrate it. This test was performed twice due to the new modifications made to the drivetrain, and the team performed one test with no extension, and a second with a 3-inch extension. The tests results are shown in **Fig. 28** and on **Table 6.** Regrettably, a water test could not be conducted due to the time constraints, but one is scheduled to occur in the upcoming days.

Table 6. *Values of the Voltage and Load with respect to Drivetrain extensions*

No Extension		3-inch Extension	
Load (lb)	**Voltage (V)**	**Load (lb)**	**Voltage (V)**
25.1	0.418	25.1	0.438
30.06	0.4112	30.9	0.435
35.5	0.41	35.3	0.433
40.8	0.406	40.6	0.43
45.91	0.404	45.2	0.428
50.9	0.403	50.5	0.425
55.3	0.4	55.3	0.422
60.6	0.397	60	0.42
65.9	0.396	65	0.417
70.1	0.392	70.5	0.413
75.6	0.39	75.2	0.411

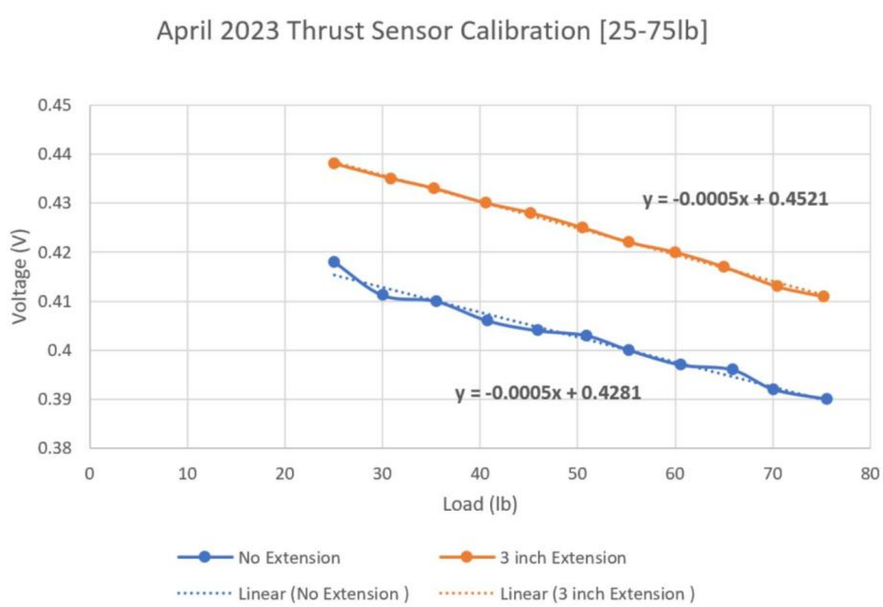


Fig. 28. *Thrust Sensor Calibration Graph. Voltage vs. Load with 3-inch extension and without.*

VIII. Project Management

The UPRM Solar Boat team is an undergraduate team sponsored primarily by private companies such as General Motors, Abbott, Lockheed Martin, and Boeing, along with UPRM through the Industries Affiliate Program of the ECE Department and the Engineering Dean. Team members of all academic years and several disciplines (refer to Appendix D – **Table D-1**) encompassed a natural balance of experience, knowledge, desire, drive, and determination. The

UPRM is represented through three Engineering Programs: Electrical, Computer, and Mechanical. The senior members are guided by the captain, Miss. Isabel Hernández, through the sub-team's structure adopted (Solar System, Electrical, Mechanical, Data Acquisition) mentored and guided the younger inexperienced students. Such a scheme along with an annual recruitment info session enables team continuity and sustainability for the years to come.

Regarding project management, this year the team adopted the use of 1) a web-based collaborative mind mapping, MindMeister, and 2) an online project and task management solution, Producteev. Initially, MindMeister enabled effective online collaboration of the whole team in the definition of the overall team and sub-team objectives through an interactive visual platform. Afterward, each member defined all the associated tasks required to complete each objective. Producteev provided a highly effective web-based solution that enabled team communication, scheduling, time management, and task assessment accessible to all members. Additionally, the team sustained weekly meetings via Zoom and in-person to discuss any relevant progress or decision to be made. Several experimental tests at Lake Cerrillos in Ponce, Puerto Rico, were conducted to validate the system performance.

IX. Conclusion and Recommendations

The UPRM Solar Boat Team performed a lesson-learned analysis following the 2022 Solar Splash Event. The main findings of the analysis were implemented as the objectives for this year. The milestones achieved in preparation for the 2023 Solar Splash Event, mainly focused on the Endurance performance, are listed below.

- A drivetrain/axis vertical extension was incorporated to allow for better clearance of the propeller to the waterline (1-3 in.).
- New propellers operating at much lower rpm (700 & 900) were designed and fabricated.
- A 24-to-36 V converter that enables higher voltage operation at the endurance qualifier was designed and implemented.
- A displacement sensor that indirectly measures the developed thrust was incorporated to the data acquisition system.

Table 7 presents a points analysis based on 2022 results and the expected performance given the enhancements in preparation for the competition. Overall, the team is excited about this year's possibilities. There's always room for improvement in many areas of the project. However, project management, fundraising, and transportation coordination continue to present real challenges to the team.

Table 7. *UPRM Solar Boat's Competition Score Assessment*

Category	2018 Rank	2019 Rank	2021 Rank	2022 Rank	2022 Points	Expected Rank	Expected Points
Endurance	4th	3rd	2nd	2nd	327/400	2nd	380
Sprint	4th	1st	1st	1st	250/250	1st	250
Slalom	1st	2nd	1st	1st	100/100	1st	100
Qualifier	-	-	1st	3rd	73/100	1st	100
Overall	2nd	2nd	1st	2nd	899/1000	1st	980

X. References

[1] K.A. Moharram,"Enhancing the performance of photovoltaic panels by water cooling", Shams Engineering Journal, vol. 4, Issue 4, pp. 869-877, 2013.

[2]"Kayaks," *Outdoor Blueprint* , 2019. [Online]. Available: http://www.outdoorblueprint.com/outfit/kayaks/. [Accessed: 04-May-2019].

[3] R. Vellinga, *Hydrofoils: Design, Build, Fly, Features & details*, Peacock Hill Publishing, 2009.

[4] *Odyssey Battery Technical Manual*, Enersys, Pennsylvania, PA, 2014. [Online]. Available: http://www.odysseybattery.com/documents/US-ODY-TM-002_1214.pdf.

[5]Stevenson University, *Solar Splash Technical Report* . pp 10-15, 2017. [Online]. Available: http://solarsplash.com/wp-content/uploads/2014/10/2017_Stevens_SS_Tech_Report_3.pdf

[6] Sprint Event, *Sprint Event-Solar Splash Event Results*, 2016.[Online]. Available: http://solarsplash.com/2016-event/#HEADING4

[7]https://www.youtube.com/watch?time_continue=530&v=Xp2bdtf-ThM

XI. Appendix

Appendix A: Battery Documentation

The 2021 UPRM's Solar Boat will use identical battery banks for energy storage.

1) Bank #1 – 95lbs
   - x2 -Odyssey Extreme PC1100 – 27.5 lbs
   - x2 -Odyssey Extreme PC950 – 20 lbs
2) Bank #2 – 95lbs
   - x2 -Odyssey Extreme PC1100 – 27.5 lbs
   - x2 -Odyssey Extreme PC950 – 20 lbs

	Voltage	PHCA ** (5 sec.)	CCA*	HCA	MCA	Nominal Capacity		Reserve Capacity Minutes	Length inches (mm)	Width inches (mm)	Height inches (mm)	Weight lbs (kg)	Terminal	Torque Specs in-lbs (Nm max)	Internal Resistance (mΩ)	Short Circuit Current
						(20 Hr Rate-Ah)	(10 Hr Rate-Ah)									
 **PC950**	12	950	400	600	500	34	32	60	9.8 (250.0)	3.8 (97.0)	6.1 (156.0)	20.0 (9.0)	M6 Stud	35 (3.9)	7.1	1700A
 **PC1100**	12	1100	500	800	650	45	43	87	9.8 (250.0)	3.8 (97.0)	8.1 (206.0)	27.5 (12.5)	M6 Stud	35 (3.9)	5.1	2450A

Table A1: Odyssey battery

ODYSSEY®
THE EXTREME BATTERY

MSDS

Section I - Product and Manufacturer Identity

Product identity:

Sealed Lead Battery

Cyclon®, Genesis®, SBS, SBS J, Hawker XE™ Odyssey® or Trolling Thunder™

Manufacturer's Name and Address:
EnerSys Energy Products Inc. (formerly Hawker Energy Products Inc.)
617 North Ridgeview Drive
Warrensburg, MO 64093-9301
Emergency Telephone Number: (660) 429-2165
Customer Service Telephone Number: 800-964-2837

Section II - Ingredients

Hazardous Components	CAS #	OSHA PEL-TWA	% (By weight)
Lead	7439-92-1	50µg/m3	45 - 60 %
Lead Dioxide	1309-60-0	50µg/m3	15 - 25 %
Sulfuric Acid Electrolyte	7664-93-9	1.0 mg/m3	15 - 20 %
Non-Hazardous Materials	N/A	N/A	5 - 10 %

Section III - Physical/Chemical Characteristics

Boiling Point - N/A   Specific Gravity (H_2O=1) - NA
Vapor Pressure (mm Hg.) - N/A   Melting Point - N/A
Solubility in Water - N/A   Appearance & Color - N/A

Section IV - Fire & Explosion Hazard Data

Flash Point (Method Used): N/A   **Flammable Limits:** N/A   **LEL:** N/A   **UEL:** N/A

Extinguishing Media:
Multipurpose Dry chemical, CO_2 or water spray.

Special Fire Fighting Procedures:
Cool Battery exterior to prevent rupture. Acid mists and vapors in a fire are toxic and corrosive. Unusual Fire and Explosion Hazards: Hydrogen gas may be produced and may explode if ignited. Remove all sources of ignition.

Section V - Reactivity Data and Shipping/Handling Electrical Safety

Conditions to Avoid: Avoid shorting, high levels of short circuit current can be developed across the battery terminals. Do not rest tools or cables on the battery. Avoid over-charging. Use only approved charging methods. Do not charge in gas tight containers.

Requirements for Safe Shipping and Handling of Cyclon® Cells: Warning – Electrical Fire Hazard – Protect Against Shorting

- Terminals can short and cause a fire if not insulated during shipping.
- Cyclon® product must be labeled "NONSPILLABLE" during shipping. Follow all federal shipping regulations. See section IX of this sheet and CFR 49 Parts 171 through 180, available anytime online at wwww.gpoaccess.gov.

Requirements for Shipping Cyclon® Product as Single Cells

- Protective caps or other durable inert material must be used to insulate each terminal of each cell unless cells are shipping in the original packaging from EnerSys, in full box quantities.
- Protective caps are available for all cell sizes by contacting EnerSys Customer Service at 1-800-964-2837.

Requirements for Shipping Cyclon® Product Assembled Into Multicell Batteries

- Assembled batteries must have short circuit protection during shipping.
- Exposed terminals, connectors, or lead wires must be insulated with a durable inert material to prevent exposure during shipping.

Section VI - Health Hazard Data

Routes of Entry: N/A

Health Hazards (Acute & Chronic): N/A

Emergency & First Aid Procedures:
Battery contains acid electrolyte which is absorbed in the separator material. If battery case is punctured, completely flush any released material from skin or eyes with water.

Proposition 65:
Warning: Battery posts, terminals and related accessories contain lead and lead compounds, chemicals known to the State of California to cause cancer and reproductive harm. Batteries also contain other chemicals known to the State of California to cause cancer. Wash hands after handling.

Section VII - Product and Manufacturer Identity

Steps to be taken in case material is released or spilled:
Avoid contact with acid materials. Use soda ash or lime to neutralize. Flush with water.

Waste Disposal Method:
Dispose of in accordance with Federal, State, & Local Regulations. Do not incinerate. Batteries should be shipped to a reclamation facility for recovery of the metal and plastic components as the proper method of waste management. Contact distributor for appropriate product return procedures.

Section VIII - Control Measures - Not Applicable

Section IX - Transportation, Shipping and Handling

EnerSys Energy Products Inc. batteries are starved electrolyte batteries which means the electrolyte is absorbed in the separator material. The batteries are also sealed. As of September 30, 1995, EnerSys Energy Products Inc. batteries were classified as "nonspillable batteries", and as such are not subject to the full requirements of 49 CFR § 173.159. The previous exempt classification, "Dry Batteries, Not Restricted" was discontinued effective September 30, 1995. "Nonspillable" batteries are excepted from the regulation's comprehensive packaging requirements if the following conditions are satisfied: (1) The battery is protected against short circuits and is securely packaged. (2) For batteries manufactured after September 30, 1995, the battery and outer packaging must be plainly and durably marked "NONSPILLABLE" or "NONSPILLABLE BATTERY". (3) The battery is capable of withstanding vibration and pressure differential tests specified in 49 CFR § 173.159(d). (4) At a temperature of 55 ºC (131ºF), the battery must not contain any unabsorbed free-flowing liquids, and is designed so that electrolyte will not flow from a ruptured or cracked case.

EnerSys Energy Products Inc. batteries have been tested by WYLE Scientific Services & Systems Laboratories Group and determined to be in compliance with the vibration and pressure differential tests contained in 49 CFR § 173.159(d), and therefore as of September 30, 1995, excepted from the DOT requirements set forth in 49 CFR § 173.159, other than paragraph (d).

Battery shipments from EnerSys Energy Products Inc. Warrensburg location, will be properly labeled in accordance with applicable DOT regulations.

Packaging changes performed at other locations may require additional labeling, since in addition to the battery itself containing the required marking, the outer packaging of the battery must also contain the required marking: "NONSPILLABLE" OR "NONSPILLABLE BATTERY". Because the batteries are classified as "Nonspillable" and meet the three conditions above, [from § 173.159(d)] they do not have an assigned UN number nor do they require additional DOT hazard labeling.

The regulation change effective September, 1995, was to clarify and distinguish to shippers and transporters, all batteries that have been tested and determined to be in compliance with the DOT Hazardous Material Regulations, the International Civil Aeronautics Organization (ICAO), and the International Air Transport Association (IATA) Packing Instruction 806 and Special Provision A67, and therefore excepted from all other requirements of the regulations and classified as a "nonspillable battery".

Per 42 USC Section 14322 (US Code Title 42 – The Public Health and Welfare), packaging must be marked with the following: "Contains Sealed Lead Battery" and "Battery Must Be Recycled".

Section X - Additional Information

The EnerSys Energy Products Inc. sealed lead acid battery is determined to be an "article" according to the OSHA Hazard Communication Standard and is thereby excluded from any requirements of the standard. The Material Safety Data Sheet is therefore supplied for informational purposes only.

The information and recommendations contained herein have been compiled from sources believed to be reliable and represent current opinion on the subject. No warranty, guarantee, or representation is made by EnerSys Energy Products Inc., as to the absolute correctness or sufficiency of any representation contained herein and EnerSys Energy Products Inc. assumes no responsibility in connection therewith, nor can it be assumed that all acceptable safety measures are contained herein, or that additional measures may not be required under particular or exceptional conditions or circumstances.

N/A or Not Applicable - Not applicable for finished product used in normal conditions.
Informational MSDS Part Number 2602-0043 Rev. 2 (09/07/06)

Appendix B: Flotation Calculations

The buoyancy force is given by the specific weight of water times the volume of water displaced by the component. The volume of the solid hull $V_S$and the fabricated hull V_H were obtained with the 3D CAD analysis through Fusion 360 as 31.95 ft^3 and 13.66 ft^3, respectively. The buoyancy force exerted by the fabricated hull when completely submerged B_H can be estimated as

$$B_H = V_H * \gamma_{Water}=13.66\ ft^3 * 62.2\ lb/ft^3 = 850\ lbs$$

where $\gamma_{Water}$is the specific weight of water at $25°C$. The weight of the boat W_B can be estimated at a maximum of 331 lbs as depicted in Table B1. Hence, the ratio of the buoyancy force to the total weight can be expressed as

$$B_H\ /W_{TOT} = 850lbs\ /\ 341lbs\ =\ 2.49 >\ 1.2$$

which complies with a 20% safety factor as required by Rule 7.14.2.

Table B1. Flotation calculations spreadsheet

Component	**Weight (lbs)**	
	Sprint	**Endurance**
Hull	56	56
Motor & Drivetrain	90	90
Controller	50	50
Batteries	100	100
Miscellaneous	15	15
Solar Array	N/A	30
TOTAL	311	341

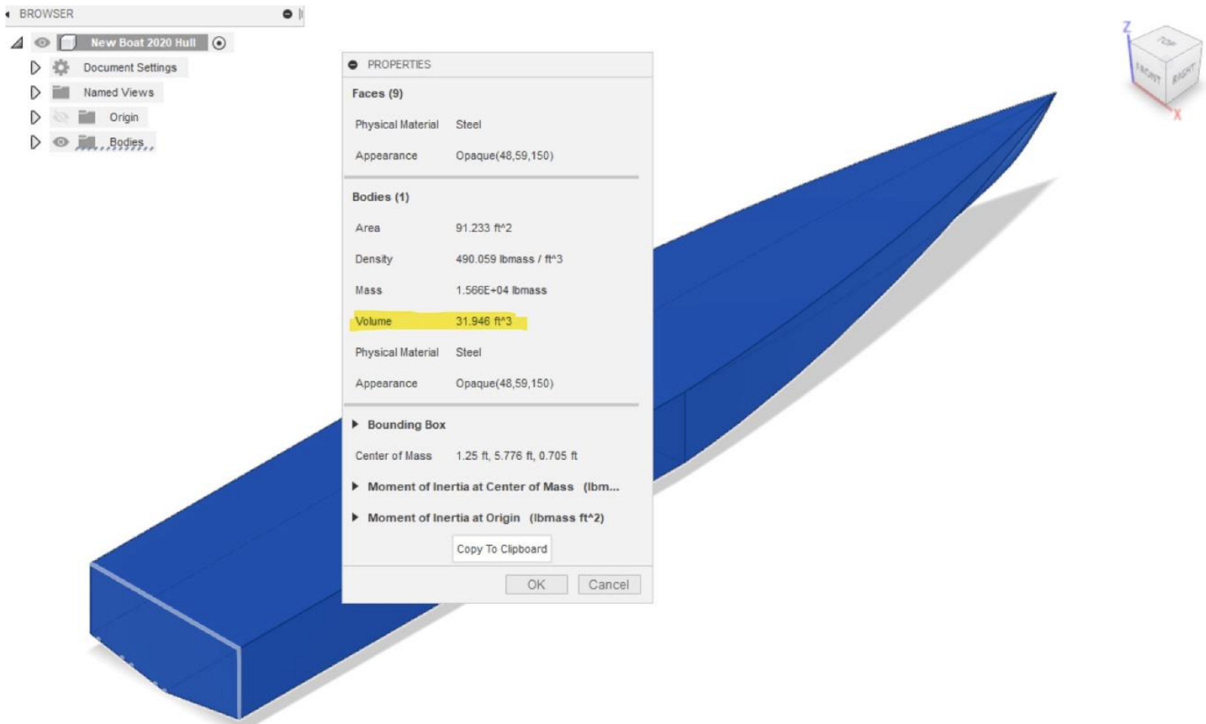


Figure B1: Volume of the solid hull V_S

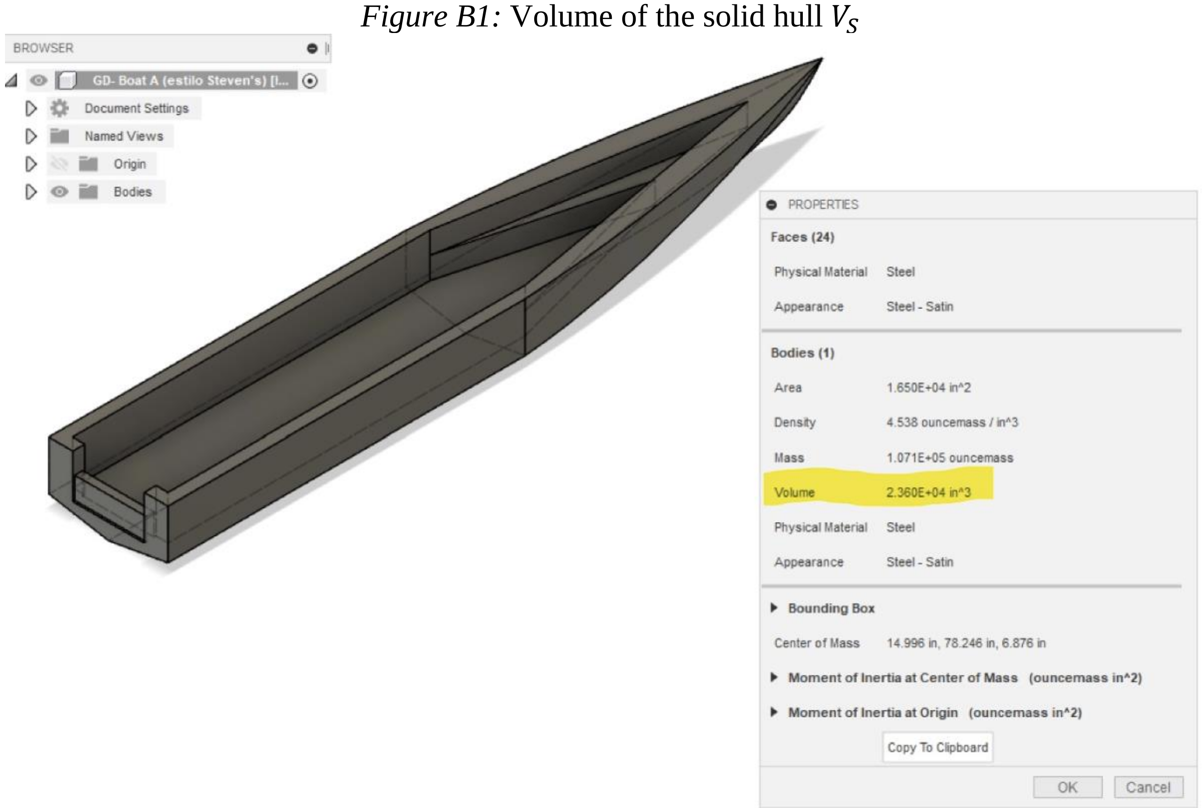


Figure B2: Volume of the fabricated hull V_H

Appendix C: Proof of Insurance

Policy Number:

Date Entered: 07/01/2022

ACORD®

CERTIFICATE OF LIABILITY INSURANCE

DATE (MM/DD/YYYY): 07/01/2022

THIS CERTIFICATE IS ISSUED AS A MATTER OF INFORMATION ONLY AND CONFERS NO RIGHTS UPON THE CERTIFICATE HOLDER. THIS CERTIFICATE DOES NOT AFFIRMATIVELY OR NEGATIVELY AMEND, EXTEND OR ALTER THE COVERAGE AFFORDED BY THE POLICIES BELOW. THIS CERTIFICATE OF INSURANCE DOES NOT CONSTITUTE A CONTRACT BETWEEN THE ISSUING INSURER(S), AUTHORIZED REPRESENTATIVE OR PRODUCER, AND THE CERTIFICATE HOLDER.

IMPORTANT: If the certificate holder is an ADDITIONAL INSURED, the policy(ies) must have ADDITIONAL INSURED provisions or be endorsed. If SUBROGATION IS WAIVED, subject to the terms and conditions of the policy, certain policies may require an endorsement. A statement on this certificate does not confer rights to the certificate holder in lieu of such endorsement(s).

PRODUCER
Seguros N. Colón, Inc.
324 Ave. F.D. Roosevelt
Comer Teniente César González Street
San Juan PR 00918, PR 00705

CONTACT NAME: FONT INSURANCE 787-9631450 100,711
PHONE (A/C, No, Ext): (787)622-0034 **FAX (A/C, No):** (787)622-0038
E-MAIL ADDRESS: cvazquez@sncolon.com / Tel Ext 1014

INSURER(S) AFFORDING COVERAGE	NAIC #
INSURER A: TRIPLE-S PROPIEDAD (B+; VIII)	
INSURER B:	
INSURER C:	
INSURER D:	
INSURER E:	
INSURER F:	

INSURED
UNIVERSIDAD DE PUERTO RICO &/OR ET ALS
TREASURY DEPT &/OR COMMONWEALTH OF PR
PO BOX 364984
SAN JUAN, PR 00936-4984

COVERAGES **CERTIFICATE NUMBER:** **REVISION NUMBER:**

THIS IS TO CERTIFY THAT THE POLICIES OF INSURANCE LISTED BELOW HAVE BEEN ISSUED TO THE INSURED NAMED ABOVE FOR THE POLICY PERIOD INDICATED. NOTWITHSTANDING ANY REQUIREMENT, TERM OR CONDITION OF ANY CONTRACT OR OTHER DOCUMENT WITH RESPECT TO WHICH THIS CERTIFICATE MAY BE ISSUED OR MAY PERTAIN, THE INSURANCE AFFORDED BY THE POLICIES DESCRIBED HEREIN IS SUBJECT TO ALL THE TERMS, EXCLUSIONS AND CONDITIONS OF SUCH POLICIES. LIMITS SHOWN MAY HAVE BEEN REDUCED BY PAID CLAIMS.

INSR LTR	TYPE OF INSURANCE	ADDL INSD	SUBR WVD	POLICY NUMBER	POLICY EFF (MM/DD/YYYY)	POLICY EXP (MM/DD/YYYY)	LIMITS	
A	[X] COMMERCIAL GENERAL LIABILITY; [ ] CLAIMS-MADE [X] OCCUR; GEN'L AGGREGATE LIMIT APPLIES PER: [X] POLICY [ ] PRO-JECT [ ] LOC; OTHER:			CL-83049539-6	7/1/2022	7/1/2023	EACH OCCURRENCE	$ 1,000,000.
							DAMAGE TO RENTED PREMISES (Ea occurrence)	$ 100,000.
							MED EXP (Any one person)	$ 5,000.
							PERSONAL & ADV INJURY	$ 1,000 000.
							GENERAL AGGREGATE	$ 3,000,000.
							PRODUCTS - COMP/OP AGG	$ 3,000,000.
								$
	AUTOMOBILE LIABILITY; [ ] ANY AUTO; [ ] OWNED AUTOS ONLY [ ] SCHEDULED AUTOS; [ ] HIRED AUTOS ONLY [ ] NON-OWNED AUTOS ONLY						COMBINED SINGLE LIMIT (Ea accident)	$
							BODILY INJURY (Per person)	$
							BODILY INJURY (Per accident)	$
							PROPERTY DAMAGE (Per accident)	$
								$
A	[X] UMBRELLA LIAB [ ] OCCUR; [ ] EXCESS LIAB [ ] CLAIMS-MADE; [ ] DED [ ] RETENTION $ 10,000			UC-67006707	7/1/2022	7/1/2023	EACH OCCURRENCE	$ 5,000,000
							AGGREGATE	$ 5,000,000
								$
A	WORKERS COMPENSATION AND EMPLOYERS' LIABILITY Y/N; ANY PROPRIETOR/PARTNER/EXECUTIVE OFFICER/MEMBER EXCLUDED? (Mandatory in NH) [N]; If yes, describe under DESCRIPTION OF OPERATIONS below	N/A		CL-83049539-6	7/1/2022	7/1/2023	[ ] PER STATUTE [X] OTH-ER	
							E.L. EACH ACCIDENT	$ 1,000,000.
							E.L. DISEASE - EA EMPLOYEE	$ 1,000,000.
							E.L. DISEASE - POLICY LIMIT	$ 1,000,000.

DESCRIPTION OF OPERATIONS / LOCATIONS / VEHICLES (ACORD 101, Additional Remarks Schedule, may be attached if more space is required)
EVIDENCIA DE CUBIERTA - EVIDENCE OF COVERAGE
Purpose: UPR-Mayaguez Campus participation at the Solar Splash 2023
Competition (June 6-10, 2023) - AT CHAMPION PARK LAKE AT CLARK COUNTY FAIRGROUNDS - 4040 LABOURNE RD. - SPRINGFIELD, OH 45505

The certificate holder is included as additional insured under this policy as specifically defined and provided under "Commercial General Liability Coverage form CG 0001 (04-13) Section II-Who is as Insured", and only with respect to the conduct, duties and scope of Solar Splash 2023 Competition (June 6-10, 2023).

CERTIFICATE HOLDER IS INCLUDED AS AN ADDITIONAL INSURED AS PER FORM 101 HERETO ATTACHED

CERTIFICATE HOLDER
SOLAR SPLASH 2023
4401 S CHARLESTON PIKE
SPRINGFIELD, OH 45505 USA

CANCELLATION
SHOULD ANY OF THE ABOVE DESCRIBED POLICIES BE CANCELLED BEFORE THE EXPIRATION DATE THEREOF, NOTICE WILL BE DELIVERED IN ACCORDANCE WITH THE POLICY PROVISIONS.

AUTHORIZED REPRESENTATIVE
SEGUROS N COLON INC

ACORD 25 (2016/03)

Appendix D: Team Roster

UPRM Solar Boat's current team is composed of 6 undergraduate students from Electrical and Mechanical engineering.

Table D-1: UPRM Solar Boat's Current Team Members Contributions by past team members were fundamental for this year's work:

Name	Last Names	Engineering Program	Studies Year	Team Role
Isabel	Hernandez	Mechanical	7th	Team Captain | Mechanical Division
Sidney	Serrano	Electrical	7th	Electrical and Solar Systems Division
Gamalier	Rivera	Electrical	7th	Electrical and Solar Systems Division
Jancarlos	Negron	Mechanical	3rd	Mechanical Division
Miguel	Estévez	Mechanical	3rd	Mechanical Division
Alexander	Nieves	Mechanical	3rd	Mechanical Division

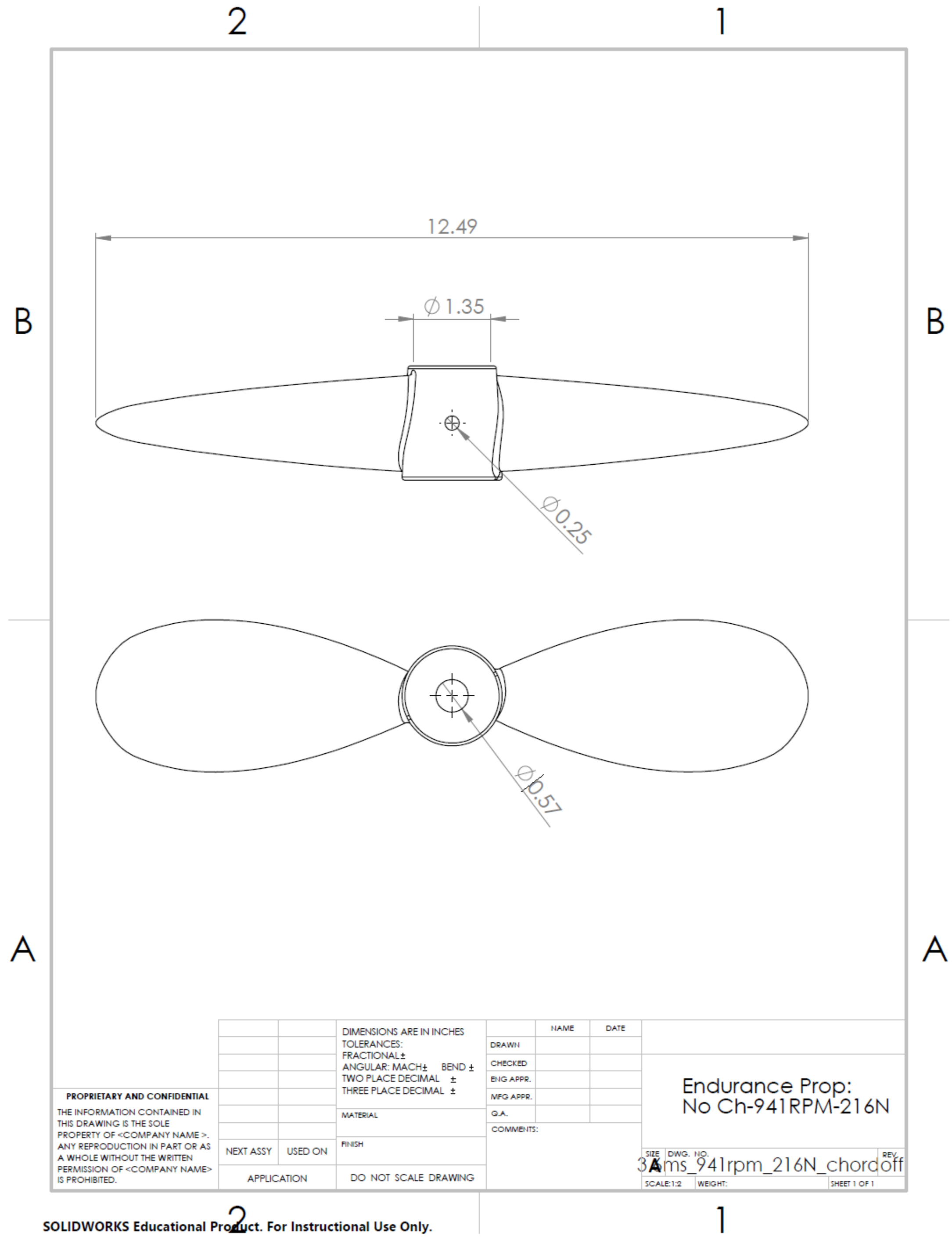
Table D-2: UPRM Solar Boat's Past Team Members

Name	Last Names	Engineering Program	Studies Year	Team Role
Emmanuel	Robles	Electrical	Grad	Team Captain
John	Ramos	Electrical	Grad	Electrical and Solar Systems Division
Saul	Figueroa	Computer	4th	Data Acquisition

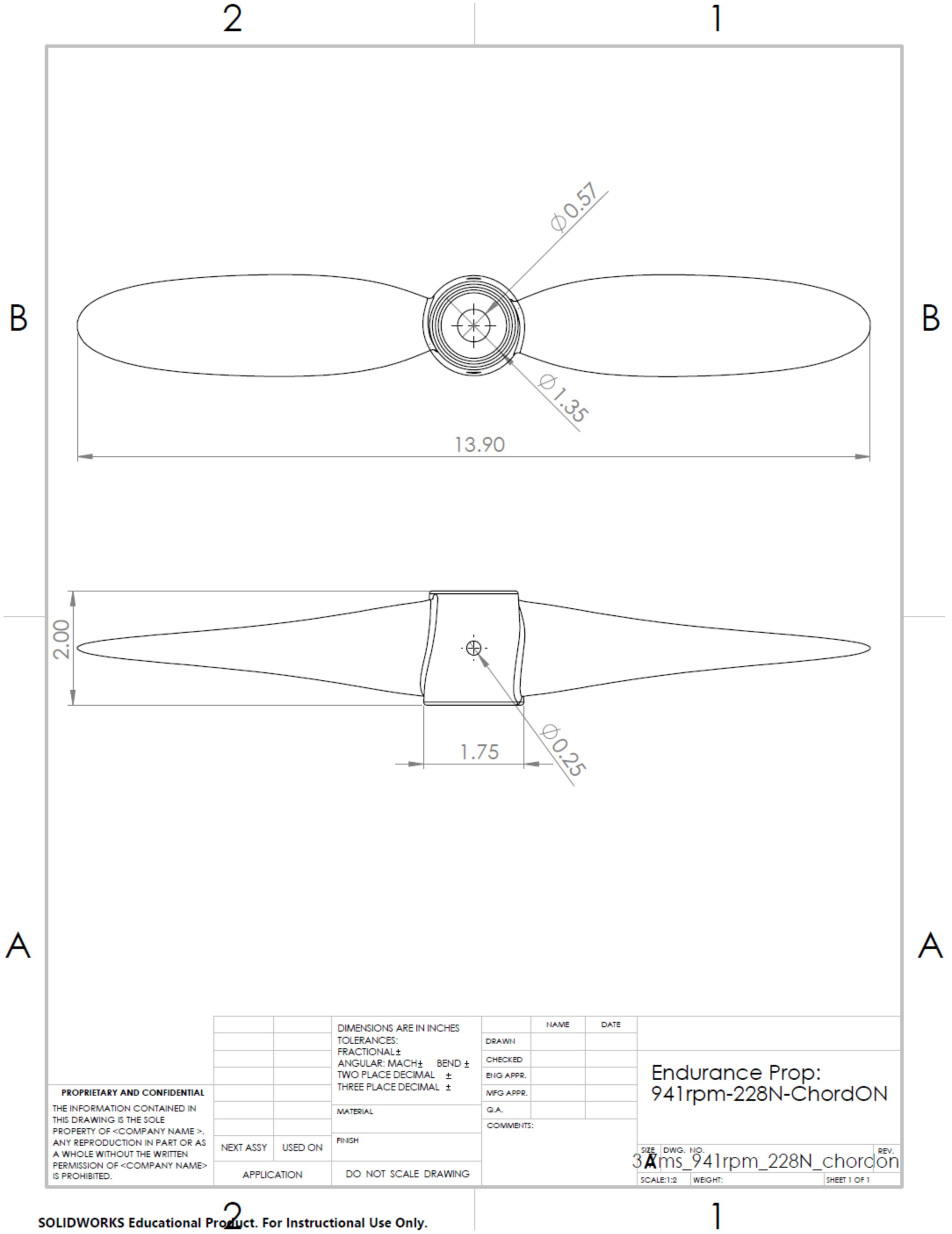
Appendix E: CAD Drawings

E-1. Propellers:

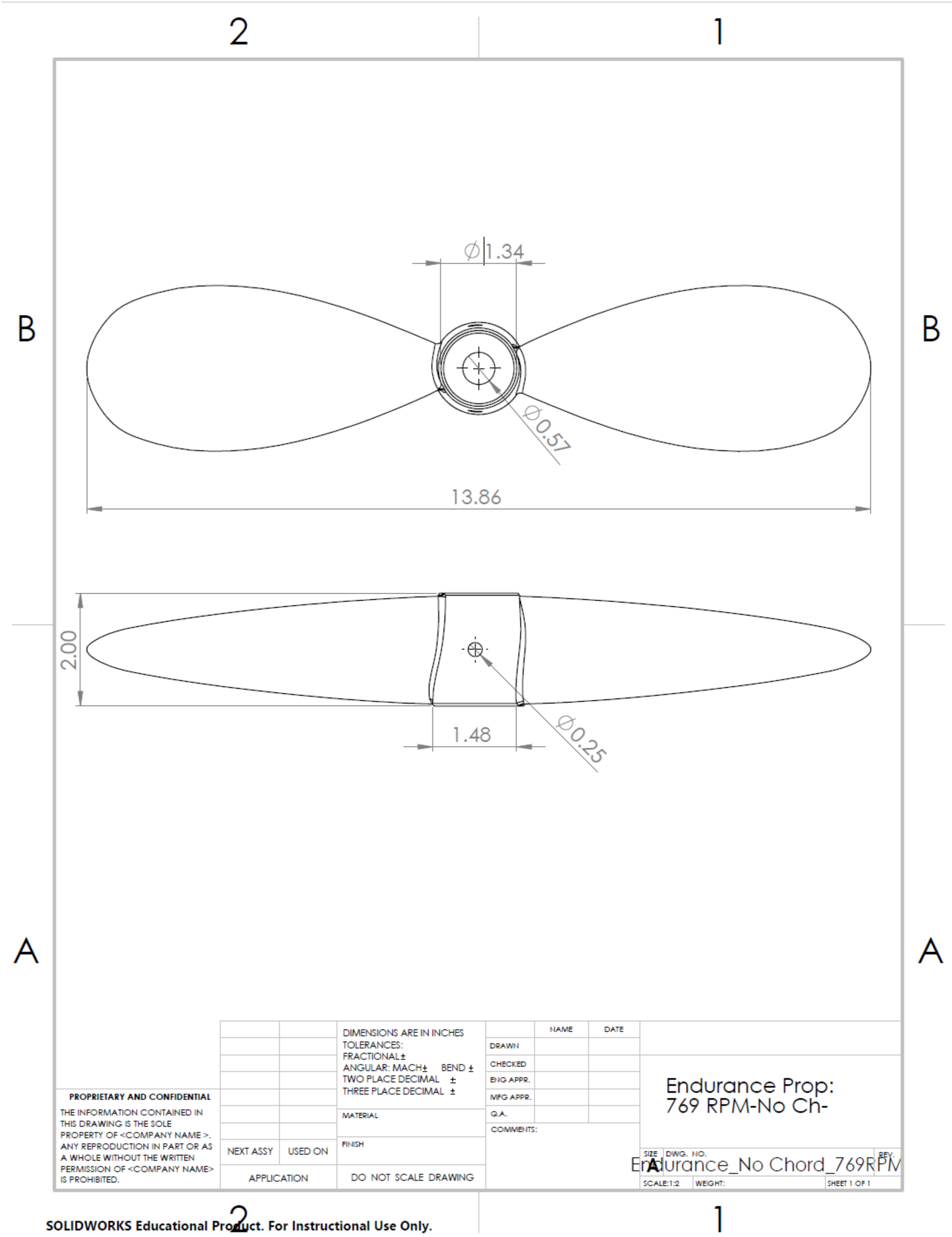
1. 941 RPM, 216N and No Chord Optimization Propeller



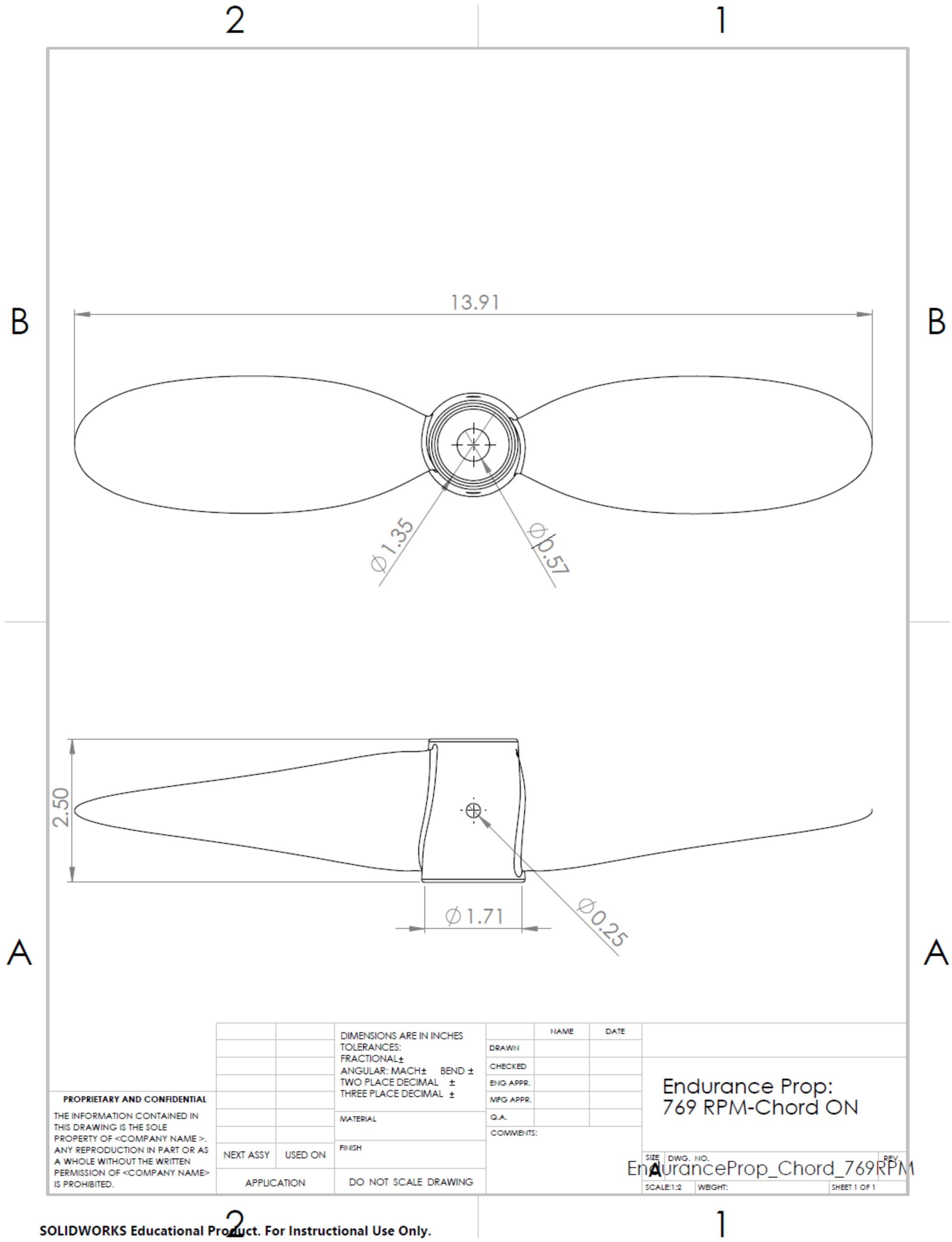
2. 941 RPM, 228N and Chord Optimization Propeller



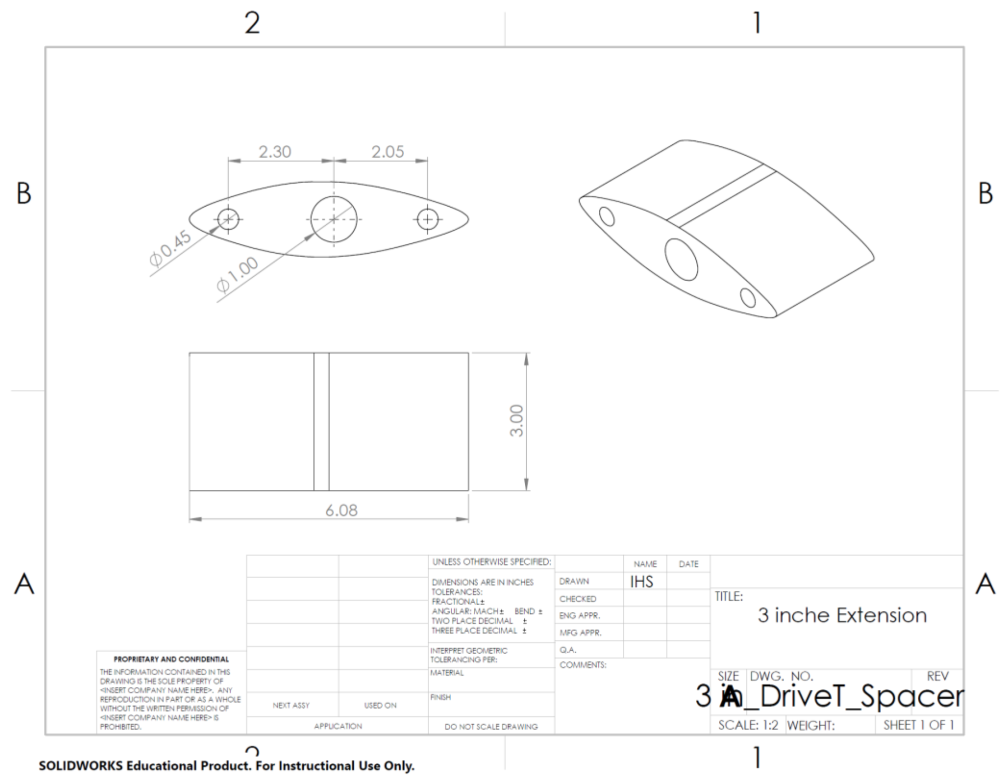
3. 769 RPM and No Chord Optimization Propeller

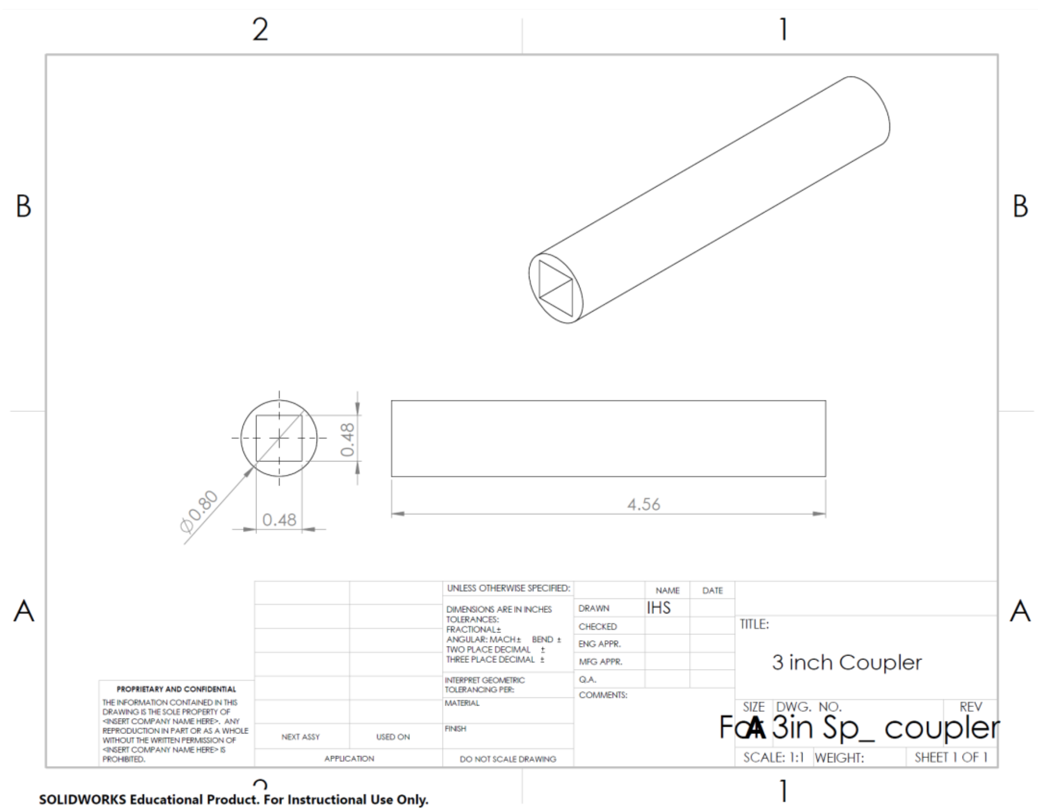


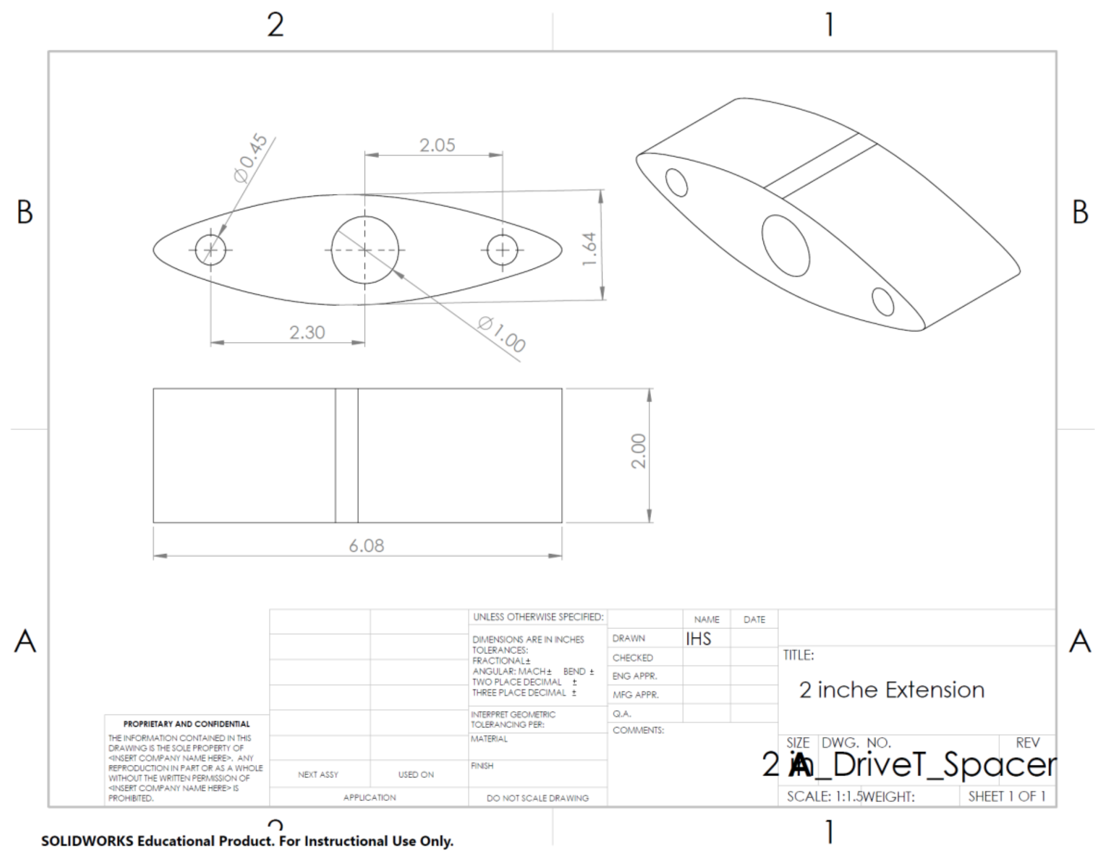
4. 769 RPM and Chord Optimization Propeller:



E-2. Drive Train Extensions:



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UNLESS OTHERWISE SPECIFIED:
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TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
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FINISH
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USED ON
APPLICATION
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DATE
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IHS
CHECKED
ENG APPR.
MFG APPR.
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WEIGHT:
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PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF <INSERT COMPANY NAME HERE> IS PROHIBITED.
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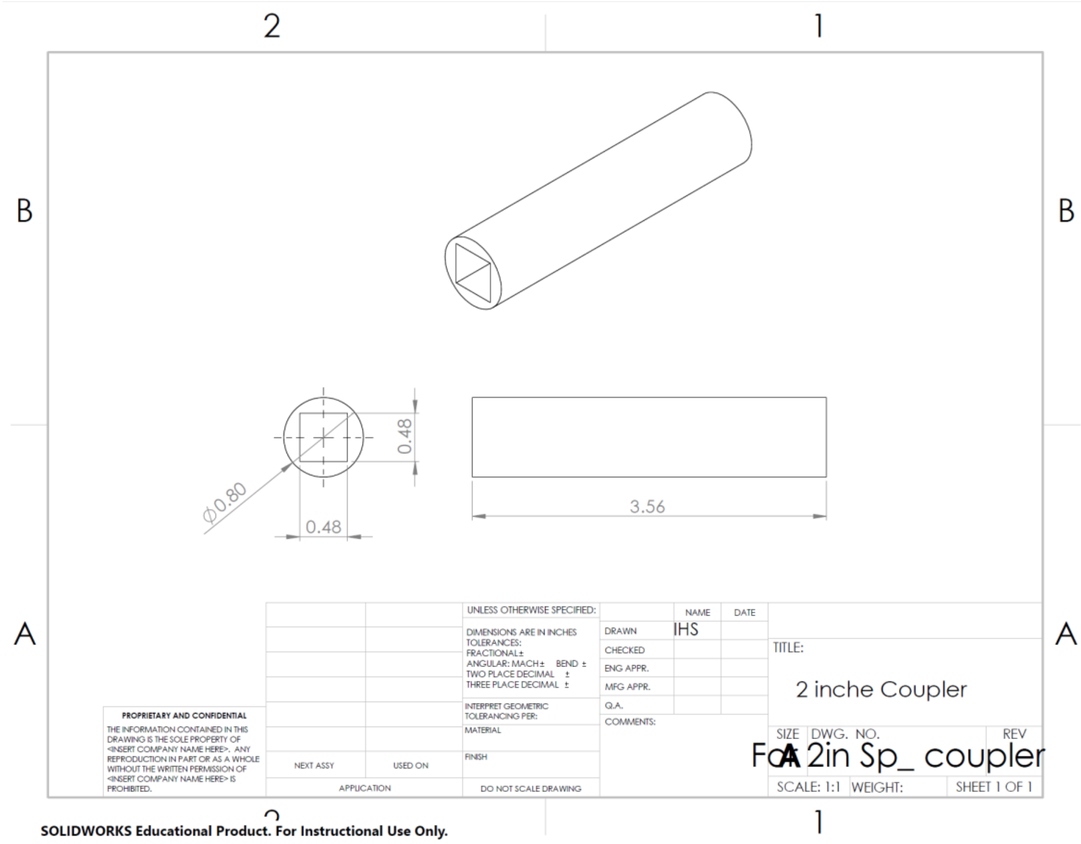
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DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±
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MATERIAL
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APPLICATION
DO NOT SCALE DRAWING
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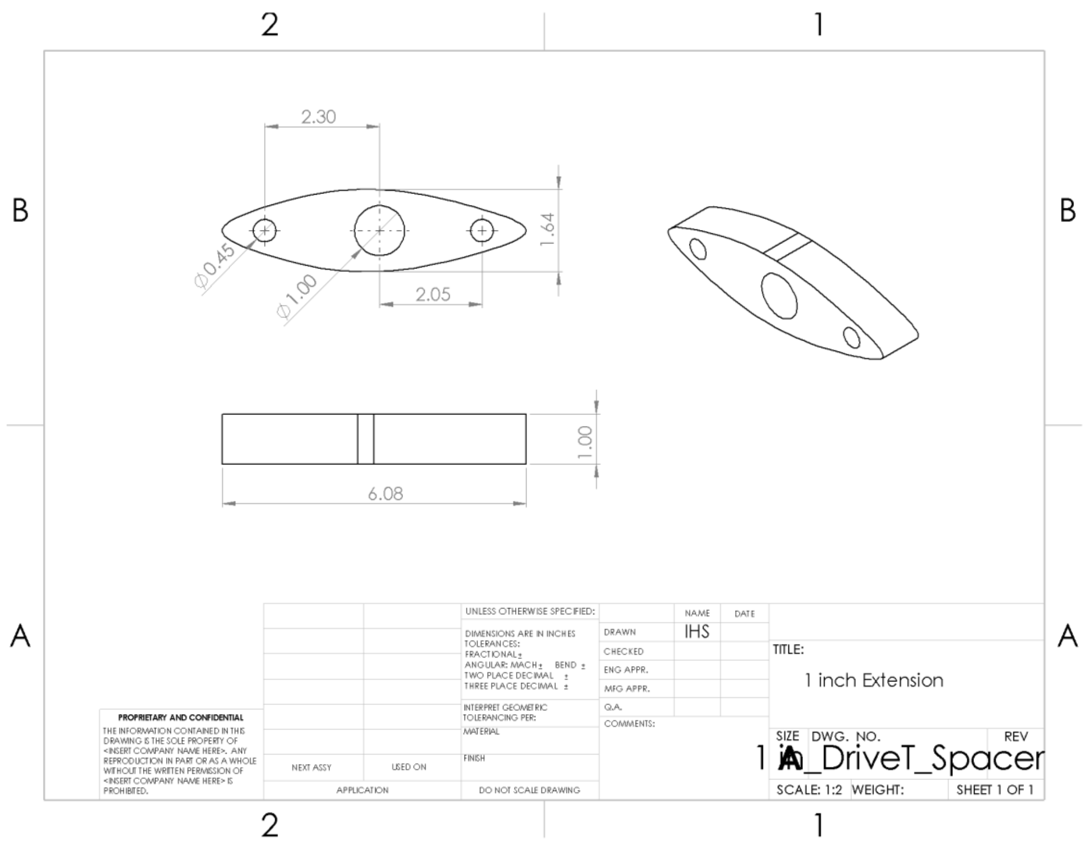

2.30
1.64
Ø0.45
Ø1.00
2.05
1.00
6.08
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING
NEXT ASSY
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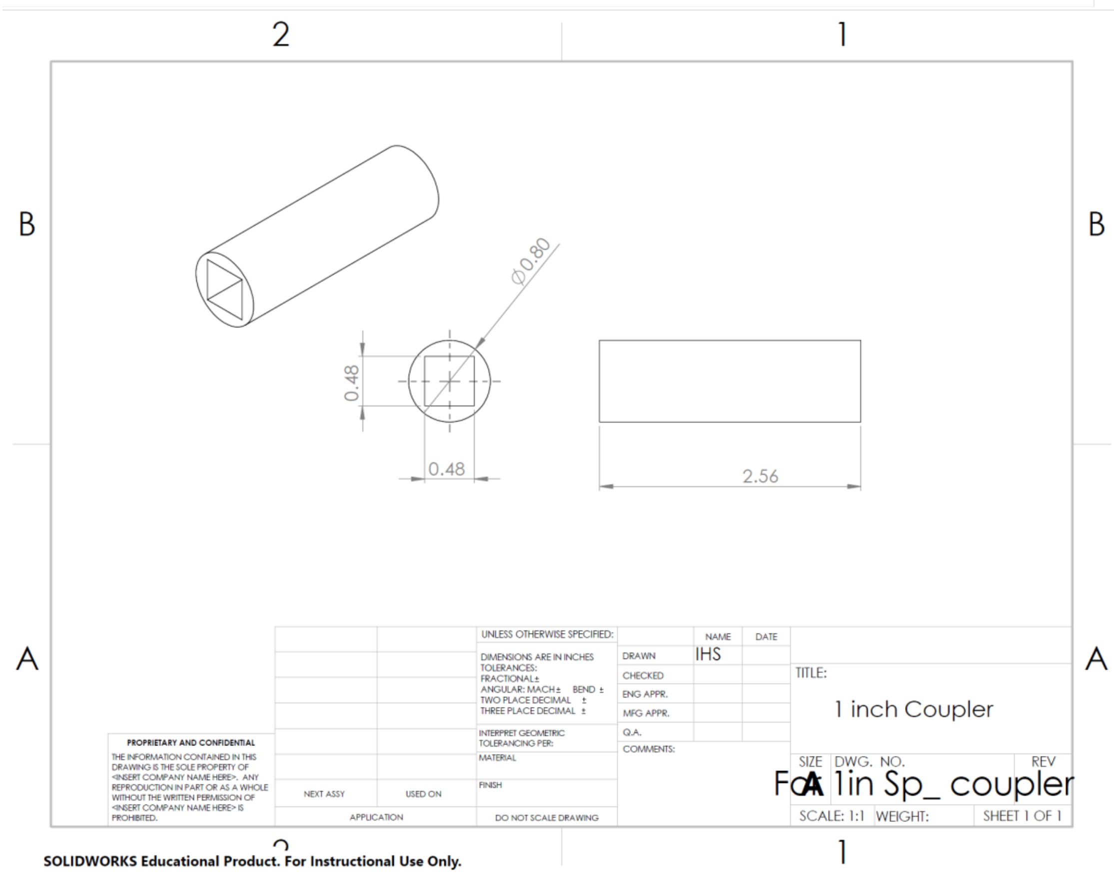
NAME
DATE
DRAWN
IHS
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
1 inch Extension
SIZE
DWG. NO.
REV
A
1 in_DriveT_Spacer
SCALE: 1:2
WEIGHT:
SHEET 1 OF 1



Ø0.80
0.48
0.48
2.56
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
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NAME
DATE
DRAWN
IHS
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
1 inch Coupler
SIZE
DWG. NO.
REV
A
Fo 1in Sp_ coupler
SCALE: 1:1
WEIGHT:
SHEET 1 OF 1
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