GENEVA COLLEGE
DEPARTMENT OF ENGINEERING

Senior Capstone Design Project
Participating in the 2015 Solar Splash Competition
June 10 – 14 in Dayton, Ohio

Geneva College's
SOLAR SPLASH TEAM

Technical Report

Boat # 14

04 May 2015

TEAM MEMBERS

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ADVISORS

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EXECUTIVE SUMMARY

The goal of Geneva's 2014-2015 Solar Splash Team is to place in the top three at the upcoming competition. To accomplish our goal this year's team will improve sprinting capability and performance (20 knot hull speeds), while maintaining endurance capability and performance (38 laps).

Our team consists of six mechanical engineering students, one electrical engineering student, and one mathematics student. Each member of the team was tasked with improving different sub-systems of the boat in accordance with stated goals. The steering unit, lower drive train, boat's weight distribution, sprint and endurance propeller fabrication, power distribution, and data acquisition systems were assigned areas for improvement. Two faculty advisors, one mechanical and one electrical engineer, oversaw the project and provided appropriate direction and consultation.

For achieving the goal of 20 knot hull speeds, the hull was modified to employ planing hull characteristics. Improvements to the sprinting performance will be obtained with the addition of step chines. Implementing step chines will provide the vessel with planing hull characteristics. An important factor to achieve planing hull speed is thrust. Maximum thrust will be achieved by adjusting the prop design. Our team is fabricating two propellers. The first type of propeller is configured for qualifying, sprint, and slalom events. The other propeller configuration is for the endurance event. Each propeller configuration is matched with appropriate gearing to direct maximum power from the motor to the water.

The drivetrain delivers power to propellers. The operating speed of the motors have been matched with gearing to deliver the power to propellers. The drive shaft has been aligned through the center of the main support bearings to reduce any loss in energy.

A change in the lower drivetrain housing shape reduced the drag force by at least 40N at sprint speeds. The new housing reduces weight by 25 percent compared to the old housing. The housing is assembled entirely from the rear of the housing, eliminating the six retaining screws and allowing for a smooth transition from the propeller housing to the propeller hub. Manufacturing is nearing completion on the unit, which will then be tested.

For the goal of improving upon prior team's endurance performance, a major design improvement for implementation is an automated data acquisition system. A data collection system tracking the vessel's power and consumption provides more efficient methods for racing during the endurance event.

The system utilizes two Motenergy MEE-909 Brush Type permanent magnet DC motors. The motors are used in tandem in the sprint competition while only one motor is used during the endurance event. The motors are capable of sustaining up to 300A for 30 seconds and operate from 12-48V. Curtis 1205 motor controller allows for an increase in maximum system voltage up to 600 amps, now limited by the motors, instead of the motor controllers. The controllers allow for up to 800 amps of current.

The Optima batteries underwent load testing to determine their viability for use testing and for the competition. Testing was completed using a 500 amp carbon pile load tester; the testing methodology can be found in Appendix F. The testing revealed that many of the batteries failed to maintain adequate voltage under load. The load tester only allowed for a 10 second test, but still provided valuable information on the state of the batteries. The testing revealed that none of the batteries were in a suitable state to be used a competition; all but two of the batteries fell below 9 volts at half the expected current and a quarter of the expected time they would have to carry the load. New CSB batteries allowed for a change between a 24 and 36 volt system during the competition. This option was an important design parameter, because it allowed for the use of the 24 volt system used in previous competition for the endurance race; saving on the cost of new peak power trackers and solar panel rearrangements.

A prioritized budget aided decisions on purchases so that each area of necessary improvement would keep designs in relative balance.

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I. Overall Project Objectives

The Geneva College Solar Splash team has placed an emphasis on the performance of the hull during the sprint event. To improve the team's placement in the competition, by scoring higher in all events, the team has focused primarily on the speed characteristics of the design. Results acquired from testing, as well as past team's test results, made it clear that increasing the speed of the craft would not be possible without modifications to the current hull design. Some of the proposed alterations to the craft included installing hydrofoils, trim tabs, or by fabricating step chines. Any alterations to the current hull design were limited in order to keep the endurance capabilities of the design. The endurance event is one of the few events past teams for Geneva have competed well in; 2nd place for two consecutive years. Modifications to the hull are to optimize the hull shape, increase the boat's speed, while keeping the endurance capabilities of the hull unaffected.

In addition to hull modifications, improvements in the sprint event required members of the team to design and manufacture propellers. These specific propellers are designed for maximum efficiency and thrust for the vessel. One of our project goals includes the design and manufacture of propellers for both endurance and sprint configurations of the boat. Geneva College has a CNC mill which has the capability to machine a propeller. Previous teams have had the ability to use the CNC but they were unable to manufacture the propellers. The current team has designed and fabricated a sprint propeller. Currently, our endurance propeller is being fabricated. In a relatively short amount of time (and effort) propellers can be designed to whatever configuration the boat's drivetrain and systems allow for the best possible product.

The team has modified the battery power for the different competition events due to a rule change allowing a 36 V system, and 100 lbs of batteries for the Endurance event. By designing the batteries to have series/parallel connections the goals are to avoid purchasing peak power trackers, to have compatibility with the old system, and to draw more current.

The team will fabricate additional solar cells/panels. Through optimization of the energy collected and overall power efficiency of the energy transferred the boat our team will increase overall endurance performance. A detailed analysis of the boat's systems, to determine where the energy is lost, and how the efficiencies can be improved, has been conducted and is available within this report for review.

In summary, the team's goals are to improve the overall performance in the competition by making modifications to increase the sprint capabilities of the boat. By placing high in the sprint and endurance events, our goal is to improve and win the competition.

II. Solar System Design

A. Current Design

The current solar panels were constructed in 2012. Six panels are used on the boat during endurance events. The panels are protected by diodes as the current passes through two maximum power point trackers which regulate the load on the supplied voltage, which ultimately provides our team the ability to expend power efficiently during an event. Solar Splash competition regulations allow the endurance configuration to be reconfigured from a 24 volt system to a 36 volt system.

B. Analysis of Design Concepts

Additional cells/panels will benefit the endurance capability of our vessel; but at the time of this report our team is uncertain if the increase can be implemented in time for the competition. Considering the low cost of materials and added equipment it is a good investment even if our power is not increased. After much research, a solar cell manufacturer and vendor are willing to supply our team the material at low cost. Cells that match specifications, size, and most importantly the current capacity with the cells currently in use, will be added to the design. The cells (in use) have an average output of 2.24 volts and an average current capacity of 4.151 amps.

	Maximum Voltage	Maximum Current	Maximum Power
Panel #1	17.1 V	4.252 A	73.9 W
Panel #2	16.6 V	4.214 A	69.3 W
Panel #3	16.7 V	4.226 A	71.3 W
Panel #4	16.9 V	3.857 A	70.5 W
Panel #5	17.0 V	4.195 A	73.0 W
Panel #6	16.9 V	4.163 A	72.1 W

Table 2.1 - Voltage, current, and power values for panels tested during competition.

Dividing maximum power by 32 averages power of each cell within the specific panel. Calculating the average of the values produces an output of 2.24 watts per cell.

UPV Solar from India agreed to provide our team solar cells. The cells requested are U5-150C-01500, which have a power output of 2.23 volts, and a current capacity of 4.500 amps at maximum power (see Table E.1., located in Appendix E). Additional cells/panels will be fabricated to match dimensions of existing panels (4 cells x 8 cells). In order to accommodate this new panel, the frame will be modified. The arrangement of panels will consist of three panels in parallel (see illustration below).

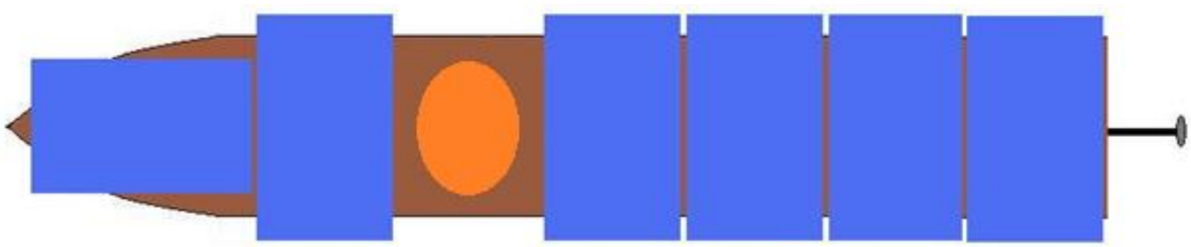

Fig. 2.2 - Old (Current) Solar Cell Panel Configuration during Endurance Event

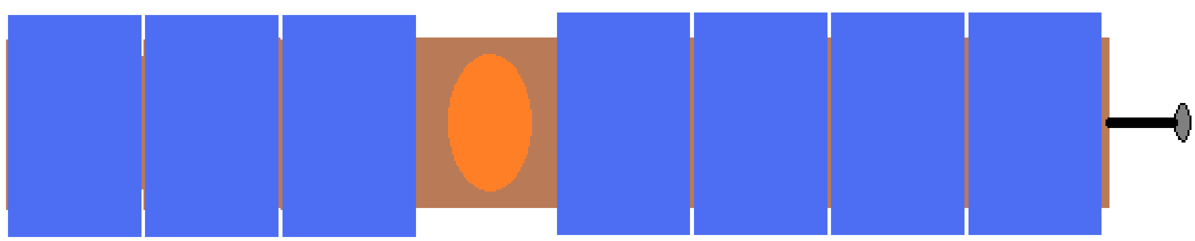

Fig. 2.3 - New Solar Cell Panel Configuration during Endurance Event

C. Design Testing and Evaluation

Modification and implementation of the design will occur within the month leading up to competition. Testing and evaluation of the design will take place as the team prepares and finalizes system configurations for the competition.

III. Electrical System

A. Wiring Configurations

No changes to the cables/wiring of the boat have been considered or implemented. The cables utilized in the electrical system are 00 gauge welding wire; with 0.261 Ω/km resistance and are rated up to 600 Amps. The dead man switch and potentiometer function properly. Labels for the wires and connections improve the process of installation. Hardware connections, consisting of brass bolts and nuts, of identical sizes; these aid installation and removal of components.

B. Data Acquisition System

The 2012-2013 team designed and implemented a data acquisition system using an Arduino-based operating system. This system was damaged during a dynamometer test of the boat's motors. The motor tests were run with a 36 volt supply; three 12 volt batteries connected in series. One of the functions of the data acquisition system is to monitor battery current and voltage. The system was connected to the batteries through voltage dividers. At the time of testing it was not known that the data acquisition system, used for calibrating the sensors, operated with a common ground. The dividers, which were used during the test, reduced 12 volts only to 5 volts, where dividers for the 36 volts were actually required. High voltages caused irreversible damage to the operating system. At the time of this report there have been no solutions implemented for the data acquisition failure.

C. Motor Controllers

1) Current Design: In past years, two Curtis 1204-001 24V/36V 275A motor controllers. Both are used during the sprint event while only one is used during endurance. One of the 1204 controllers was determined to be defective.

2) Analysis of Design: Multiple options were examined to solve the motor controller problem. The solutions included sending out the defective motor controller for repair, utilizing the backup motor controller (Alltrax AXE4855), and purchasing new motor controllers. The Alltrax AXE4855 was tested with the current set up; during testing the controller was damaged beyond repair. The possible solutions for the motor controllers were laid out comparing the specifications of each. The options were limited to available golf cart motor controllers by Curtis and Alltrax. The controllers were compared by laying out the condition, operating voltage, amperage limit, price, cutoff voltage, potentiometer setting, durability, and time it would take to receive it. Based on the matrix the best option was the Curtis 1205 24V/36V 400A motor controller. The loss of the backup motor controller during testing made it necessary to purchase two identical controllers.

Controller	Condition	Voltage	Amp	Price	Cutoff V	Pot
Curtis 1204	Reman.	24/36	275	275	16	0-5k
Curtis 1204	New	24/36	275	450	16	0-5k
Curtis 1204M	New	36/48	275	260	24	0-5k
Curtis 1205X	Reman.	24/36	400	210	16	5k-0
Curtis 1205	Reman.	24/36	400	160	16	5k-0
Alltrax	New	24-48	300	350	16	0-5k
Repair	Repaired	24/36	275	200	16	0-5k

Fig. 3.1 - Motor Controller Comparison

Controller	Condition	Voltage	Amp	Price	Cutoff V	Pot	Durability	Time	Total
Weight	6	8	7	10	9	6	7	6	
Curtis 1204	9	9	6	6	10	10	9	4	465
Curtis 1204	10	9	6	3	10	10	9	8	465
Curtis 1204M	10	7	6	7	0	10	9	6	387
Curtis 1205X	9	9	8	8	10	9	9	8	517
Curtis 1205	9	9	8	10	10	9	9	8	537
Alltrax	10	10	7	5	10	10	5	7	466
Repair of Old	9	9	6	8	10	10	9	0	461

Fig. 3.2 - Motor Descision Matrix

3) Design Testing and Evaluation: The Curtis 1205 motor controller allows for an increase in maximum system voltage up to 600 amps, now limited by the motors, instead of the motor controllers. The controllers allow for up to 800 amps of current, allowing room for growth in the future; the full specifications of the controller can be found in Appendix J The new controllers were the lowest cost option, while still allowing a higher amperage and the familiarity of the Curtis controllers. The only drawback to this choice is the reversal of the throttle; this should not cause any major difficulties. The motor controllers were unable to be tested at the time of writing, but based off their similarities with the old controllers, it should allow for a simple transition.

IV. Power Electronics System

A. Batteries

1) Current Design: The original power system utilized three Optima REDTOP batteries for both sprint and endurance, but these batteries are near the end of their usable life cycle. The battery system used was developed before the implementation of the "100 lb. of battery rule" and was originally intended to use on 2 batteries in endurance. This rule change caused the current 24 volt system in endurance to be outdated. Another major issue was on the water testing revealed that some of the batteries were not functioning under load. The battery decision focused on determining the state of the existing Optima batteries and purchasing new batteries to update the system.

2) Analysis of Design Concepts: The Optima batteries underwent load testing to determine their viability for use testing and for the competition. Testing was completed using a 500 amp carbon pile load tester; the testing methodology can be found in Appendix F. The testing revealed that many of the batteries failed to maintain adequate voltage under load. The load tester only allowed for a 10 second test, but still provided valuable information on the state of the batteries. The testing reveal that none of the batteries were in a suitable state to be used a competition; all but two of the batteries fell below 9 volts at half the expected current and a quarter of the expected time they would have to carry the load. The batteries could still be used for testing, the batteries were selected based on the results show in Figure 4.1.

After 10 seconds		
Optima	Current	Voltage
Battery 1	227.3	6.69
Battery 2	311.0	9.55
Battery 3	263.1	8.25
Battery 4	307.5	9.00
Battery 5	269.3	8.29
Battery 6	112.1	4.10
Battery 7	235.8	8.93
Battery 8	192.0	7.19
Battery 9	99.7	3.90
Battery 10	112.8	4.77
Battery 11	275.6	8.67
Battery 12	249.1	7.57
Battery 13	173.8	6.21
Battery 14	264.7	8.93
Battery 15	33.8	0.00

Fig. 4.1 - Optima Load Testing

The testing revealed a need to purchase two new sets of batteries for use. The focus of the search was honed in on 12V batteries that could be used for a 36 volt sprint system, because any lower voltage would lead to a loss of possible power output. Additionally, a lead acid batteries energy is very closely related to the weight of the battery therefore emphasis was placed on selecting of batteries weighing as close to 100 lbs. as possible. This lead to examining batteries of weights of approximately 11, 16, and 33 lbs., which form sets of 9, 6, and 3 batteries respectively.

The maximum current during competition is limited to 600 amp the motors. Amperages this high should be obtainable for the vast majority of lead acid batteries; meaning any choice should be adequate for the sprint competition. Therefore, emphasis was placed on the performance of the batteries energy potential in 2 hours to match the endurance competition time.

Battery Comparison		
Drawn Voltage	Battery	2 hr Power
V		Watts
9.9	BP 40-12	499.5
10.02	G42EP	649.5
9.6	BP 20-12	501.4
10.02	G16EP	490.1
9.6	HR22-12	554.4
9.6	EVH 12240	659.6
10	PSH 12180FR	544.8
9.6	PS-12400	498.7
9.6	PS-12200	501.9
9.6	GPL 12400	567.4
9.6	UB12500	627.4
9.6	UB12200	552.1
9.6	Optima 75/25	540.9

Fig. 4.2 - Hr Constant Power Comparison

Data for the batteries was compiled from manufacturers' specifications and past testing for thirteen batteries. Utilizing the available information and Peukert's law, a two hour constant current rate was determined for each battery, with a draw down to approximately 9.6 volts. Four possible batteries were selected based on the information in Figure 4.2: CSB EVH12240, Optima REDTOP, Genesis G13EP, and G42EP. Fortunately, past Geneva teams completed extensive testing of the REDTOP batteries both in the lab and the Genesis batteries have been extensively tested by the other teams competing. Meaning only the CSB EVH12240 was unknown, the decision was made to purchase one of the batteries for testing.

3) Design Testing and Evaluation: The CSB battery was tested using banks of 5Ω nominal resistors in parallel, the full procedure and results can be found in Appendix F.

These testing results were combined with the results of past testing in Figure 4.3.

Test	Time	Energy	100 lbs. of Battery	Source
	Min	Joules	Joules	
CSB12240	105	6.23E+05	1.25E+06	CSB Testing 2015
CSB12241	141	5.34E+05	1.07E+06	CSB Testing 2015
CSB12242	54	5.77E+05	1.15E+06	CSB Testing 2015
Optima	98	1.23E+06	1.23E+06	Geneva End. Testing 2014
Optima	90	1.12E+06	1.12E+06	Geneva End. Testing 2014
Optima	90	1.14E+06	1.14E+06	Geneva End. Testing 2014
Optima	90	1.15E+06	1.15E+06	Geneva End. Testing 2014
Optima	135	9.83E+05	9.83E+05	Geneva Sprint Testing 2014
Optima	150	1.12E+06	1.12E+06	Geneva Sprint Testing 2014
Optima	120	4.08E+05	2.04E+05	Endurance Comp Data 2013
EP 42	120	4.68E+06	1.56E+06	Cedarville Tech. Report 2014
Final Voltage Approximately 11 volts for Each Test				

Fig. 4.3 Optima, CSB, Genesis End. Comparison

The figure shows that the amount of energy pulled from the Optima and CSB batteries in two hours is extremely similar. Both the Optima and CSB batteries are well below that of the Genesis batteries. The final decision came down to a number of variables; some of which are listed in Figure 4.4. The cost of the Genesis batteries is far greater than the cost of both the CSB and Optima batteries; especially taking into account that two sets of batteries needed to be purchased. All four of the battery options weight neared the limit, but only the CSB battery allowed for a change between a 24 and 36 volt system during the competition. This option was an important design parameter, because it allowed for the use of the 24 volt system used in previous competition for the endurance race; saving on the cost of

Battery	System V	Weight of Set	Set Cost	2 Hr Power
		lb	Dollars	Watt
CSB EVH12240	24V/36V	99.84	320	576
Genesis G42EP	36V	98.7	750	630
Genesis G13EP	36V	97.2	1215	630
Optima REDTOP	36V	99.3	450	541

Fig. 4.4 - Optima, CSB, Genesis Overall Comparison

new peak power trackers and solar panel rearrangements. All of the batteries preformed similarly in endurance testing.

The concern with the CSB was whether the batteries would be capable of sustaining the high currents in sprint mode. The terminals on the CSB EVH12240 are threaded to receive an M5 bolt and therefore have a sustainably smaller surface area than that of an automotive terminal offered on many other batteries. A design engineer at CSB was contacted and confirmed to us that the batteries would be able to discharge at that rate. In order to verify this, the 500A carbon pile load tester was used to draw a high current from the CSB battery. The steel bolt provided by the manufacturer was replaced with a brass bolt to increase conductivity. The results in Figure 4.5 show that the CSB battery was capable of handling loads similar to the loads it will experience during the sprint event.

CSB Battery - After 10 seconds		
Trial	Current	Voltage
Trail 1	292.8	8.72
Trial 2	283.4	8.41
Trial 3	280.9	8.16
Trial 4	262.8	8.59

Fig. 4.5 - CSB Load Testing

Another concern with the CSB batteries was that they were to be wired in parallel and series, instead of simply in series. Any difference in voltage between the units could result in a discharge between the batteries, potentially resulting in damage to the unit. The use of a resister during the initial connecting of the batteries was discussed, but it was determined that the internal resistance of the battery prevent damage. Overall, the CSB EVH 12240 batteries were selected because of their cost, flexibility in system voltage, and high performance. One set of six batteries was purchased for on the water testing; with the plan to purchase another set pending the results of testing under actual conditions.

B. Configuration

Past battery configuration designs utilized a system of 36 volt for sprint and 24 volt for endurance, which were based on the competition rules that allowed 100 lbs of batteries for Sprint and only 68 lbs of batteries for Endurance. Due to past rules the solar system was designed for a 24 volt system. In order to avoid purchasing new peak power trackers, and to have compatibility with the old system, it was decided that it was necessary to have a way to convert between 24 volt and 36 volt. Copper bus bars were designed and bent to allow the batteries to be combine in different configurations of series and parallel. The wires will be connected and disconnected by hand to switch configurations from the sprint to endurance race. The endurance competition configuration utilizes only one of the motors and motor controllers, and can be configured into the 24 volt system shown in figure 4.5. The Sprint competition configuration utilizes both motors and motor controllers, and is configured into the 36 volt system shown in figure 4.6.

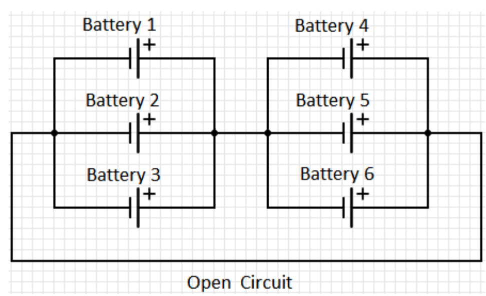

Fig. 4.5 - Endurance configuration

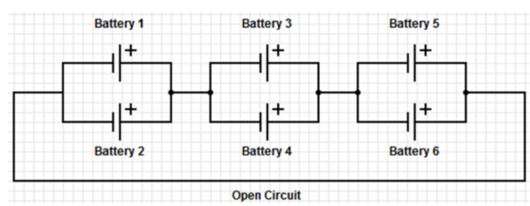

Fig. 4.6 - Sprint Configuration

C. Energy Balance

A major design goal was to maximize the power the system could supply to the water. In order to better utilize the available systems two power budgets were created, the full power budgets are located in Appendix G. These two budgets are used to estimate the amount of power in the system at certain points, as well as determine areas of the system where the biggest improvements could be made. These budgets allowed for a clear understanding of the amount of power available at the propeller; allowing for a more accurate design of the propeller. The efficiency of every component of the power system was recorded based on past testing and manufactures data; this was used to compare the relative amount of power lost in the system as in figure 4.8. The power budgets proved useful when examining the requirement of the motors, motor controllers, fuses, and the design conditions of the propeller; laying out the specification of the system to show where the current power was limited. The overall budget determined that 842 watts are available for the duration of the endurance race under a 1 sun condition and approximately 11,000 watts are available at the propeller during the sprint race.

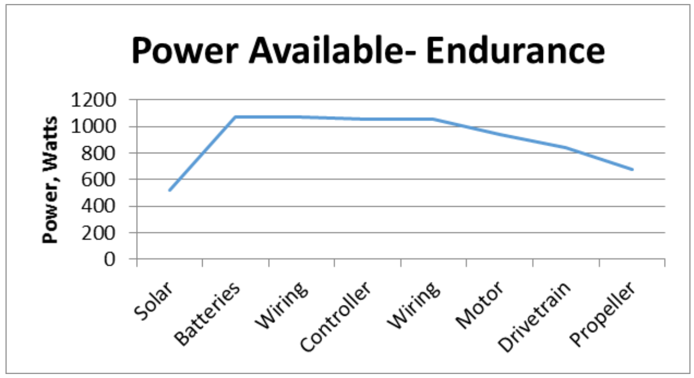

Fig. 4.7 - Power available at each stage of system

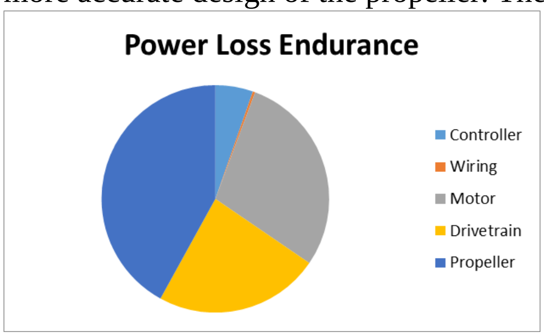

Fig. 4.8 - Comparison of power losses in endurance

V. Hull Design

A. Current Design

The 2008-2009 team decided to build a custom cedar strip hybrid mono-hull design from proposed hull designs through a history of analysis of single displacement hulls which were performed by previous teams. This design has consecutively been awarded 2nd place in past Solar Splash endurance races.

The goal for our team is to increase hull speed. In order to place higher, in the sprint and slalom competition events, hull speed must be improved. Higher speed is dependent on hull characteristics; specifically planing hull characteristics. An important factor to achieve planing is thrust. Adjusting motor power and prop design are ways to increase thrust; each of which have been discussed in further detail within their respective sections below.

Our team recorded the fastest hull speed, considering past teams for Geneva. On October 25th, 2014 our team conducted a scheduled testing on the Beaver River. Speeds above 17 mph, roughly 15 knots, were recorded from two of the test-runs that day. After obtaining those results, the team decided a more aggressive gearing ratio would improve test results. However, no speeds higher than 15 knots were recorded. On November 15th, the team again conducted testing on the Beaver River. A larger diameter propeller was utilized during the test. The results from the testing obtained speeds less than 17 mph. We modified the gearing and prop sizes because our calculations showed us we could increase thrust; however that did not happen as expected.

The team discussed hull limitations as preventing increases in hull speed from being achieved. Limitations which reduce a vessel's top speed due to hull characteristics. According to Savitsky, "a particular type of hull form is mainly dependent upon its operational speed/length ratio (SLR)." The equation for determining the SLR is as follows:

$$SLR = Velocity\ (knots) \div \sqrt{load\ waterline\ length\ (feet)}$$

Calculating the SLR for our vessel: $15\text{ knots } \div \sqrt{16.5}\text{ ft} = \mathbf{3.7}$

Looking at Figure A.1., there is a similarity between Geneva's hull design and the high speed displacement model of the figure. Whereas the figure of the high speed planing hull, in Figure A.2., is more common to hulls with planing characteristics. According to the above ratio, a high SLR number above 3, for displacement hulls, creates greater resistance, thus making increases in speed more difficult to achieve. The design of our hull, when looking at the two figures, could be modified to add more planing hull characteristics. Our team discussed adding material to form a chine line or design spray rails. Spray rails can reduce the effect of bow spray and enable sufficient dynamic lift for the vessel. Savitsky states "the hard-chine planning hull is configured to develop positive dynamic bottom pressures at high speed." Higher speeds can be obtained through the fabrication of a hard-chine, as Savitsky recommends the use of the hard-chine planning hull for hulls operating above SLR values of 3.

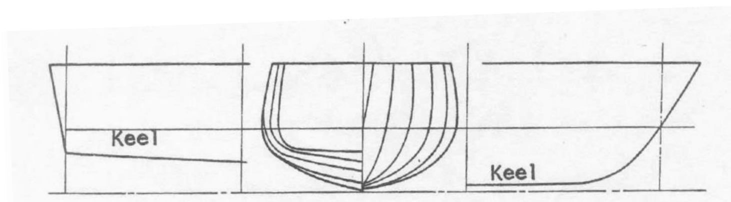

Fig. 5.1. – Savitsky's high speed displacement hull geometry

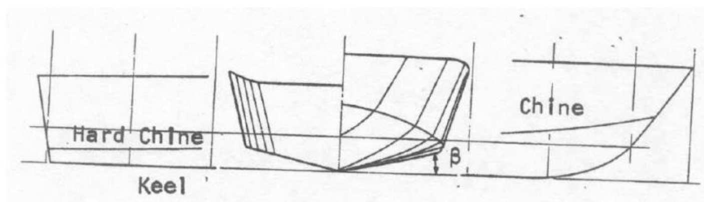

Fig. 5.2. – Savitsky's high speed planing hull geometry

B. Analysis of Design Concepts

This is the overall goal for our team: to design a vessel which performs efficiently in displacement (endurance race) and performs with higher speeds (sprint and slalom events). One of those goals has yet to be accomplished. Considering hull limitations had been reached, various options to alter the hull, in order to promote planing, and attain higher speeds, our team discussed the following options:

- Fabricate hydrofoils with the hull.
- Install trim tabs at the transom of the vessel, use them to "encourage" planing.
- Construct a step chine along the aft sections of the hull.

Fabricating hydrofoils as an option for increasing the speed of the vessel has merit when considering some of the past teams competing in Solar Splash have developed crafts with hydrofoils. Cedarville is one team from the competition that has developed a vessel with hydrofoils. They are consistently one of the top teams to compete within the events. Hydrofoil fabrication is a challenging endeavor. The hydrofoil must be constructed strong enough to withstand the dynamic stresses applied. Also, the hydrofoil must be articulated in such a way as to vary the angle of attack, thus varying the lift. Various systems were devised, however no plans were actually fabricated. In general, the proposed design plan was to build a conventional hydrofoil configuration with the leading foil placed near the pilot of the craft. The trailing foil would need to be placed at the driveshaft strut. Altering the angle of attack would be a complicated and time intensive endeavor. If given more time the hydrofoil design would be further investigated.

Savitsky describes the implementation of transom mounted trim tabs and concludes that there is an overall reduction in acceleration by approximately 65%. The team researched the cost of trim tabs (see Appendix H), and the cost for the equipment was roughly \$800. The cost of the equipment is more than the proposed hull modification.

Construction of a step chine along the aft sections of the vessel involved the addition of material to the existing hull. The team researched the cost of hull modifications to include the material involved with fabricating step chines. The material compared for constructing the modification was between balsa wood and Corecell. The balsa wood is roughly half the cost, however it is twice the weight of Corecell foam (see Appendix H).

Measurements for the amount of material needed, for the step chine, were supported by the design modeled in Inventor (Appendix B details the physical properties of the design). Particularly, the volume difference between the proposed design step chine from the current model was calculated to be 1,738 cubic inches.

Gurit Corecell-A is developed for marine sandwich structures, has high ductility and damage tolerance, can be heated to a pliable temperature (to form to a specific shape), is half the density of balsa, and would limit resin amounts. Given the research, the better option for the hull modification would utilize Corecell foam. Due to the density of WEST system epoxy resin and hardener, 73.63 lb./ft^3, minimal application necessary is recommended. For the modification, utilizing balsa would increase the amount of epoxy applied during construction; increasing the overall weight of the vessel compared to Corecell.

The cost for the materials, as noted in Appendix H, Fig. 10, was a total of \$475 through Jamestown Distributors.

In order to analyze the hull modification, CFD analysis was performed using Autodesk Simulation CFD 2015. The hull was analyzed in the sprint and endurance configurations; comparing the hull both pre and post modification. The analysis performed examined the drag and lift forces exerted on the hull as it travels through the water at different speeds. A full report of this analysis's findings is located in Appendix P. The analysis showed that the addition of chines had minimal effect on the drag force the hull experiences during endurance; matching the goal of not harming the endurance performance of the hull with the modification. The modification showed the added benefit of increasing the lift force during the endurance competition, which should serve to reduce the drag force by raising the hull further out of the water. The sprint analysis showed the hull would experience up to a 50 percent increase in drag force at sprint speeds, but that this force is more than offset by a 100 percent increase in the amount of lift force. Based on the results of the CFD analysis the chine lines are preforming as hoped.

C. Design Testing and Evaluation

A design limitation for the hull modification was to construct the step chine so that it would not interfere with the endurance characteristics of the past hull. In testing, the modified hull did not appear to be interfering with the endurance waterline when tested on the Beaver River. The following figure illustrates how, according to initial design intentions, that once the boat is prepared for endurance there should be limited interference between the step chines and the surface of the water.

Fig. 5.3 – Picture of the step chine not interacting with the water and the theoretical model

At the time of writing this report, more testing is needed in order to confirm that the step chine will not interfere, create drag on the surface of the water, when testing the endurance capabilities of the newer vessel. Currently the testing for the improvement in planing characteristics and speed are ongoing before endurance testing will be conducted. A recent malfunction with a motor controller has limited the team’s ability to test the full capability of the modified hull design.

VI. Drive Train and Steering

A. Motor

The motor system was not changed. The system utilizes two Motenergy MEE-909 Brush Type permanent magnet DC motors. The motors are used in tandem in the sprint competition while only one motor is used during the endurance event. The motors are capable of sustaining up to 300A for 30 seconds and operate from 12-48V. The motors weight 24.1 lbs. each and are mounted to a motor plate inside the vessel.

The manufacturer's motor curves were verified with dynamometer testing. Graphs showing this agreement can be seen in Appendix J. These graphs clearly show that the trend of the motor's power as tested follows a similar path to that of the manufacturer's specifications.

B. Gearing & Chains

Gear selection for the drive train is based on the desired boat speed, the angular velocity of the input shaft from the motor, and the angular velocity required of the propeller to achieve the desired speed. The desired speed of the boat for Sprint is 22 Knots, or 25 mph. The angular velocity of the input shaft from the motor is 2155 rpm based on the ME909 motor curve data. The angular velocity required of the propeller is 2500 rpm based on the nominal propeller selected using Crouch's Method. Calculations for the angular velocities and torque output are show in figure I.3 on appendix I.

The gear ratio is calculated by diving the angular velocity required of the propeller by the angular velocity of the input shaft from the motor. The theoretical desired gear ratio is determined to be 1.16:1. The available drive shaft teeth numbers are 12, 18, and 20, and the available motor shaft teeth numbers are 18, 21, 22, and 24 shown in Appendix I1. In order to achieve the calculated gear ratio the selected gears were 18-teeth on the drive shaft, and 22-teeth on the motor's input shaft shown in Figure 6.1. Based on previous reports the 1.22:1 ratio was chosen, because it was evident there was a lack of overdrive with the 1.16:1 ratio. During the Sprint testing in the Fall of 2014 the new gearing was used, and a max speed of 17.4 mph was reached.

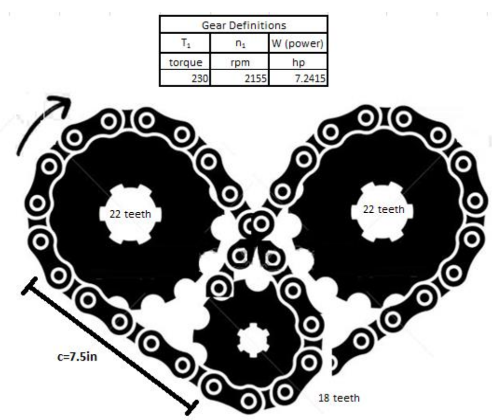

Fig. 6.1 – Gear and chain orientation

The chains used for Sprint testing are size 40, and the dimensions of the chain are shown in Appendix I4. New chains needed to be cut based on the change in the drive shaft and motor input gear sizes, because the new gears have larger outside diameters compared to the previous setup shown in figure I.2. Two chains with 23 links were cut and fastened together with spring clips which are shown in figure I.6.

C. Driveshaft

The driveshaft of the Solar Splash vessel drivetrain was fabricated from nitride coated 1045 steel bar stock. The 1045 steel has a yield strength of 45,000 psi.[13] The driveshaft is half an inch in diameter. The driveshaft is connected to two collars (Gear collars) at the top end by a key way and retaining nut. The driveshaft is supported in three places. The first two locations are roller bearings located inside the gear/motor housing mounting plate. The last support is the driveshaft strut attached to the underside of the hull. The driveshaft is connected with the constant velocity joint at the lower end. A clearance hole at the lower end is the connection for the constant velocity joint by a pin.

The driveshaft strut was designed in 2013, and is fabricated from 1061-T6 aluminum. Our team noticed that the strut was initially installed off-center. The driveshaft was not aligned through the center of the aluminum motor mount two main bearings. The driveshaft strut was centered to the axis, through the two main bearings, after relocating the structure. The driveshaft now freely aligns with the two main bearings in the motor mount. Installation and removal of the driveshaft is noticeably smooth.

E. Bearing Housing

1) Current Design: The past propeller shaft housing consisted of a hollow steel cylinder housing bearings. The past housing produced unnecessary drag; the roller bearing sat flush in the front of the housing, with no rounding of the surface. Another issue was the retaining plate; its screws interfered with the transition from the housing to the propeller hub. The steel design added significant weight to the steering unit.

Fig. 6.2 - Solid model of one piece semi-spherical housing

2) Analysis of Design Concepts: Multiple new design options were developed. Three final options were further investigated. The designs included a two piece elliptical housing, a one piece elliptical housing, and a cylindrical housing with a semi-sphere front end. The two piece housing was quickly eliminated, because it create more complexity in machining and assembly. The two one piece bearing housings were similar in all aspects except for fluid flow. Both of the remaining housing options were compared using Autodesk Simulation CFD in order to calculate the drag force on the bearing housing at different boat velocities; graphical results are included in Figure 6.5. The methodology and verification of computer model are located in Appendix L. The results show that all three of the housing produced similar resistances at slow speeds; the differences in drag force were more substantial at higher speeds. The analysis illustrates

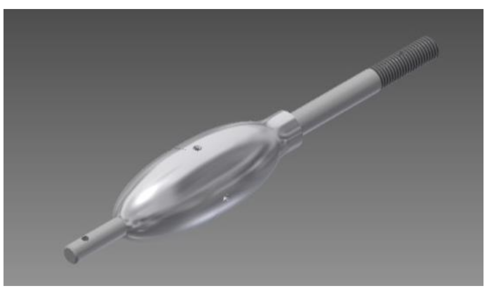

Fig. 6.3 - Solid model of new bearing housing to reduce drag and reduce the overall weight of the drivetrain

Fig. 6.4 - Solid model of one piece elliptical bearing housing

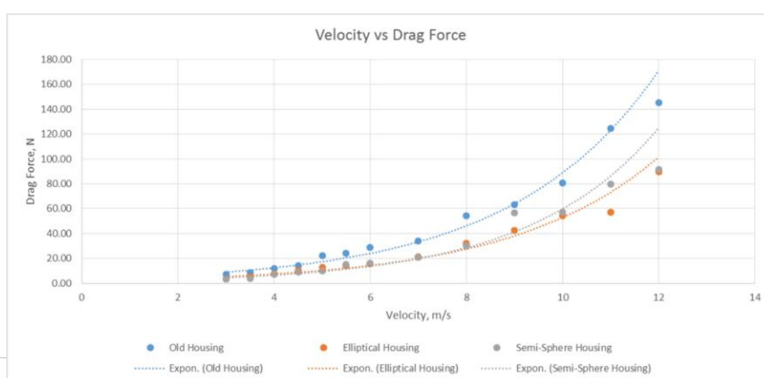

Fig. 6.5-CFD analysis of possible bearing housings

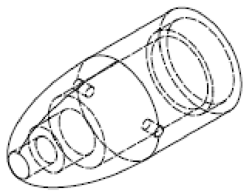

Fig. 6.6 - Solid model of one piece elliptical bearing housing

that the elliptical housing is the lowest drag option and therefore was the chosen design.

3) Design Testing and Evaluation:

Analysis of the new design options verses the old design shows that the change in housing shape reduced the drag force by at least 40N at sprint speeds. The new housing reduces weight by 25 percent compared to the old housing. The housing is assembled entirely from the rear of the housing, eliminating the six retaining screws and allowing for a smooth transition from the propeller housing to the propeller hub. Manufacturing is nearing completion on the unit, which will then be tested. The full design specification for the new housing and propeller shaft are located in Appendix L.

F. Propellers

1) Current Design: Previously, attempts have been made to design optimized propellers for use in the competition. Past teams had created a successful endurance propeller, but it was broken during on the water testing last year; leaving the current team with no manufactured propellers. All previous sprint propellers had been purchased prefabricated and were not successful in drawing the expected power from the system. The propellers had been selected to draw 550 amps from the system but only managed to draw 350 amps during testing. All of the current propeller owned by the team were cataloged and examined; it was determined that none of the current propellers would suffice for the endurance competition and only two of the propellers would function properly in the sprint, neither of which would be optimal, the sprint propeller currently used in the sprint configuration of the system is a 10 x 14 (10 inch diameter by 14 inch pitch) propeller. Therefore propellers were designed that match the ideal criteria: an endurance propeller with high efficiency and to a sprint propeller capable of reaching the maximum power from the system.

2) Analysis of Design Concepts: Since optimal propeller design is based on hull thrust, speed through the water, diameter, rpm, and number of blades, the first step was determining the power available from the batteries and solar panels during the race. This was determined through battery testing and the endurance and sprint power budgets (App. G) as discussed in the Power Systems area of the report. The next step was to determine the amount of drag expected at different speeds of travel, as the drag force will be equivalent to the thrust force generated by the propeller. The goal of the hull modification this year was to permit the hull to reach plane while additionally allowing the endurance race to occur in full displacement mode. Based on past on the water testing, previous Michelet results, and an updated model of the craft in the DELFTship program; the results from these different methods were combine to create a full displacement speed versus drag graph. These programs would not be suitable for the sprint mode, because of the goal of transitioning to planing. In order to properly estimate the boat in planing position Crouch's Planing Speed Formula,[5] thrust estimation from the testing in semi-displacement load, and Savitsky Planing Hull Analysis were used. Past teams had been using the assumption that the motor was acting under the 36 nominal volts drawn from the battery during competition; in reality the system's voltage falls under load; meaning the motor is acting under 27-30 volts during the sprint competition, because of this decrease in voltage a custom motor curve was created at 30 volts using given manufactures data as well as verification results from dynamometer testing of the motors which is shown in Figure 6.7. Based on advice from Gerr's

Handbook[5] it was determined that the tip of the propeller should be no closer than 4 inches to the surface of the water. This limited the maximum diameter of both propellers to 14 inches.

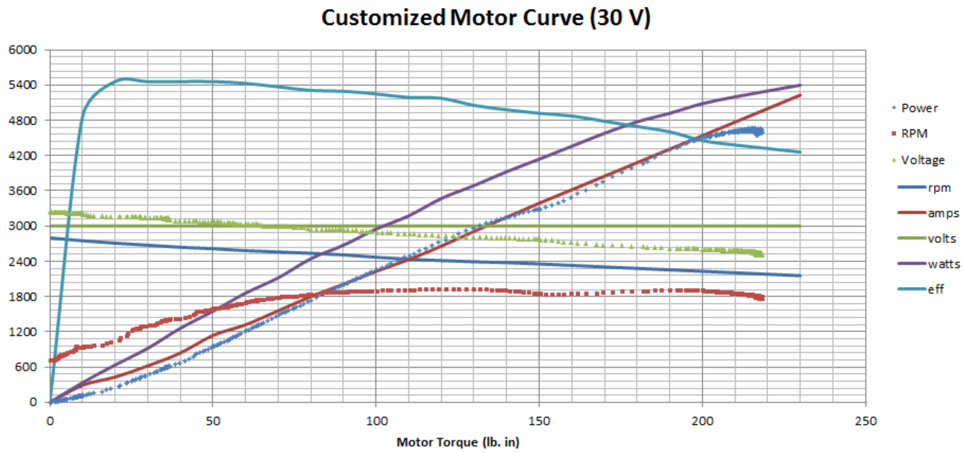

Fig. 6.7 – Customized 30 Volt motor curve

The legend entries that are just points are the results of dynamometer testing (Power is in Watts)

Watts and RPM based on scale of 6000=6000

Voltage based on Scale of 6000=60

Amps based on scale of 6000=300

Eff based on scale 6000=1

A rough propeller design was created using the methods of Gerr's Handbook; these methods specified certain pitches and diameters for possible propellers but failed to take into account foil shape and were limited in the ability to optimize them. It was determined that the best method would be to utilize the OpenProp and JavaProp software. Past teams have had success utilizing the JavaProp software in the endurance competition. Multiple designs of each propeller were created utilizing JavaProp. By varying the diameter, rpm, thrust and velocity point; with the goal of hitting the power limit defined in the power budget, maximum efficiency, large enough area to avoid cavitation, and good performance at off design conditions. The JavaProp software proved sufficient to design an endurance propeller.

The sprint propeller design proved to be more complex. The JavaProp outputs for the sprint propeller generated a propeller with insufficient area to prevent cavitation due ot allowable balde loading. This cavitation would prevent planing. Attempts to change the blade shape using JavaProp to increase the area greatly reduced the efficiency and changed the expected power drawn. These issues led to OpenProp being utilized, since it allowed for easier manipulation of the area of the propeller blade. There were issues with the OpenProp model as well, the geometric output from OpenProp appeared much more simplistic and rounded than that generated by JavaProp; additionally, with two identically sized propellers OpenProp suggested that the propeller would draw approximately ten percent less power than that offered in JavaProp. Finally, the macro provided for the importation of the OpenProp model into Solidworks, did not function as expected due to differences in the older versions of SolidWorks verses the current. These led to taking the geometric text file generated in OpenProp and importing it into JavaProp; this allowed for the updating of foil shapes as well as further analysis of the propeller at the design conditions.

3) Design Testing and Evaluation: The final design geometry for each propeller was exported using the geometry tab in JavaProp. This file was then opened in AutoCAD and a 3-D model was created by tracing the given foil shapes at each station and then those stations lofted to create a solid.

A prototype machining was completed prior to the designing of the propellers as the team created a procedure for using the CNC mill to machine the propellers for the competition. The team used Autodesk Inventor's CAM software, Inventor HSM, to generate the g-code for use with the 3-axis CNC mill. To avoid any deformation from the milling forces on the thin propeller blades supports were added to the solid model and machined into the stock so that the part could be flipped and still maintain structural integrity through the machining process. This prototype allowed for an efficient and effective process for the machining of a sprint propeller.

Aluminum 6061 grade stock was chosen as the material for both of the propellers because of its machinability as well as its strength. Due to restrictions in the size of the mill table, the three-bladed sprint propeller design had to be divided into three sections so each blade could be machined individually and the entire propeller could be assembled after the milling process. This process is detailed in appendix M. The size of the mill table does not restrict the ability to machine the endurance propeller because of the two blade design. The milling of the endurance propeller is to be completed within the next month before competition and with ample time to conduct significant endurance testing.

G. Steering

1) Current Design: The 2013-2014 team designed and fabricated a steering device which they located at the stern of the boat. After the installation of the device the steering swivel failed during testing. During a test run of the boat on the Beaver River, an incident occurred with the propeller kicking back up into the steering strut, hitting the strut with enough force to sheer one of the propeller blades from the main hub. Damage to the propeller, steering strut, steering pivot rod, drive shaft, and drive shaft strut occurred from the incident.

2) Analysis of Design Concepts: The team developed solutions to each of the affected steering sub-systems. The original steering swivel was made from aluminum. The material, fabricated to the designed size, could not handle the loads it was subject to which added to the overall system failure. A robust new pivot rod was fabricated out of steel and the diameter was slightly increased from 1/2 inch to 5/8 inch. Add. The 2013-2014 team was unable to implement all of the design solutions before competition. Thus the team left the improvements to be implemented by the following team. In order to prepare the boat for testing last fall, the 2014-2015 team focused on implementing all necessary corrective actions.

3) Design Testing and Evaluation: To solve the problem of the propeller kicking up, an aluminum tab was welded to the steering strut; just above where the lower unit is attached. This new piece restricts the vertical motion of the lower drive unit, stopping upward motion before the propeller can come into contact with the steering strut.

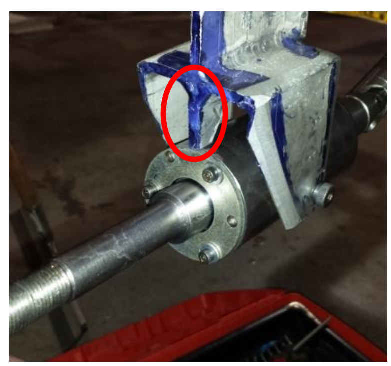

Fig. 6.4 – Implementation of the tab welded to the steering strut

VII. Project Management

A. Team Members and Leadership Roles

There are currently five mechanical engineering students who make up the Geneva College Solar Splash team. There were also two other engineering students who participated this year as members of the design team. This competition serves as the capstone project for these engineers in their Senior Design Project (EGR 481 and 482) to be accomplished starting two semester before graduation.

The work that was done on the project was divided up between the individual group members. Each of the five primary team members for this year had a section that was their responsibility.

- Hull Modification
- Batteries
- Solar Array
- Propeller Manufacturing
- Propeller Design

Weekly meetings ensured progress and helped individuals receive assistance with issues. Most work was done collaboratively depending on the volume of the work to be done but individuals were responsible leading the efforts in their areas.

The team was advised by two faculty members: a mechanical engineering professor and the engineering technician. The guidance and assistance of these two individuals aided in the design process as well as technical skills required in the fabrication and manufacturing involved in the project.

B. Project Planning and Schedule

The team was organized in September and responsibilities were assigned based on the project bid that was placed by each team member for selection into the senior design team. A gantt chart was created for the spring semester to detail the timeline of work to be accomplished leading up to the competition. Deadlines were made for individuals' work as to maintain steady progress on overall systems throughout the semester. Difficulties and set backs on larger aspects of the project have caused the need for the most significant testing and evaluation of the designs implemented to occur after this report was submitted and before the competition.

C. Financial and Fundraising

In working with the Institutional Advancement Office a fundraising thank-you letter was drafted and sent to engineering alumni and previous benefactors in order to express the gratitude and solicit support. The letter informed the receiver about the competition, the opportunity provided through it to help the team put their education to practice, and the chance for professional development and experience. Alumni and benefactors were thanked and welcomed to join the team by investing in the team's future.

A prioritized budget aided decisions on purchases so that each area of necessary improvement would keep designs in relative balance. Apart from fixed costs (entry fee and travel expenses), batteries and hull redesign were given the highest priority. This decision was based on the inefficiency of the endurance and sprint batteries as well as hull limitations.

D. Team Continuity and Sustainability

A weekly report template was utilized through both semesters for consistent, structured communication between all project areas. The weekly meetings lasted roughly from one hour to one and a half hours. Team members communicated when they would be available to each other for consultation and collaboration on the project.

E. Discussion and Self-Evaluation

The approach taken to divide the responsibilities of the project and work collaboratively on those aspects was effective for the majority of the work accomplished. However, this led to an imbalance in the work load for the individuals in the project that allowed difficulties to delay the completion of certain systems that did not allow for the self-installed deadlines to be met. Better care could have been taken to assure that the proper number of individuals and effort was put into the aspects of the project that required the extra work.

VIII. Conclusions and Recommendations

The following addresses project strengths and weaknesses for the past year

A. Strengths

- Increased planing characteristics of the hull by increasing the surface area in the rear of the boat as well as adding a hard chine line.
- Manufactured optimized propellers using calculated values and CNC machining.
- Created an energy budget to gauge the power losses in the system
- Increased the solar array to improve charging capacity.

B. Weaknesses

- Inability to test new modifications fully to evaluate performance because of malfunctioning equipment.
- Lack of foresight in work to be done before testing can occur led to delays in testing.

C. Did we meet our overall and sub-system objectives?

- Hull modifications are complete.
- Sprint propeller has been successfully machined and assembled.
- New batteries have been purchased for use in the endurance event.
- Solar cells have been ordered to assemble a new solar panel

In general, objectives have been met but still require testing and evaluation under competition conditions as well as final fabrication and implementation.

D. Where we go from here?

Significant testing is required for the completed projects. Main areas of focus between the time of submitting this report and competition will be the solar array and configuring the boat for the endurance event.

E. Recommendations

- Future teams should carefully document all tests and modifications made, including wiring diagrams for test setups for equipment such as the dynamometer and battery testers.
- Set realistic goals and deadlines and stick to them as closely as possible.
- Delegate jobs and projects to team members based on skill, workload, and available time.
- Enlist the help of other seniors and underclassmen who are not assigned to the project as their senior design capstone. They can help in administrative and marketing roles as well as technical roles.

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Acknowledgments

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Thanks extended to Tom Magnone for assistance and expertise in fabrication and welding, as well as his moral support.

Special thanks to Bret Moyer for his technical assistance with our design, fabrication, and welding. Without the use of Bret's shop, The Race Place, and expertise many of our designs would have been costly to fabricate.

Thanks to Geneva College Department of Engineering secretary Karen Mlynarski for assistance in administrative matters.

The team would also like to express thanks to Lisa Burke for being skipper for tests in the Fall semester. Alexa Springer for photographing our tests. Wyatt Lueck for his cooperation and assistance with the dynamometer testing. Our current skipper, Michelle Greco.

A very special and gracious thanks to all of our supporters, donators, and benefactors whose generous funds provided our team the capacity to accomplish our goals.

Finally, acknowledgement is extended to past teams for their hard work and for providing an excellent boat for the current and future teams to improve on in the years to come.

Appendix A: Battery Documentation

Competition Batteries- (12 12-volt batteries)
CSB EVH 12240 12V 24Ah
Specifications and MSDS attached – nominal weight of 16.64 lbs.

Back-up Competition Batteries- (3 12-volt batteries)*
Optima REDTOP 75/25 12V 44Ah
Specifications and MSDS attached – nominal weight of 31.4 lbs.

Auxiliary Battery – (1 12-volt battery)
CSB GP 1272 F2 12V 7.2Ah
Specifications and MSDS attached – nominal weight of 5.5 lb.

DAS Battery- (1 9.6-volt battery)
TENERGY 9.6-volt 2000mAh Nickel-Metal Hydride Battery
Specifications and MSDS attached – nominal weight of 8.5 ounces.

*It is expected that 12 EVH 12240 batteries will be used for competition pending the results of on the water testing. If an issue with the EVH 12240 batteries is discovered during testing at least one set the Optima REDTOP batteries will be used, because of this the MSDS and specifications for the Optima REDTOP are included.

CSB BATTERY

Material Safety Data Sheet

SECTION 1: PRODUCT IDENTIFICATION

Chemical/Trade Name (as used on label)	Chemical Family/Classification
Sealed Lead Acid Battery . Valve Regulated Lead Acid Battery (VRLA Battery).	Electric Storage Battery

Manufacturer's Name:	Address:
CSB Battery Co., Ltd.	10Fl, No. 301, Sec. 2, Ti-Ding Blvd., Nei Hu, Taipei 114, Taiwan

SECTION 2: CONTACT

CSB Safety Department	+886-2-8751-5000

SECTION 3: HAZARDOUS INGREDIENTS/IDENTITY INFORMATION

(Note: Product contains toxic chemicals that are subject to the reporting requirements of Section 302 and 313 of the Emergency Planning and Community Right-to-Know Act of 1986).

Exposure Limits			(Air Exposure Limits (ug/m^3))		
Material	**% by Wt.**	**CAS Number**	**OSHA**	**AGGIH**	**NIOSH**
Lead	57	7439-92-1	50	150	100
Lead Oxide	22	1309-60-0	50	150	100
Electrolyte (Sulfuric Acid)	14	7664-93-9	1	1	1

SECTION 4: PHYSICAL/CHEMICAL CHARACTERISTIC DATA

Material is solid at normal temperatures.

Electrolyte:

Boiling Point:	230° F/110°C	Melting Point	Lead 327.4° C
Specific Gravity:	1.215 – 1.350	Vapor Density	Not determined
% Volatiles By Weight:	Not Applicable	Vapor Pressure	Not determined
Solubility in Water:	100% (electrolyte)	Evaporation Rate	Not determined

Appearance and Odor:

Electrolyte is a clear liquid with an acidic odor.

SECTION 5: HEALTH HAZARD INFORMATION

Under normal operating conditions, the internal material will not be hazardous to your health. Only internally exposed material during production or case breakage or extreme heat (fire) may be hazardous to your health.

Routes of Entry:

- Inhalation: Acid mist from formation process may cause respiratory irritation.
- Skin Contact: Acid may cause irritation, burns and/or ulceration.
- Skin Absorption: Not a significant route of entry.
- Eye Contact: Acid may cause sever irritation, burns, cornea damage and/or blindness.
- Ingestion: Acid may cause irritation of mouth, throat, esophagus and stomach.

Date: 09/03/2006
Version: CBN-A2

- 1 -

Fig. A.1 CSB Seal Lead Acid Battery Data Sheet (1 of 4)

Material Safety Data Sheet

Sign and Symptoms of Over Exposure:

Acute Effects: Over exposure to lead may lead to loss of appetite, constipation, sleeplessness and fatigue. Over exposure to acid may lead to skin irritation, corneal damage of the eyes and upper respiratory system.

Chronic Effects: Lead and its components may cause damage to kidneys and nervous system. Acid and its components may cause lung damage and pulmonary conditions.

Potential to Cause Cancer: The International Agency for Research on Cancer has classified "strong inorganic acid mist containing sulfuric acid" as a Category 1 carcinogen, a substance that is carcinogenic to humans. This classification does not apply to liquid forms of sulfuric acid or sulfuric acid solutions contained within a battery. Inorganic acid mist is not generated under normal use of this product. Misuse of the product, such as overcharging, may however result in the generation of sulfuric acid mist.

Emergency and First Aid Procedures:

- Inhalation: Remove from exposure and apply oxygen if breathing is difficult.
- Skin: Wash with plenty of soap and water. Remove any contaminated clothing.
- Eyes: Flush with plenty of water immediately for at least 15 minutes. Consult a physician.
- Ingestion: Consult a physician immediately.

California Proposition 65:
The State of California has determined that certain battery terminals and related accessories contain lead and lead compounds, chemicals known to the State of California to cause cancer and reproductive harm. **Warning: Wash hands thoroughly after handling batteries.**

SECTION 6: FIRE AND EXPLOSION HAZARD DATA:

Flash Point:	Hydrogen = 259°C
Auto ignition Temperature:	Hydrogen = 580°C
Extinguishing Media:	Dry chemical, foam, CO_2
Flamability Limits:	LEL 4.1% (Hydrogen gas)

Unusual Fire and Explosion Hazards: Hydrogen and oxygen gases are produced in the cells during normal battery operation (hydrogen is flammable and oxygen supports combustion). These gases enter the air through the vent caps. To avoid the chance of a fire or explosion, keep sparks and other sources of ignition away from the battery.

SECTION 7: REACTIVITY DATA:

Stability:	Stable
Conditions to Avoid:	Sparks and other sources of ignition.

Incompatibility: **(materials to avoid)**

Lead/lead compounds: Potassium, carbides, sulfides, peroxides, phosphorus, sulfur.
Battery electrolyte (acid): Combustible materials, strong reducing agents, most metals, carbides, organic materials, chlorates, nitrates, picrates, and fulminates.

Hazardous Decomposition Products:

Lead/lead compounds: Oxides of lead and sulfur.
Battery electrolyte (acid): Hydrogen, sulfur dioxide, and sulfur trioxide.

Date: 09/03/2006
Version: CBN-A2
- 2 -

Fig. A.1 Cont. CSB Seal Lead Acid Battery Data Sheet (2 of 4)

CSB BATTERY

Material Safety Data Sheet

Conditions to Avoid:

High temperature. Battery electrolyte (acid) will react with water to produce heat. Can react with oxidizing or reducing agents.

SECTION 8: CONTROL MEASURES:

Engineering Controls:

Store lead/acid batteries with adequate ventilation. Room ventilation is required for batteries utilized for standby power generation. Never recharge batteries in an unventilated, enclosed space.

Work Practices:

Do not remove vent caps. Follow shipping and handling instructions that are applicable to the battery type. To avoid damage to terminals and seals, do not double-stack industrial batteries.

SECTION 9: PERSONAL PROTECTIVE EQUIPMENT:

Respiratory Protection:

None required under normal handling conditions. During battery formation (high-rate charge condition), acid mist can be generated which may cause respiratory irritation. Also, if acid spillage occurs in a confined space, exposure may occur. If irritation occurs, wear a respirator suitable for protection against acid mist.

Eyes and Face:

Chemical splash goggles are preferred. Also acceptable are "visor-gogs" or a chemical face shield worn over safety glasses.

Hands, Arms, Body:

Vinyl coated, VC, gauntlet type gloves with rough finish are preferred.

Other Special Clothing and Equipment:

Safety shoes are recommended when handling batteries. All footwear must meet requirements of ANSI Z41.1 – Rev. 1972.

SECTION 10: PRECAUTIONS FOR SAFE HANDLING AND USE:

Hygiene Practices:

Following contact with internal battery components, wash hand thoroughly before eating, drinking, or smoking.

Respiratory Protection:

Wear safety glasses. Do not permit flames or sparks in the vicinity of battery(s). If battery electrolyte (acid) comes in contact with clothing, discard clothing.

Protective Measures:

Remove combustible materials and all sources of ignition. Cover spills with soda ash (sodium carbonate) or quicklime (calcium oxide). Mix well. Make certain mixture is neutral then collect residue and place in a drum or other suitable container. Dispose of a hazardous waste.
Wear acid-resistant boots, chemical face shield, chemical splash goggles, and acid-resistant gloves. **Do not release un-neutralized acid.**

Date: 09/03/2006
Version: CHN-A2

- 3 -

Fig. A.1 Cont. CSB Seal Lead Acid Battery Data Sheet (3 of 4)

Waste Disposal Method:

Battery electrolyte (acid): Neutralize as above for a spill, collect residue, and place in a drum or suitable container. Dispose of as hazardous waste. **Do not flush lead contaminated acid to sewer.**
Batteries: Send to lead smelter for reclamation following applicable Federal, state and local regulations. Product can be recycled along with automotive (SLI) lead acid batteries, or use CSB Recycling Program number (800) 3CSB/USA.

Other Handling and Storage Precautions:

None Required.

SECTION 11: NFPA HAZARD RATING:

Sulfuric Acid:

Flammability (Red) =	**0**
Health (Blue) =	**3**
Reactivity (Yellow) =	**2**

SECTION 12: DEPARTMENT OF TRANSPORTATION AND INTERNATIONAL SHIPPING REGULATIONS:

Proper Shipping Name	Batteries – Non-Spillable, Electric Storage
U.S. DOT (U.S. Department of Transportation)	Classified as non-spillable, meets non-spillable criteria listed at 49 CFR 173.159 (d). See comments.
IATA (International Air Transportation association) **ICAO (International Civil Aviation Administration)**	Classified as non-spillable, meets the requirements of Special Provisions A67, Non-spillable batteries shloud be packed according to IATA packaging instruction 806. See comments.
IMO (International Maritime Organization) **IMDG (International Maritime Dangerous Goods)**	Classified as non-spillable, meets the criteria listed in special Provision 238. See comments.

Comments:

CSB seal lead-acid batteries are classified as "non-spillable" for the purpose of transportation by DOT, and IATA/ICAO as result of passing the Vibration and Pressure Differential Test described in DOT [49 CFR 173.159 (d)] and IATA/ICAO [Special Provision A67].

CSB seal lead-acid batteries can be safely transported on deck, or under deck stored on either a passenger or cargo vessel as result of passing the Vibration and Pressure Differential Tests as described in the IMDG regulations.

To transport these batteries as "non-spillable" they must be shipped in a condition that would protect them from short-circuits and be securely packaged so as to withstand conditions normal to transportation by a consumer, in or out of a device, they are unregulated thus requiring no additional special handling or packaging.

For all modes of transportation, each battery and outer package is labeled "NON-SPILLABLE" per 49 CFR 173.159 (d). If you repackage our batteries either as batteries or as a component of another product you must label the outer package "NON-SPILLABLE" per 49 CFR 173.159 (d).

Fig. A.1 Cont. CSB Seal Lead Acid Battery Data Sheet (4 of 4)

Title:	Date:	Rev:	Page:	File Name:
OPTIMA BATTERIES — Material Safety Data Sheet for All Optima Batteries	10/17/11	M	1 of 5	MSDS battery

MSDS No.	L 8A
Date Issued	Feb. 20, 1990
Date Revised	Oct. 17, 2011

Chemical/Trade Name (identity used on label)	Chemical Family/Classification	
Sealed Lead Acid Battery/ OPTIMA BATTERY ™	Electric Storage Battery	HMIS Rating for Sealed, Lead Acid Battery 0 0 0; For sulfuric acid 3 0 2

Synonyms/Common Name	DOT, IATA and IMO Description
Sealed Lead Acid Battery	Non-Spillable Battery , Exempt from UN2800 Classification

Company Name OPTIMA Batteries, Inc.	Address 5757 N. Green Bay Avenue Milwaukee, WI 53209
Division or Department Wholly- owned subsidiary of Johnson Controls Inc.	

CONTACT	TELEPHONE NUMBER
Questions Concerning MSDS OPTIMA Batteries, Environmental, Health & Safety Department	Day: (800) 333-2222, Ext. 3138
Transportation Emergencies CHEMTREC	24 Hours: (800) 424-9300 International: (703) 527-3887 (Collect)

NOTE: The OPTIMA sealed lead acid battery is considered an article as defined by 29 CFR 1910.1200 © OSHA Hazard Communication Standard. The information on this MSDS is supplied at customer's request for information only.

II. Hazardous Ingredients

Material	% by Wt.	CAS Number	Eight Hour Exposure Limits		
			OSHA PEL	ACGIH TLV	NIOSH REL
Specific Chemical Identity Lead & lead compounds	63-81	7439-92-1	50 μg/m^3	150 μg/m^3	100 μg/m^3
Specific Chemical Identity Sulfuric Acid (35%) Common Name Battery Electrolyte (Acid)	17 - 25	7664-93-9	1mg/m^3	0.2 mg/m^3 (respirable thoracic fraction)	1 mg/m^3
Common Name Case Material Polypropylene	2-8	9010-79-1	–	–	–
Common Name Separator/Paster Paper Fibrous Glass	1-4	65997-17-3	–	–	–

NOTE: The contents of this product are toxic chemicals that are subject to the reporting requirements of section 302 and 313 of the Emergency Planning and Community Right-To-Know Act of 1986 (40CFR 355 and 372).

III. Physical Data

Material is (at normal temperatures) ☒Solid ☒Liquid		Appearance and Odor Battery Electrolyte (acid) is a clear to cloudy liquid with slight acidic odor. Acid saturated lead oxide is a dark reddish-brown to gray solid with slight acidic odor.
Boiling Point (at 760 mm Hg) Lead 1755°C Batt. Electrolyte (Acid) 110-112°C	Melting Point Lead 327.4°C	
Specific Gravity (H_2O =1) Battery Electrolyte (Acid) 1.210 - 1.300		Vapor Pressure ☒(mm Hg at 20°C) ☐(PSIG) Battery Electrolyte (Acid) 11.7
Vapor Density (Air =1) Battery Electrolyte (Acid) 3.4		Solubility in H_2O Lead and Lead Dioxide are not soluble. Battery Electrolyte (acid) is 100% soluble in water.
% Volatile By Weight Not Determined		Evaporation rate (Butyl Acetate = 1) Not Determined

Fig. A.2 MSDS for All Optima Batteries (1 of 5)

OPTIMA BATTERIES	Title: Material Safety Data Sheet for All Optima Batteries	Date: 10/17/11	Rev: M	Page: 2 of 5	File Name: MSDS battery

IV. Health Hazard Information

NOTE: Under normal conditions of use, this product does not present a health hazard. The following information is provided for battery electrolyte (acid) and lead for exposure that may occur during battery production or container breakage or under extreme heat conditions such as fire

ROUTES AND METHODS OF ENTRY

Inhalation
Acid mist may be generated during battery overcharging and may cause respiratory irritation. Seepage of acid from broken batteries may present inhalation exposure in a confined area.

Skin Contact
Battery electrolyte (acid) can cause severe irritation, burns and ulceration.

Skin Absorption
Skin absorption is not a significant route of entry.

Eye Contact
Battery electrolyte (acid) can cause severe irritation, burns, and cornea damage upon contact.

Ingestion
Hands contaminated by contact with internal components of a battery can cause ingestion of lead/lead compounds. Hands should be washed prior to eating, drinking, or smoking.

SIGNS AND SYMPTOMS OF OVEREXPOSURE

Acute Effects
Acute effects of overexposure to lead compounds are GI (gastrointestinal) upset, loss of appetite, diarrhea, constipation with cramping, difficulty in sleeping, and fatigue. Exposure and/or contact with battery electrolyte (acid) may lead to acute irritation of the skin, corneal damage of the eyes, and irritation of the mucous membranes of the eyes and upper respiratory system, including lungs.

Chronic Effects
Lead and its compounds may cause chronic anemia, damage to the kidneys and nervous system. Lead may also cause reproductive system damage and can affect developing fetuses in pregnant women. Battery electrolyte (acid) may lead to scarring of the cornea, chronic bronchitis, as well as erosion of tooth enamel in mouth breathers in repeated exposures.

POTENTIAL TO CAUSE CANCER

The National Toxicological Program (NTP) and The International Agency for Research on Cancer (IARC) have classified "strong inorganic acid mist containing sulfuric acid" as a Category 1 carcinogen, a substance that is carcinogenic to humans. The ACGIH has classified "strong inorganic acid mist containing sulfuric acid" as an A2 carcinogen (suspected human carcinogen). These classifications do not apply to liquid forms of sulfuric acid or sulfuric acid solutions contained within a battery. Inorganic acid mist (sulfuric acid mist) is not generated under normal use of this product. Misuse of the product, such as overcharging, may result in the generation of sulfuric acid mist.

The NTP and the IARC have classified lead as an A3 carcinogen (animal carcinogen). While the agent is carcinogenic in experimental animals at relatively high doses, the agent is unlikely to cause cancer in humans except under uncommonly high levels of exposure. For further information, see the ACGIH's pamphlet, *1996 Threshold Limit Values and Biological Exposure Indices.*

EMERGENCY AND FIRST AID PROCEDURES

Inhalation
Not expected for product under normal conditions of use. However, if acid vapor is released due to overcharging or abuse of the battery, remove exposed person to fresh air. If breathing is difficult, oxygen may be administered. If breathing has stopped, artificial respiration should be started immediately. Seek medical attention immediately.

Skin
Exposure not expected for product under normal conditions of use. However, if acid contacts skin, flush with water and mild soap. If irritation develops, seek medical attention immediately.

Eyes
Exposure not expected for product under normal conditions of use. However, if acid from broken battery case enters eyes, flush with water for at least 15 minutes. Seek medical attention immediately.

Ingestion
Not expected due to physical form of finished product. However, if internal components are ingested:
Lead/Lead compounds: Consult a physician immediately for medical attention.
Battery Electrolyte (Acid): Do not induce vomiting. Refer to a physician immediately for medical attention.

MEDICAL CONDITIONS AGGRAVATED BY EXPOSURE

Inorganic lead and its compounds can aggravate chronic forms of kidney, liver, and neurologic diseases. Contact of battery electrolyte (acid) with the skin may aggravate skin diseases such as eczema and contact dermatitis.

Fig. A.2 Cont. MSDS for All Optima Batteries (2 of 5)

OPTIMA BATTERIES	Title: Material Safety Data Sheet for All Optima Batteries	Date: 10/17/11	Rev: M	Page: 3 of 5	File Name: MSDS battery

V. Fire and Explosion Data

Flash Point (test method)	Autoignition Temperature	Flammable Limits in Air, % by Vol.
Hydrogen - 259°C	Hydrogen 580°C	Hydrogen LEL - 4.1 UEL - 74.2

Extinguishing Media
Dry chemical, foam, or CO_2

Special Fire Fighting Procedures
Use positive pressure, self-contained breathing apparatus.

Unusual Fire and Explosion Hazard
The sealed lead acid battery is not considered flammable, but it will burn if involved in a fire. A short circuit can also result in a fire. Acid mists, smoke and decomposition products may be produced. Remove all ignition sources. Cool battery(s) to prevent rupture.

VI. Reactivity Data

Stability	Conditions to Avoid
☐ Unstable ☒ Stable	Sparks and other sources of ignition may ignite hydrogen gas.

Incompatibility (materials to avoid)
Lead/lead compounds: Potassium, carbides, sulfides, peroxides, phosphorus, sulfur.
Battery electrolyte (acid): Combustible materials, strong reducing agents, most metals, carbides, organic materials, chlorates, nitrates, picrates, and fulminates.

Hazardous Decomposition Products
Lead/Lead compounds: Oxides of lead and sulfur
Battery electrolyte (acid): Hydrogen, sulfur dioxide, sulfur trioxide

Hazardous Polymerization	Conditions to Avoid
☐ May Occur ☒ Will Not Occur	High temperature. Battery electrolyte (acid) will react with water to produce heat. Can react with oxidizing or reducing agents.

VII. Control Measures

Engineering Controls
Store sealed lead acid batteries at ambient temperature. Never recharge batteries in an unventilated, enclosed space. Do not subject product to open flame or fire. Avoid conditions that could cause arcing between terminals.

Work Practices
Do not carry battery by terminals. Do not drop battery, puncture or attempt to open battery case. Avoid contact with the internal components of a battery.

PERSONAL PROTECTIVE EQUIPMENT

Respiratory Protection
None required for normal handling of finished product.

Eyes and Face
None required under for finished product under normal conditions of use. If necessary to handle broken product, chemical splash goggles are recommended.

Hands, Arms, and Body
None required for normal handling of finished product. If necessary to handle broken product, vinyl-coated, PVC, gauntlet-type gloves with rough finish are recommended..

Other Special Clothing and Equipment
Safety footwear meeting the requirements of ANSI Z 41.1 – 1991 is recommended when it in necessary to handle the finished product.

VIII. Safe Handling Precautions

Hygiene Practices
Wash hands thoroughly before eating, drinking, or smoking after handling batteries.

Protective Measures to be Taken During Non-Routine Tasks, Including Equipment Maintenance
Do not carry battery by terminals. Do not drop battery, puncture or attempt to open battery case. Do not subject product to open flame or fire and avoid situations that could cause arcing between terminals.

SPILL OR LEAK PROCEDURES

Fig. A.2 Cont. MSDS for All Optima Batteries (3 of 5)

Protective Measures to be Taken if Material is Released or Spilled

Remove combustible materials and all sources of ignition. Avoid contact with acid materials. Use soda ash, baking soda or lime to neutralize any acid that may be released.

If battery is broken, wear chemical goggles and acid-resistant gloves for handling the parts.

DO NOT RELEASE UNNEUTRALIZED ACID!

Waste Disposal Method

Battery Electrolyte (Acid): Neutralize as above for a spill, collect residue, and place in a drum or suitable container. Dispose of as a hazardous waste.

DO NOT FLUSH LEAD-CONTAMINATED ACID INTO SEWER.

Send spent or broken batteries to a lead recycling facility or smelter that follows applicable Federal, State and Local regulations for routine disposition of spent or damaged batteries. The distributor / user is responsible for assuring that these "spent" or "damaged" batteries are disposed of in an environmentally sound way in accordance with all regulations. OPTIMA batteries are 100% recyclable by any licensed reclamation operation..

SUPPLEMENTAL INFORMATION

Proposition 65 Warning (California) Proposition 65 Warning: The state of California has listed lead as a material known to cause cancer or cause reproductive harm (July 9, 2004 California List of Chemicals Known to Cause Cancer or Reproductive Toxicity) Battery posts, terminals and related accessories contain lead and lead compounds. Batteries also contain other chemicals known to the State of California to cause cancer. Wash hands after handling.

TSCA Registry: Ingredients listed in the TSCA Registry are lead, lead compounds, and sulfuric acid.

Transportation: Sealed Lead Acid Battery is not a DOT Hazardous Material.

Other: Per DOT, IATA, ICAO and IMDG rules and regulations, these batteries are exempt from "UN2800" classification as a result of successful completion of the following tests:

1) **Vibration Tests**
2) **Pressure Differential Tests**
3) **Case Rupturing Tests (no free liquids)**

US MILITARY NATIONAL STOCK NUMBER (NSN)

Model Number	P/N	NSN
34/78	8004-003	6140-01-374-2243, 6140-01-457-4339
34	8002-002	6140-01-378-8232, 6140-01-493-1962
34R	8003-151	6140-01-475-9357
34VX	8008-158	6140-01-534-6466
25	8025-160	
35	8020-164	
75/25	8022-091	6140-01-475-9361
78	8078-109	
850/6 -1050 SLI	8010-044	6140-01-475-9414
DS46B24R	8171-767	
850/6 - 950 (DC)		
D51	8071-167	6140-01-523-6288
D51R	8073-167	6140-01-529-7226
D35	8040-218	
D75/25	8042-218	

Fig. A.2 Cont. MSDS for All Optima Batteries (4 of 5)

OPTIMA BATTERIES	Title: Material Safety Data Sheet for All Optima Batteries	Date: 10/17/11	Rev: M	Page: 5 of 5	File Name: MSDS battery

D34	8012-021	6140-01-450-0141
D34/78	8014-045	6140-01-441-4272
D27F	8037-127	
D31T	8050-160	6140-01-457-5469
D31A	8051-160	6140-01-502-4973
34M	8006-006	6140-01-441-4280, 6140-01-526-2605
D34M	8016-103	6140-01-475-9355
D27M	8027-127	6140-01-589-0622
D31M	8052-161	6140-01-502-4405

Disclaimer: This information has been compiled from sources considered to be dependable and is, to the best of our knowledge and belief, accurate and reliable as of the date compiled. However, no representation, warranty (either express or implied) or guarantee is made to the accuracy, reliability or completeness of the information contained herein. This information relates to the specific material designated and may not be valid for such material used in combination with any other materials or in any process. It is the user's responsibility to satisfy himself as to the suitability and completeness of this information for his own particular use. We do not accept liability for any loss or damage that may occur, whether direct, indirect, incidental or consequential, from use of this information.

Fig. A.2 Cont. MSDS for All Optima Batteries (5 of 5)

TENERGY

Tenergy Corporation
436 Kato Terrace
Fremont, CA 94539
Tel: 510.687.0388 Fax: 510.687.0328
www.Tenergy.com email: sales@tenergy.com

Section I - Product Identification and company/undertaking

Product Name	: Nickel Metal Hydride Battery
Trade Name	: HFR
Chemical System	: Nickel/Metal Hydride
Nominal Voltage	: 1.2V
Designated for Recharge	: X Yes __ No
Telephone No.	: 510-687-0388
Fax	: 510-687-0328
Company and Address	: 436 Kato Terrace, Fremont, CA94539
Effective Date	: Jan.01,2015

Section II - Hazardous Ingredients

IMPORTANT NOTE: The product is a manufactured article as described in 29 CFR 1910.1200. The battery cell is contained in a hermetically-sealed case, designed to withstand temperatures and pressures encountered during normal use. As a result, during normal use, hazardous materials are fully contained inside the battery cell. The battery cell should not be opened or exposed to heat because exposure to the following ingredients contained within could be harmful under some circumstances. The following information is provided for the user's information only.

Chemical Name	CAS No.	OSHA PEL (mg/m^3)	ACGIH TLV (mg/m^3)
Nickel (powder)	7440-02-0	1TWA	1 TWA
Nickel hydroxide	12054-48-7	1 TWA	1 TWA
Cobalt	7440-48-4	0.1 TWA	Dust & Fume 0.005
Manganese	7439-96-5	Fume: 5 Ceiling Limit	Dust: 5 Fume: 1
Lanthanum	7439-91-0	NA	NA
Cerium	7440-45-1	NA	NA
Neodymium	7440-00-8	NA	NA
Potassium hydroxide	1310-58-3	NA	2 Ceiling Limit
Sodium hydroxide	1310-73-2	2 TWA	2 Ceiling Limit
Lithium hydroxide	1310-65-2	NA	NA

The information and recommendations set forth are made in good faith and believed to be accurate as of the date of preparation. **Tenergy Corporation**, makes no warranty, expressed or implied, with respect to this information and disclaims all liabilities from reliance on it.

Notes: 1. Concentrations vary depending on the state of charge or discharge.
2. TWA is the time weighted average concentration over an 8-hour period.

Section III — Physical Data for Battery

Melting point (°F) NA	Boiling point (°F) NA	% Volatile by Volume NA
Vapor Pressure (mm Hg) NA	Evaporation Rate Vapor	Density (Air = 1) NA
Specific Gravity (H_2O) NA	Solubility in Water NA	Appearance and Odor No Odor

Specifications and data are subject to change without notice. Contact Tenergy for latest information.

Page 2 of 5

Fig. A.3 Tenergy Nickel Metal Hydride Battery MSDS (1 of 4)

TENERGY

Tenergy Corporation
436 Kato Terrace
Fremont, CA 94539
Tel: 510.687.0388 Fax: 510.687.0328
www.Tenergy.com email: sales@tenergy.com

Section IV - Fire and Explosion Hazard Data

Flash Point: NA Lower Explosive Limit: NA Upper Explosive Limit: NA
Extinguishing Media: Any class of extinguishing medium may be used on the batteries or their packing material.
Special Fire Fighting Procedures: Exposure to temperatures of above 212°F can cause venting of the liquid electrolyte.
Internal shorting could also cause venting of the electrolyte. There is potential for exposure to iron, nickel, cobalt, rare earth metals (cerium, lanthanum neodymium, and praseodymium), manganese, and aluminum fumes during fire; use self-contained breathing apparatus.

Section V – First Aid Measures

If electrolyte leakage occurs and makes contact with skin, wash with plenty of water immediately.
If electrolyte comes into contact with eyes, wash with copious amounts of water fifteen(15)minutes, and contact a physician.

Section VI - Health Hazard Data

Threshold Limit Values: See Section II
Effects of a Single (Acute) Overexposure:
Inhalation: During normal use inhalation is an unlikely route of exposure due to containment of hazardous materials within the battery case. However, should the batteries be exposed to extreme heat or pressures causing a breach in the battery cell case, exposure to the constituents may occur. Inhalation of cobalt dusts may result in pulmonary conditions.
Ingestion: If the battery case is breached in the digestive tract, the electrolyte may cause localized burns.
Skin Absorption: No evidence of adverse effects from available data.
Skin Contact: Exposure to the electrolyte contained inside the battery may result in chemical burns. Exposure to nickel may cause dermatitis in some sensitive individuals.
Eye Contact: Exposure to the electrolyte contained inside the battery may result in severe irritation and chemical burns.
The information and recommendations set forth are made in good faith and believed to be accurate as of the date of preparation. Tenergy Corporation. makes no warranty, expressed or implied, with respect to this information and disclaims all liabilities from reliance on it.

Carcinogenicity:
Nickel has been identified by the National Toxicology Program (NTP) as reasonably anticipated to be a carcinogen. Cobalt has been identified by IARC as a 2B carcinogen.
Other Effects of Repeated (Chronic) Exposure:

Chronic overexposure to nickel may result in cancer; dermal contact may result in dermatitis in sensitive individuals.

Medical Conditions Aggravated by Overexposure:
A knowledge of the available toxicology information and of the physical and chemical properties of the material suggests that overexposure in unlikely to aggravate existing medical conditions.

Emergency and First Aid Procedures:

Swallowing: Do not induce vomiting. Seek medical attention immediately.
Skin: If the internal cell materials of an opened battery cell come into contact with the skin, immediately flush with water for at least 15 minutes.

Specifications and data are subject to change without notice. Contact Tenergy for latest information.

Page 3 of 5

Fig. A.3 Cont. Tenergy Nickel Metal Hydride Battery MSDS (2 of 4)

Inhalation: If potential for exposure to fumes or dusts occurs, remove immediately to fresh air and seek medical attention.

Eyes: If the contents from an opened battery come into contact with the eyes, immediately flush eyes with water continuously for at least 15 minutes. Seek medical attention.

Section VII - Reactivity Data

The batteries are stable under normal operating conditions.

Hazardous polymerization will not occur.

Hazardous decomposition products: oxides of nickel, cobalt, manganese, lanthanum, and cerium.

Conditions to avoid: heat, open flames, sparks, and moisture.

Potential incompatibilities (i.e., materials to avoid contact with): The battery cells are encased in a non-reactive container; however, if the container is breached, avoid contact of internal battery components with acids, aldehydes, and carbamate compounds.

Section VIII - Spill and Leak Procedures

Spill and leaks are unlikely because cells are contained in an hermetically-sealed case. If the battery case is breached, don protective clothing that is impervious to caustic materials and absorb or pack spill residues in inert material. Dispose in accordance with applicable state and federal regulations.

Section VIX - Safe Handling and Use (Personal Protective Equipment)

Ventilation Requirements: Not required under normal use.

The information and recommendations set forth are made in good faith and believed to be accurate as of the date of preparation. Tenergy Corporation. makes no warranty, expressed or implied, with respect to this information and disclaims all liabilities from reliance on it.

Respiratory Protection: Not required under normal use.
Eye Protection: Not required under normal use.
Gloves: Not required under normal use.

Section X- Precautions for Safe Handling and Use

Storage: Store in a cool place, but prevent condensation on cell or battery terminals. Elevated temperatures may result in reduced battery life. Optimum storage temperatures are between -31°F and 95°F.

Mechanical Containment: If there are special encapsulations or sealing requirements, consult your Tenergy Corporation. representative about possible cell hazard precautions or limitations.
Handling: Accidental short circuit will bring high temperature elevation to the battery as well as shorten the battery life. Be sure to avoid prolonged short circuit since the heat can burn attendant skin and even rupture of the battery cell case.
Batteries packaged in bulk containers should not be shaken. Metal covered tables or belts used for assembly of batteries into devices can be the source of short circuits; apply insulating material to assembly work surface.
If soldering or welding to the case of the battery is required, consult your Tenergy Corporation. representative for proper precautions to prevent seal damage or external short circuit.

Specifications and data are subject to change without notice. Contact Tenergy for latest information.

Fig. A.3 Cont. Tenergy Nickel Metal Hydride Battery MSDS (3 of 4)

Tenergy Corporation
436 Kato Terrace
Fremont, CA 94539
Tel: 510.687.0388 Fax: 510.687.0328
www.Tenergy.com email: sales@tenergy.com

Charging: This battery is designed for recharging. A loss of voltage and capacity of batteries due to self-discharge during prolonged storage is unavoidable. Charge battery before use. Observe the specified charge rate since higher rates can cause a rise in internal gas pressure which may result in damaging heat generation or cell rupture and/or venting.
Labeling: If normal label warnings are not visible, it is important to provide a device label stating: CAUTION: Do not dispose in fire, mix with other battery types, charge above specified rate, connect improperly, or short circuit, which may result in overheating, explosion or leakage of cell contents.

Section XI – Measures for fire extinction

In case of fire, it is permissible to use any of extinguishing medium on these batteries or their packing material.
Cool exterior of batteries if exposed to fire to prevent rupture
Fire fighters should wear self-contained breathing apparatus

Section XII – Ecological information

N.A

Section XIII - Recycling and Disposal

Tenergy encourages battery recycling. Our Nickel Metal Hydride batteries are not defined by the federal government as hazardous waste and are safe for disposal in the normal municipal waste stream. ,

DO NOT INCINERATE or subject battery cells to temperatures in excess of 212°F. Such treatment can cause cell rupture.

Section XIV – Transportation

Tenergy sealed Nickel Metal Hydride batteries are considered to be "dry cell" batteries and are not subject to dangerous goods regulation for the purpose of transportation by the U.S. Department of Transportation (DOT), the International Civil Aviation Organization (ICAO), the International Air Transport Association (IATA) or the International Maritime Dangerous Goods regulations (IMDG). More information concerning shipping, testing, marking and packaging can be obtained from Labelmaster at http://www.labelmaster.com. IATA DANGEROUS GOODS REGULATIONS A-123 EDITION 56th 2016 & IMDG requires that batteries being transported must be protected from short-circuiting and protected from movement that could lead to short-circuiting.

The information and recommendations set forth are made in good faith and believed to be accurate as of the date of preparation. Tenergy Corporation. makes no warranty, expressed or implied, with respect to this information and disclaims all liabilities from reliance on it.

Section XV – Regulatory Information

Special requirement be according to the local regulatory

Section XVI – Other Information

The data in this Material Safety Data Sheet relates only to the specific material designated herein

Fig. A.3 Cont. Tenergy Nickel Metal Hydride Battery MSDS (4 of 4)

Powered by CSB BATTERY®

EVH 12240 ► 12V 24Ah

EVH 12240 (2nd generation) is designed specially with increase cycle performance and reliability from previous generations in electric vehicles application. It has high cycling life, high efficiency and long service life.

► Specification

Cells Per Unit	6
Voltage Per Unit	12
Capacity	24Ah @ 20hr-rate to 1.75V per cell @25℃(77℉)
Weight	Approx. 7.55 kg (16.64 lbs)
Maximum Discharge Current	320A(5sec)
Internal Resistance	Approx. 9 mΩ
Operating Temperature Range	Discharge: -15℃~50℃(5℉~122℉) Charge: -15℃~40℃(5℉~104℉) Storage: -15℃~40℃(5℉~104℉)
Nominal Operating Temperature Range	25℃±3℃(77℉±5℉)
Float Charging Voltage	13.5 to 13.8 VDC/unit Average at 25℃(77℉)
Recommended Maximum Charging Current Limit	7.2A
Equalization and Cycle Service	14.4 to 15.0 VDC/unit Average at 25℃(77℉)
Self Discharge	CSB Batteries can be stored for more than 6 months at 25℃(77℉). Please charge batteries before using. For higher temperatures the time interval will be shorter.
Terminal	I1-Thread lead alloy recessed terminal to accept M5 bolt
Container Material	ABS(UL 94-HB) & Flammability resistance of (UL 94-V0) can be available upon request.

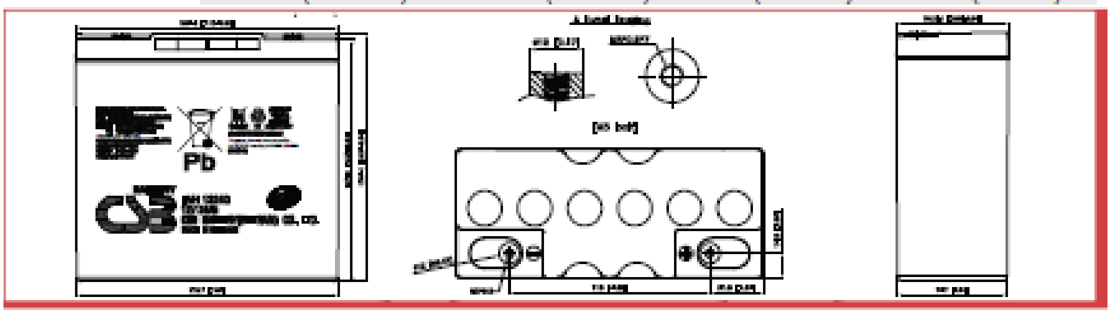
MH14533

CSB-manufactured VRLA (Absorbent Glass Mat type) batteries are UL-recognized components under UL1989.

CSB is also certified by ISO 9001 and ISO 14001.

► Dimensions : Unit: mm (inch)

Overall Height (H)	Container height (h)	Length (L)	Width (W)
170±1 (6.69 ±0.04)	170±1 (6.69 ±0.04)	181±2 (7.13±0.08)	76.2±1 (3.0±0.04)



Constant Current Discharge Characteristics Unit:A (25℃,77℉)

F.V/Time	30MIN	60MIN	90MIN	2HR	3HR	4HR	5HR	8HR	10HR	20HR
1.60V	29.9	17.7	13.0	10.3	7.50	5.84	4.84	3.16	2.57	1.31
1.67V	29.6	17.5	12.9	10.2	7.44	5.83	4.78	3.15	2.56	1.30
1.70V	29.4	17.4	12.8	10.1	7.41	5.82	4.77	3.14	2.55	1.29
1.75V	29.0	17.2	12.7	10.0	7.32	5.74	4.73	3.09	2.52	1.28
1.80V	28.4	17.0	12.5	9.98	7.16	5.65	4.64	3.06	2.49	1.27
1.85V	27.0	16.2	11.9	9.56	6.85	5.44	4.47	2.91	2.34	1.17

Constant Power Discharge Characteristics Unit:W (25℃,77℉)

F.V/Time	30MIN	60MIN	90MIN	2HR	3HR	4HR	5HR	8HR	10HR	20HR
1.60V	346	208	154	123	88.9	69.9	58.6	38.3	31.4	16.2
1.67V	343	207	153	122	88.7	69.8	57.6	38.1	31.2	16.1
1.70V	340	206	152	121	87.9	69.1	57.4	38.0	31.0	16.0
1.75V	338	205	151	120	87.3	68.4	56.9	37.8	30.7	15.9
1.80V	331	199	147	118	85.1	67.1	55.9	37.2	30.3	15.7
1.85V	313	193	142	115	82.9	65.3	54.4	36.1	29.6	15.4

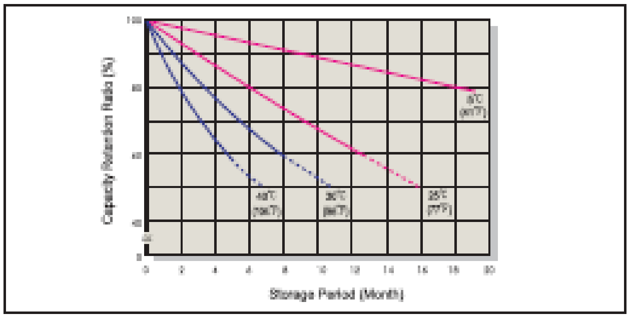
Ratings presented herein are subject to revision without notice. Please refer to www.csb-battery.com to confirm the latest version.

RA1410

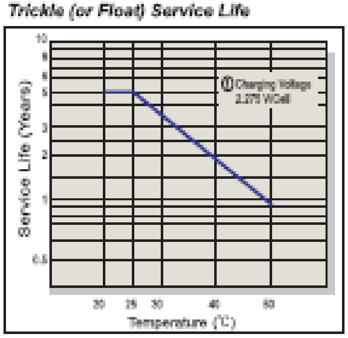
Fig. A.4 CSB EVH 12240 Specification Sheet (1 of 2)

EVH12240 12V 24Ah

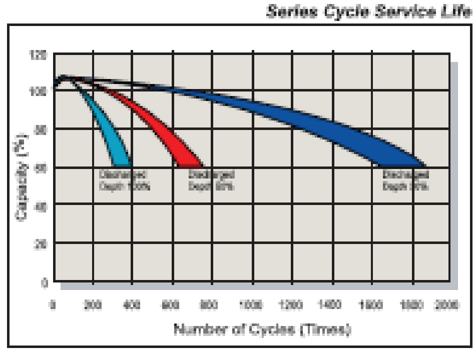
Capacity Retention Characteristic



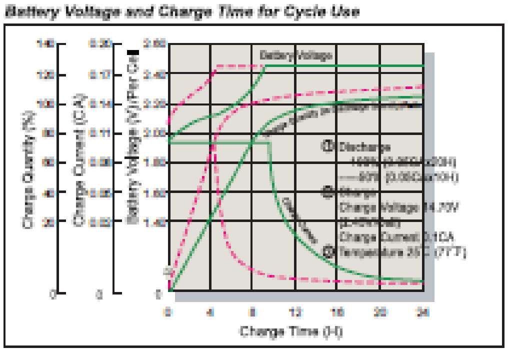
Trickle (or Float) Service Life



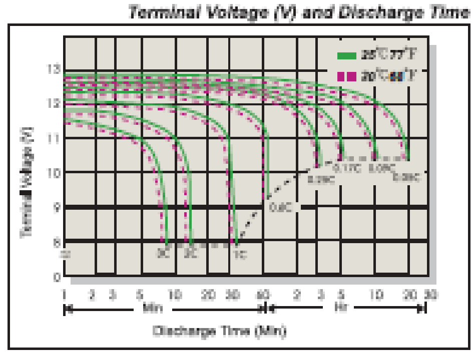
Series Cycle Service Life



Battery Voltage and Charge Time for Cycle Use



Terminal Voltage (V) and Discharge Time



Charging Procedures

Application	Charge Voltage(V/Cell)			Max.Charge Current
	Temperature	Set Point	Allowable Range	
Cycle Use	25℃(77℉)	2.45	2.40~2.50	0.3C
Standby	25℃(77℉)	2.275	2.25~2.30	

Discharge Current VS. Discharge Voltage

Final Discharge Voltage V/Cell	1.75	1.70	1.60	1.30
Discharge Current(A)	0.2C>(A)	0.2C<(A)<0.5C	0.5C<(A)<1.0C	(A)>1.0C

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Fig. A.4 Cont. CSB EVH 12240 Specification Sheet (2 of 2)

Powered by
BATTERY®
CSB

GP 1272 ▶ 12V 7.2Ah

GP 1272 is a general purpose battery up to 5 years in standby service or more than 260 cycles at 100% discharge in cycle service. As with all CSB batteries, all are rechargeable, highly efficient, leak proof and maintenance free.

▶ **Specification**

Cells Per Unit	6
Voltage Per Unit	12
Capacity	7.2Ah @ 20hr-rate to 1.75V per cell @25°C (77°F)
Weight	Approx. 2.4 kg(5.29 lbs)
Maximum Discharge Current	100A/130A(5sec)
Internal Resistance	Approx. 23 mΩ
Operating Temperature Range	Discharge: -15°C~50°C (5°F~122°F) Charge: -15°C~40°C (5°F~104°F) Storage: -15°C~40°C (5°F~104°F)
Nominal Operating Temperature Range	25°C±3°C (77°F±5°F)
Float Charging Voltage	13.5 to 13.8 VDC/unit Average at 25°C (77°F)
Recommended Maximum Charging Current Limit	2.16A
Equalization and Cycle Service	14.4 to 15.0 VDC/unit Average at 25°C (77°F)
Self Discharge	CSB Batteries can be stored for more than 6 months at 25°C (77°F). Please charge batteries before using. For higher temperatures the time interval will be shorter.
Terminal	F1/F2-Faston Tab187/250
Container Material	ABS(UL 94-HB) & Flammability resistance of (UL 94-V0) can be available upon request.

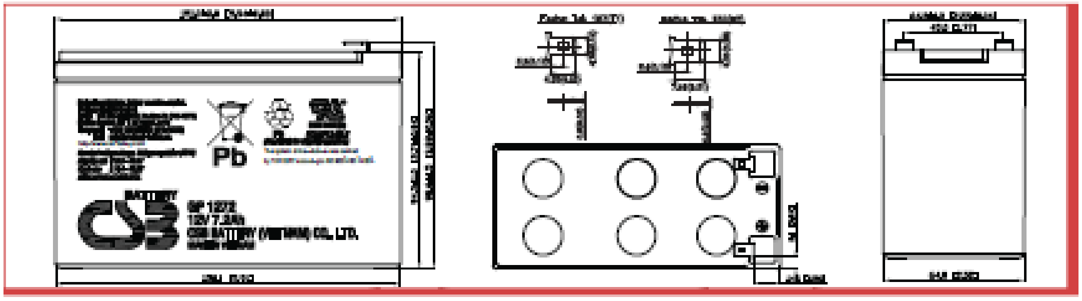
MH14533

CSB-manufactured VRLA (Absorbent Glass Mat type) batteries are UL-recognized components under UL1989.

CSB is also certified by ISO 9001 and ISO 14001.

▶ **Dimensions :**
Unit: mm (inch)

Overall Height (H)	Container height (h)	Length (L)	Width (W)
98.6±1.5 (3.88±0.06)	94.3±1 (3.71±0.04)	151±2 (5.94±0.08)	64.8±1 (2.55±0.04)



Constant Current Discharge Characteristics Unit:A (25°C,77°F)

F.V/Time	5MIN	10MIN	15MIN	30MIN	60MIN	90MIN	2HR	3HR	5HR	8HR	10HR	20HR
1.60V	35.6	22.0	16.5	9.61	5.51	3.92	3.08	2.13	1.34	0.92	0.77	0.45
1.67V	33.1	21.0	15.9	9.36	5.41	3.85	3.02	2.08	1.31	0.90	0.76	0.44
1.70V	31.9	20.5	15.6	9.24	5.37	3.82	3.00	2.06	1.30	0.89	0.75	0.43
1.75V	29.6	19.6	15.1	9.03	5.30	3.77	2.96	2.02	1.27	0.88	0.74	0.42
1.80V	27.2	18.6	14.4	8.77	5.23	3.71	2.91	1.98	1.25	0.87	0.73	0.42
1.85V	24.5	17.4	13.7	8.44	5.14	3.66	2.87	1.95	1.22	0.86	0.71	0.40

Constant Power Discharge Characteristics Unit:W (25°C,77°F)

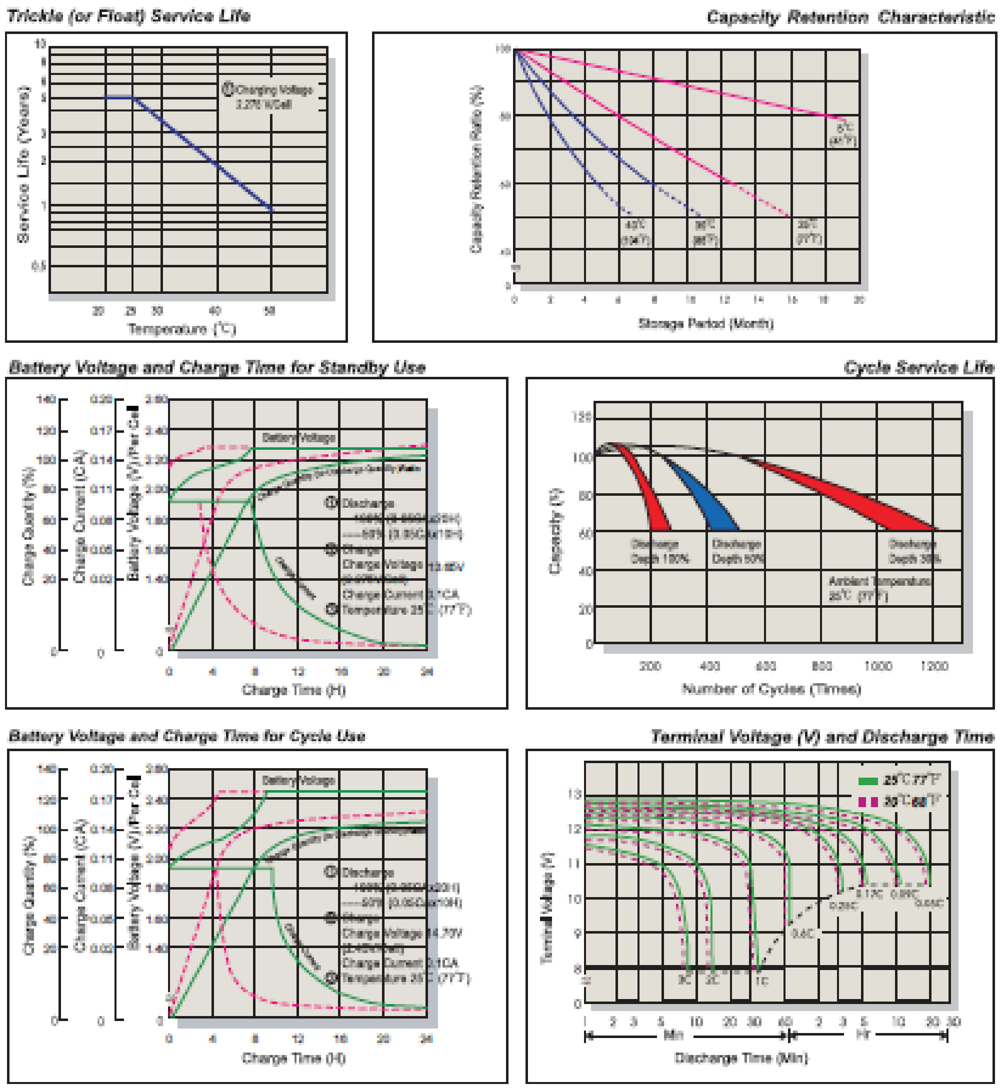
F.V/Time	5MIN	10MIN	15MIN	30MIN	60MIN	90MIN	2HR	3HR	5HR	8HR	10HR	20HR
1.60V	360	245	183	108	64.4	47.1	37.7	26.6	17.3	11.8	9.80	5.37
1.67V	340	235	177	106	63.6	46.4	37.1	26.3	17.0	11.6	9.68	5.27
1.70V	331	231	174	105	63.1	46.1	36.9	26.2	16.9	11.5	9.54	5.23
1.75V	313	222	170	103	62.4	45.5	36.4	25.9	16.7	11.4	9.47	5.15
1.80V	295	213	165	101	61.7	45.0	35.9	25.6	16.5	11.3	9.40	5.07
1.85V	276	202	158	99	60.8	44.3	35.4	25.2	16.3	11.2	9.29	4.99

Ratings presented herein are subject to revision without notice. Please refer to www.csb-battery.com to confirm the latest version.

RA1406

Fig. A.5 CSB GP 1272 12V 7.2Ah Specification Sheet (1 of 2)

GP1272 12V 7.2Ah



Charging Procedures

Application	Charge Voltage(V/Cell)			Max.Charge Current
	Temperature	Set Point	Allowable Range	
Cycle Use	25℃(77℉)	2.45	2.40~2.50	0.3C
Standby	25℃(77℉)	2.275	2.25~2.30	

Discharge Current VS. Discharge Voltage

Final Discharge Voltage V/Cell	1.75	1.70	1.60	1.30
Discharge Current(A)	0.2C>(A)	0.2C<(A)<0.5C	0.5C<(A)<1.0C	(A)>1.0C

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mail : she@csb-battery.com.cn

Fig. A.5 Cont. CSB GP 1272 12V 7.2Ah Specification Sheet (1 of 2)

Battery Model: 75/25
Part Number: 8022-091
Nominal Voltage: 12 volts
NSN: 6140 01 475 9361
Description: High power, sealed lead acid, engine starting battery

Physical Characteristics:

Plate Design:	High purity lead-tin alloy. Wound cell configuration utilizing proprietary *SPIRALCELL*® technology.
Electrolyte:	Sulfuric acid, H_2SO_4
Case:	Polypropylene
Color:	Case: Dark Gray Cover: "OPTIMA" Red
Group Size:	BCI: 75/25

	Standard	Metric
Length:	9.340"	237.24 mm
Width:	6.772"	172.01 mm
Height:	7.697"	195.50 mm (Height at the top of terminals)
Weight:	33.1 lb	15.0 kg

Terminal Configuration: SAE / BCI automotive and GM style side terminal (3/8"-16UNC-2B threaded nut).

Performance Data:

Open Circuit Voltage (Fully charged):	12.8 volts
Internal Resistance (Fully charged):	.0030 ohms
Capacity:	44 Ah (C/20)
Reserve Capacity:	BCI: 90 minutes (25 amp discharge, 80°F (26.7°C), to 10.5 volts cut-off)

Power:

CCA (BCI 0°F):	720 amps
MCA (BCI 32°F):	910 amps

Recommended Charging:

The following charging methods are recommended to ensure a long battery life: (Always use a voltage regulated charger with voltage limits set as described below.)

Model: 75/25
These batteries are designed for engine starting applications. They are not recommended or warranted for use in deep cycle applications.

Fig. A.6 Optima REDTOP 75/25 Specification Sheet (1 of 2)

Recommended Charging Information:

Alternator:	13.3 to 15.0 volts
Battery Charger (Constant Voltage):	13.8 to 15.0 volts; 10 amps maximum; 6-12 hours approximate
Float Charge:	13.2 to 13.8 volts; 1 amp maximum; (indefinite time at lower voltages)
Rapid Recharge: (Constant voltage charger)	Maximum voltage 15.6 volts. No current limit as long as battery temperature remains below 125°F (51.7°C). Charge until current drops below 1 amp. **All limits must be strictly adhered to.**

Recharge Time: (example assuming 100% discharge – 10.5 volts)

Current	Approximate time to 90% charge
100 amps	35 minutes
50 amps	75 minutes
25 amps	140 minutes

Recharge time will vary according to temperature and charger characteristics. When using Constant Voltage chargers, amperage will taper down as the battery becomes recharged. When amperage drops below 1 amp, the battery will be close to a full state of charge.

(All charge recommendations assume an average room temperature of 77°F (25°C).

Always wear safety glasses when working with batteries.

Always use a voltage regulated battery charger with limits set to the above ratings. Overcharging can cause the safety valves to open and battery gases to escape, causing premature end of life. These gases are flammable! You cannot replace water in sealed batteries that have been overcharged. Any battery that becomes very hot while charging should be disconnected immediately.

Not fully charging a battery can result in poor performance and a reduction in capacity.

Shipping and Transportation Information:

OPTIMA batteries can be shipped by AIR. The battery is nonspillable and is tested according to ICAO Technical Instructions DOC. 9284-AN/905 to meet the requirements of Packing Instructions No. 806 and is classified as non-regulated by IATA Special Provision A-48 and A-67 for UN2800. Terminals must be protected from short circuit.

BCI = Battery Council International

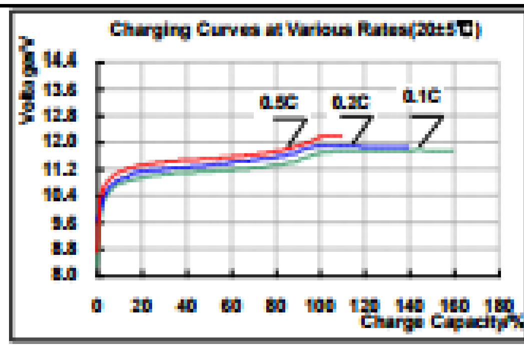
OPTIMA Batteries
Product Specifications: Model 75/25
December 2008

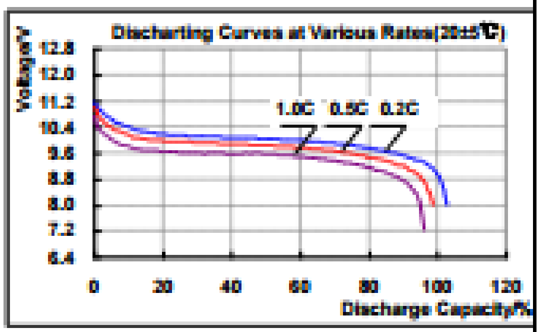
Fig. A.6 Cont. Optima REDTOP 75/25 Specification Sheet (2 of 2)

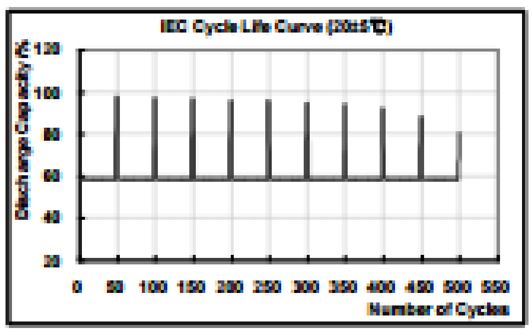
Tenergy Corporation
436 Kato Terrace
Fremont, CA 94539
Tel: 510.687.0388 Fax: 510.687.0328
www.TenergyBattery.com email: sales@tenergybattery.com

Data Sheet

Battery Model： 11401-01		
Nominal Voltage（V）		9.6
Capacity* （mAh）	Nominal	2000
	Minimum	2000
Charge**	Standard	200mA×16hours
	Quick	400mA×7hours
	Rapid	1000mA×2.4hours -ΔV=5mV/cell
Weight		Approx.220g
Cycle Life		≥500cycles (IEC61951-2)
Open Circuit Voltage		≥10.0V
End Voltage		1.0V/cell
Charge(Capacity)retention		≥60%
Internal Resistance		≤370mΩ
Temperature recommended （℃）	Standard charge	0~40
	Quick Charge	10~40
	Rapid Charge	10~30
	Discharge	0~50
	storage	-20~30







Note： *:The Cycle Life Curve describes battery unit. Please discharge to the 1.0V/cell end voltage with 400mA before charging the battery unit.

The data sheet is for reference only and should not be used as a basis for product described guarantee or warranty.

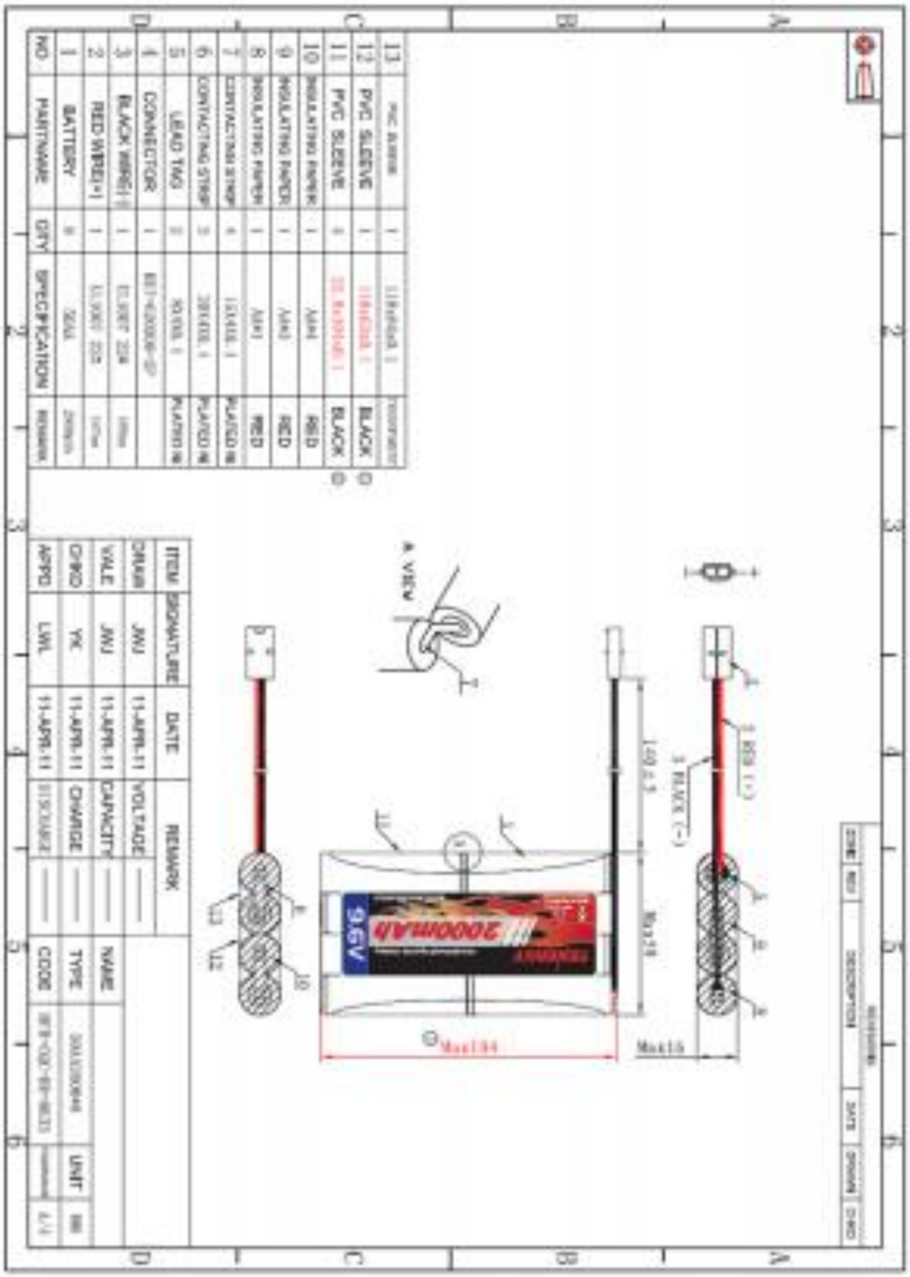
Specifications and data are subject to change without notice. Contact Tenergy for latest information.

Page 7 of 8

Fig A.7 Tenergy 9.6V Battery Data Sheet (1 of 2)

TENERGY

Tenergy Corporation
436 Kato Terrace
Fremont, CA 94539
Tel: 510.687.0388 Fax: 510.687.0328
www.TenergyBattery.com email: sales@tenergybattery.com



Specifications and data are subject to change without notice. Contact Tenergy for latest information.

Page 8 of 8

Fig. A.7 Cont. Tenergy 9.6V Battery Data Sheet (2 of 2)

Appendix B: Flotation Calculations

Solar Splash 2015 Rule 7.14.2 Buoyancy of Craft - *Sufficient flotation must be provided on board so that the craft cannot sink, even when filled with water. A 20% safety factor must be included in the calculations. Verification calculations must be included in the Technical Report. Failure to do so will result in a 5-point penalty. Revised calculations must be presented at Inspection if significant changes have been made since submission of the Technical Report.*
Per the stated rule, our team has performed the following calculations, submitted below for official review.

Density water (lbf/ft^3) =	62.4
Density styrofoam (lbf/ft^3) =	56.56

Sprint Mode

Components	Weight (lb)	Volume (ft^3)	Buoyant Force
Batteries	100	0.500	31.20
Gears & Chain	5	0.010	0.62
Gear/Motor Mounting Plate	10	0.070	4.37
auxilliary battery	5	0.035	2.18
boat hull	98	3.15	196.56
ME909 motor (x2)	48	1.11	69.26
Curtis Motor Controller (x2)	12	0.063	3.93
Drive System	6	0.012	0.76
Steering System	12	0.04	2.50
Total	296	4.99	311.4
Total + 20% Safety Factor	355.2		
Amount of flotation needed =		**0.8**	**cubic feet**

Endurance Mode

Components	Weight (lbf)	Volume (ft^3)	Buoyant Force
solar panels	66	0.835	52.104
PPTs	10	0.053	3.3072
Total	372	5.878	366.8
Total + 20% Safety Factor	446.4		
Amount of flotation needed =		**1.4**	**cubic feet**

The buoyancy calculation for the batteries is given by either of the following calculations:

<u>Buoyant Force on the Batteries</u>: 31 lbs.

Utilizing six (6) of the CSB EVH 12240, each battery weighs 16.64 lbs. and has a nominal volume of 0.083 ft^3 (see Fig. A.1. in Appendix A – Battery Documentation). The following calculation for the buoyancy force on the batteries is given by:

$$0.5\ ft^3 \times 62.4\ \frac{lb.}{ft^3} = 31.2\ lbs.$$

<u>Buoyant Force on the Batteries</u>: 52.6 lbs.

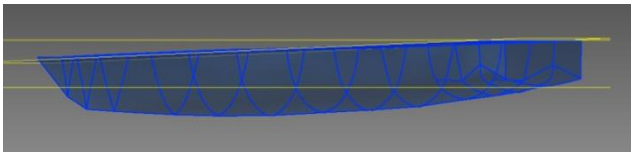
Utilizing three (3) of the Optima Red Top Model 75/35, each battery weighs 33.1 lbs. and has a nominal volume of 0.28 ft^3 (see Fig. A.1. in Appendix A – Battery Documentation). The following calculation for the buoyancy force on the batteries is given by

$$0.8\ ft^3 \times 62.4\ \frac{lb.}{ft^3} = 52.6\ lbs.$$

The following calculation for the buoyancy force on the hull is given through the next series of calculations. In summation, the **Buoyant Force on the Hull**: **196.6 lbs.**

$$3.15\ ft^3\ \times 62.4\ \frac{lb.}{ft^3} = 196.56\ lbs.$$

Physical Properties for Inventor boat - solid model



General Properties:

Material:	{Water}
Density:	0.998 g/cm^3
Mass:	2346.815 lb_{mass} (Relative Error = 0.000000%)
Area:	14952.495 in^2 (Relative Error = 0.000004%)
Volume:	65070.225 in^3 (Relative Error = 0.000000%)

Center of Gravity:

X:	-0.000 in (Relative Error = 0.000000%)
Y:	39.133 in (Relative Error = 0.000000%)
Z:	-115.722 in (Relative Error = 0.000000%)

Calculating for the Cedar material surface area: <u>Cedar Surface Area = 69.2 ft^2</u>

Area from the Inventor Model: *14952.495 in^2*

Approximate Area for Calculation: *14,953 in^2*

Top Surface Area Calculated from Inventor Model: *5,046.797 in^2*

Approximate Area for Calculation: *5,047 in^2*

$$14{,}953\ in^2 - 5{,}047\ in^2 (neglect\ top\ surface\ area\ of\ the\ model) = 9{,}906\ in^2$$

$$9{,}906\ in^2 \times \frac{1\ ft^2}{144\ in^2} = 68.8\ ft^2$$

Adding the thickness of cedar, measured at 0.25 in.

Boat length measured 17.5 ft.

$$68.8\ ft^2 + \left(0.25\ in.\ \times \frac{1\ ft}{12\ in.} \times 17.5\ ft\right) = 69.2\ ft^2$$

Calculating for the Cedar material volume of the Hull: <u>Volume of Cedar = 1.43 ft^3</u>

Measured thickness of cedar: *0.25 in*

$$9{,}906\ in^2 \times 0.25\ in\ = 2{,}476.5\ in^3 \times \frac{1\ ft^3}{1728\ in^3} = 1.43\ \ ft^3$$

Calculating for the Weight of the Cedar material: <u>Weight of the Cedar = 33 lbs.</u>

Density of Cedar: 23 lb./ft^3 *value given through Reference [10]*

$$1.43\ ft^3 \times 23\ \frac{lb.}{ft^3} = 32.9\ lbs.$$

Calculating for the Epoxy material Volume: <u>Volume Epoxy = 0.72 ft^3</u>

Approximate thickness of epoxy coat: 0.125 in

$$9{,}906\ in^2 \times 0.125\ = 1238.25\ in^3$$

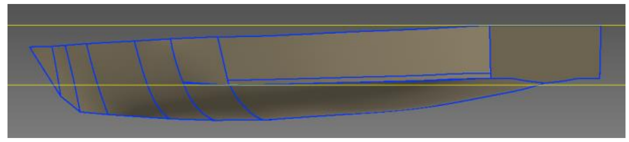
$$1238.25\ in^3 \times \frac{1\ ft^3}{1728\ in^3} = 0.72\ ft^3$$

Calculating for the Weight of the Epoxy material: <u>Weight of the Epoxy = 53 lbs.</u>

Density of Epoxy = 73.63 lb./ft^3 ****value given through Reference [11]*

$$0.72\ ft^3 \times 73.63\ \frac{lb.}{ft^3} = 53\ lbs.$$

Hull Weight before modification: 86 lbs.



Physical Properties for Inventor boat mod - solid model

General Properties:

Material:	{Water}
Density:	0.998 g/cm^3
Mass:	2409.495 lb_{mass} (Relative Error = 0.538063%)
Area:	15333.782 in^2 (Relative Error = 0.453298%)
Volume:	66808.170 in^3 (Relative Error = 0.538063%)

Center of Gravity:

X:	-0.000 in (Relative Error = 0.538063%)
Y:	39.097 in (Relative Error = 0.538063%)
Z:	-116.860 in (Relative Error = 0.538063%)

Calculating for the Hull Modification Volume: Volume of the Modification = 1 ft^3

Volume from the (Displacement Hull) Inventor Model: *65070.225 in^3*

Approximate Volume for Calculation: *65,070.23 in^3*

Volume from the (Modified Hull) Inventor Model: *66808.170 in^3*

Approximate Volume for Calculation: *66808.2 in^3*

$$66{,}808.2\ in^3 - 65{,}070.23\ in^3 = 1{,}737.97\ in^3$$

Calculating for the Composite material of the modification:

Calculating for the Cedar material volume: Volume of Cedar = 0.22 ft^3

Measurements taken from the modification: Volume of Cedar = 380 in^3

$$380\ in^3 \times \frac{1\ ft^3}{1728\ in^3} = 0.22\ ft^3$$

Composite material remaining volume: Volume = 0.78 ft^3

Calculating for the Weight of the Cedar material: Weight of the Cedar = 5.1 lbs.

Density of Cedar = 23 lb./ft^3 **value given through Reference [10]*

$$0.22\ ft^3 \times 23\ \frac{lb.}{ft^3} = 5.06\ lbs.$$

Calculating for the Corecell material volume: Volume of Corecell = 0.75 ft^3

Measurements taken during modification: Volume Corecell = 0.75 ft^3

Calculating for the Weight of the Corecell material: Weight of the Corecell = 4.3 lbs.

Density of Corecell = 5.7 lb./ft^3 ***value given through Reference [9]*

$$0.75\ ft^3 \times 5.7\frac{lb.}{ft^3} = 4.275\ lbs$$

Calculating for the Epoxy material Volume: Volume Epoxy = 0.03 ft^3

Hull Modification Volume minus the volume of cedar and Corecell:

$$1\ ft^3 - 0.22\ ft^3 - 0.75\ ft^3 = 0.03\ ft^3$$

Calculating for the Weight of the Epoxy material: Weight of the Epoxy = 2.21 lbs.

Density of Epoxy = 73.63 lb./ft^3 ****value given through Reference [11]*

$$0.03\ ft^3 \times 73.63\ \frac{lb.}{ft^3} = 2.2089\ lbs.$$

Calculating for the Hull Modification Weight: Hull Modification Weight = 11.6 lbs.

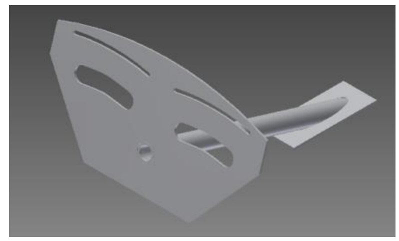
$$5.1\ lbs. + 4.275\ lbs. + 2.21\ lbs. = 11.59\ lbs.$$

Hull Weight after modification: 97.6 lbs.

Calculating for the Volume of Hull: **Volume of Hull = 3.15 ft^3**

$$1.43\ ft^3 + 0.72\ ft^3 + 1\ ft^3 = 3.15\ ft^3$$

Physical Properties for Gear Plate



General Properties:

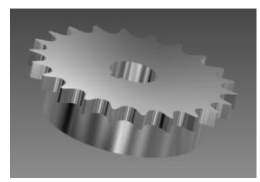
Material:	{Aluminum 6061, Welded}
Density:	2.710 g/cm^3
Mass:	9.990 lb_{mass} (Relative Error = 0.315481%)
Area:	825.504 in^2 (Relative Error = 0.000056%)
Volume:	102.041 in^3 (Relative Error = 0.315481%)

Physical Properties for 18 Teeth Gear (x2)

General Properties:

Material:	{Steel, High Strength Low Alloy}
Density:	7.840 g/cm^3
Mass:	1.052 lb_{mass} (Relative Error = 0.486784%)
Area:	23.332 in^2 (Relative Error = 0.000000%)
Volume:	3.715 in^3 (Relative Error = 0.486784%)

Physical Properties for 22 Teeth Gear (x2)



General Properties:

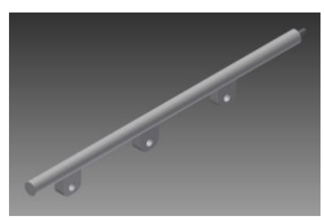
Material:	{Steel, High Strength Low Alloy}
Density:	7.840 g/cm^3
Mass:	1.879 lb_{mass} (Relative Error = 0.449698%)
Area:	31.713 in^2 (Relative Error = 0.000000%)
Volume:	6.634 in^3 (Relative Error = 0.449698%)

Physical Properties for Drive Shaft

General Properties:

Material:	{Steel, High Strength Low Alloy}
Density:	7.840 g/cm^3
Mass:	3.204 lb_{mass} (Relative Error = 0.120466%)
Area:	92.386 in^2 (Relative Error = 0.026252%)
Volume:	11.311 in^3 (Relative Error = 0.120466%)

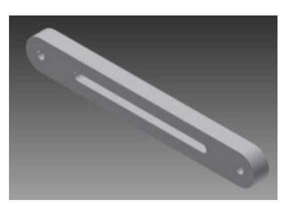
Physical Properties for Steering Swivel



General Properties:

Material:	{Steel}
Density:	7.850 g/cm^3
Mass:	1.639 lb_{mass} (Relative Error = 0.039274%)
Area:	39.666 in^2 (Relative Error = 0.000000%)
Volume:	5.778 in^3 (Relative Error = 0.039274%)

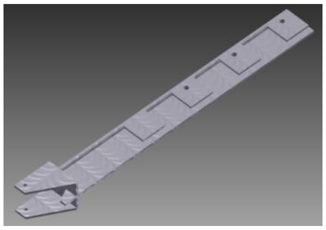
Physical Properties for Transverse Arm (x6)



General Properties:

Material:	{Aluminum 6061}
Density:	2.710 g/cm^3
Mass:	0.323 lb_{mass} (Relative Error = 0.000149%)
Area:	27.463 in^2 (Relative Error = 0.000000%)
Volume:	3.302 in^3 (Relative Error = 0.000149%)

Physical Properties for Steering Strut



General Properties:

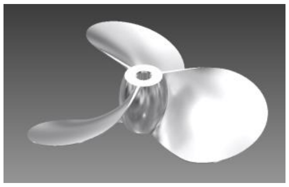
Material:	{Aluminum 6061, Welded}
Density:	2.710 g/cm^3
Mass:	2.083 lb_{mass} (Relative Error = 0.001178%)
Area:	180.251 in^2 (Relative Error = 0.00000%)
Volume:	21.278 in^3 (Relative Error = 0.001178%)

Physical Properties for ACME screw

General Properties:

Material:	{Steel}
Density:	7.850 g/cm^3
Mass:	0.407 lb_{mass} (Relative Error = 0.053793%)
Area:	15.536 in^2 (Relative Error = 0.000000%)
Volume:	1.436 in^3 (Relative Error = 0.053793%)

Physical Properties for Propeller



General Properties:

Material:	{Aluminum 6061}
Density:	2.710 g/cm^3
Mass:	1.181 lbmass (Relative Error = 0.887189%)
Area:	154.660 in^2 (Relative Error = 0.281014%)
Volume:	12.061 in^3 (Relative Error = 0.887189%)

Appendix C: Proof of Insurance

Solar Splash 2015 Rule 2.7 Insurance - *Each participating Team is required to provide proof of general liability insurance from their educational institution or written proof that, as a state institution, they are self-insured. Proof of insurance must be supplied with the Technical Report. Failure to do so will result in a 10 point penalty applied to the Technical Report score.*

The current insurance policy from Geneva College expires on June 1, 2015. Our team will obtain a paper copy, after June 1, 2015, and provide competition officials, upon arrival, proof of insurance from Geneva College.

Per the stated rule, our team is submitting an insurance form which expires before competition.

Client#: 4234 GENECO

ACORD™ CERTIFICATE OF LIABILITY INSURANCE

DATE (MM/DD/YYYY): 5/04/2015

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 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 HDH Pittsburgh P&C 210 Sixth Avenue, 30th Floor Pittsburgh, PA 15222 412 391-7300	CONTACT NAME: PHONE (A/C, No, Ext): 412 391-7300 FAX (A/C, No): 412 391-7322 E-MAIL ADDRESS:
	INSURER(S) AFFORDING COVERAGE — NAIC # INSURER A : Travelers Indemnity Company — 25658
INSURED Geneva College Trustees 3200 College Avenue Beaver Falls, PA 15010	INSURER B : INSURER C : INSURER D : INSURER E : INSURER F :

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 INSR	SUBR WVD	POLICY NUMBER	POLICY EFF (MM/DD/YYYY)	POLICY EXP (MM/DD/YYYY)	LIMITS	
A	GENERAL LIABILITY X COMMERCIAL GENERAL LIABILITY CLAIMS-MADE X OCCUR GEN'L AGGREGATE LIMIT APPLIES PER: POLICY / PRO-JECT / LOC			Y6302920M248TIA14	05/31/2014	05/31/2015	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	$2,000,000
								$
	AUTOMOBILE LIABILITY ANY AUTO ALL OWNED AUTOS / SCHEDULED AUTOS HIRED AUTOS / NON-OWNED AUTOS						COMBINED SINGLE LIMIT (Ea accident)	$
							BODILY INJURY (Per person)	$
							BODILY INJURY (Per accident)	$
							PROPERTY DAMAGE (Per accident)	$
								$
	UMBRELLA LIAB / OCCUR EXCESS LIAB / CLAIMS-MADE DED / RETENTION $						EACH OCCURRENCE	$
							AGGREGATE	$
								$
	WORKERS COMPENSATION AND EMPLOYERS' LIABILITY Y/N ANY PROPRIETOR/PARTNER/EXECUTIVE OFFICER/MEMBER EXCLUDED? (Mandatory in NH) If yes, describe under DESCRIPTION OF OPERATIONS below	N/A					WC STATU-TORY LIMITS / OTH-ER	
							E.L. EACH ACCIDENT	$
							E.L. DISEASE - EA EMPLOYEE	$
							E.L. DISEASE - POLICY LIMIT	$

DESCRIPTION OF OPERATIONS / LOCATIONS / VEHICLES (Attach ACORD 101, Additional Remarks Schedule, if more space is required)

CERTIFICATE HOLDER	CANCELLATION
Evidence of Coverage	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

ACORD 25 (2010/05) 1 of 1 The ACORD name and logo are registered marks of ACORD
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Appendix D: Team Roster

Name	Degree Program	Year	Team Role
Bradley Alan	Mechanical Engineering	Senior	Team leader, steering and hull design
Ray Burns	Electrical Engineering	Senior (Graduated December 2014)	Data acquisition and electrical systems design
Michelle Greco	Mathematics	Sophomore	Skipper
Tyler Harbison	Mechanical Engineering	Senior	Propeller design and manufacture
Andy Klein	Mechanical Engineering	Senior (Graduated December 2014)	Solar panel and drive train manufacture
Sean Pace	Mechanical Engineering	Senior	Steering, motor testing, and solar panel design
Matt Watson	Mechanical Engineering	Senior	Gears, drive train, and battery management
Dylan Weaver	Mechanical Engineering	Senior	Drive train, propeller design, and power management

Appendix E: Solar System Design

The diagrams and detailing of the past solar system design and the new configuration for competition this year are contained in this appendix.

Cell Electical & Mechnical specifications
All data and standard testing conditions

S.No	Description	U5-150C -01775	U5-150C -01730	U5-150C -01680	U5-150C -01635	U5-150C -01590	U5-150C -01540	U5-150C -01500
1	Efficiency (%)	17.75%	17.30%	16.80%	16.35%	15.90%	15.40%	15.0%
2	Power Output (Pm)	2.64	2.57	2.50	2.43	2.36	2.29	2.23
3	Tolerance (%)	+4%	+4%	+4%	+5%	+5%	+5%	+5%
4	Voltage at Maximum Power (vpm)	0.525	0.520	0.515	0.510	0.505	0.500	0.495
5	Current at Maximum Power (Ipm)	5.02	4.490	4.850	4.760/td>	4.680	4.580	4.500
6	Open Circuit Voltage(voc)	0.625	0.620	0.615	0.610/td>	0.605	0.600	0.595
7	Short Circuit Current (Isc)	5.430	5.350	5.270	5.210	5.140	5.05	5.030
8	Fill Factor (FF)	0.778	0.775	0.770	0.765	0.760	0.755	0.745
9	Cell Dimension (mm)	125 PSQ						
10	Diagonal(mm)	150						
11	Thickness (mic)	200+30						
12	Cell Area (cm2)	148.50						

The shaded column, under U5-150C-01500, on the far right of the above table, were ordered.

Fig. E.1 – UPV Solar Cell Product Specifications

Appendix F: Battery Testing

A. Endurance Testing

Fig. F.1 - CSB Endurance Simulation Test1

Fig.F.2 - CSB Endurance Simulation Test 3

The endurance testing utilized two sets of 5 ohm resistors. Three separate tests were completed using different combinations of the resistors in parallel. Test 1 used four resistors in parallel, Test 2 used three resistors in parallel, and Test 4 used six resistors in parallel. The resistors were connected along with a switch, voltage meter, and clip-on amp meter to complete the simple testing circuit. The resistors were fan cooled to prevent overheating and to keep the resistance constant. The tests were ran until the CSB battery reached 11 volts. The testing showed that the resistance of the resistors stayed near constant during testing; varying by less than 10 percent. The results of the testing fell in line as expected with the voltage falling faster the lower the resistance of the test. The three test took 105, 55, and 142 minutes respectivley for the battery to fall below 11 volts. These times allowed the team to examine discharge rates near the two hour endurance time. Along with plotting the voltage over time of discharge for each test; the power over that time was compared as well. The power over time graph allowed for the calculation of the constant discharge power available during use. Test 1 showed that the battery was capable of an average of 96.2 watts of power for 105 minutes taking into account that the batery was brought down to only 11 volts. It was assumed that a power level near this value could be maintained for the endurance competition. Taking into account that six of these

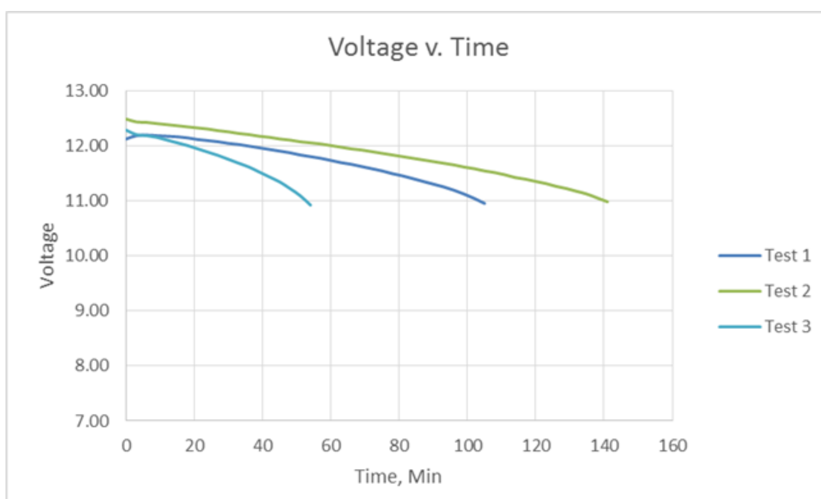


Fig. F.3 - CSB Endurance Simulation Test1 batteries will be used during the competition, that totals a constant power of approximately 575 watts for the two hour period. When, running a 24 volt system this equal to a constant power draw of 24 amps. The area under each power curve was taken for each test.The total energy taken from each test varied slightly with the rate the current was drawn as well as slight differences in charging. These energy values were used to compare the CSB batteries to the Optima and Genesis batteries. The Peukert's constant for the CSB battery was calculated using the average current value as well as the time it took for each test. The natural log of the time was plotted verse the natural log of the current and a linear best fit line was applied. The slope of this line is equal to the Peukert's of the battery. This value was used to compare the battery to other batteries based on manufacturers' data; as well as compare the actual test results to CSB's data on the battery.

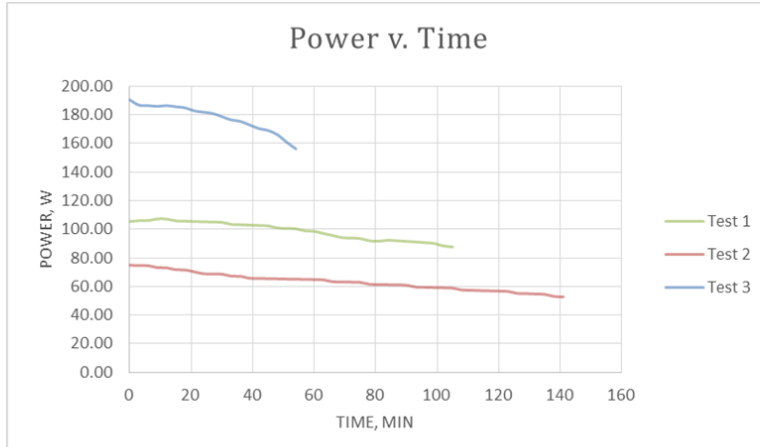


Fig. F.4 - CSB Power v Time Graph – Endurance Testing

Test	Overall Values		Average Values				
	Time	Energy	Ending V	Current	Voltage	Power	Resistance
	Min	KJ	V	A	V	W	Ohm
Test 1	105	623.06	10.95	8.18	11.78	96.16	1.40
Test 2	141	534.41	10.98	5.32	11.85	63.18	2.23
Test 3	54	576.61	10.92	15.12	11.75	177.72	0.78

Fig. F.5 - CSB Average Test Results

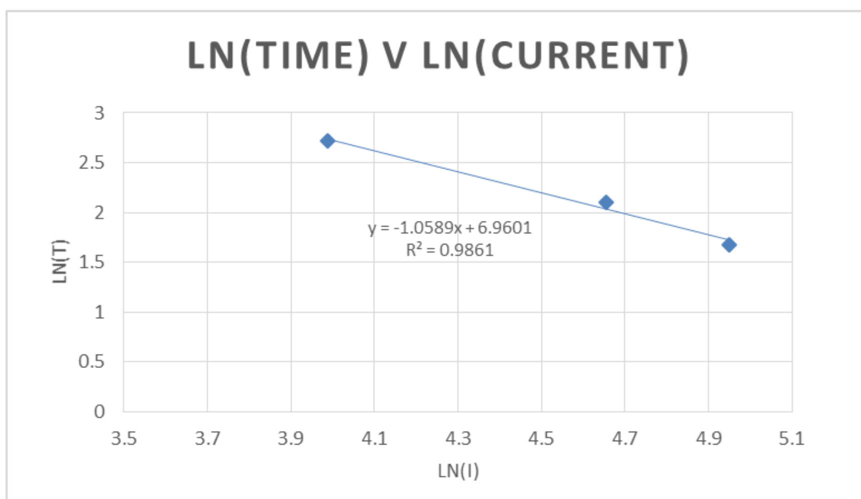


Fig. F.6 - CSB Peukert's Constant Graph

B. Sprint Testing Procedure and Setup

The Sprint test utilized a 500 amp Carbon Pile Load Tester to draw a high current from the CSB battery. The load tester was connected along with a switch, voltage meter, and clip-on amp meter to complete the simple testing circuit. Four test lasting 10 seconds each were performed in order to determine if the CSB battery was capable of handling loads similar to the loads it will experience during the sprint even. Between each test the load tester was given approximately 30mins to cool down. Load testing the CSB battery confirmed that the battery was capable of handling Sprint loads.

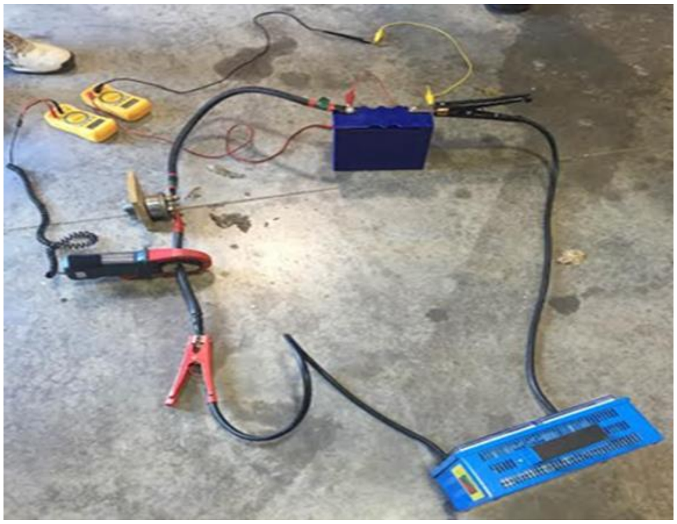


Fig. F.7 - CSB Sprint Simulation Test

The Optima batteries underwent load testing to determine their viability for use testing and for the competition. The Sprint tests utilized a 500 amp Carbon Pile load tester to draw a high current from the Optima Batteries. The load tester was connected along with a switch, voltage meter, and clip-on amp meter to complete the simple testing circuit. One test lasting 10 seconds was performed for each of the 15 Optima batteries kept in shop. Between each test the load tester was given approximately 30mins to cool down. The testing revealed that many of the batteries failed to maintain adequate voltage under load.

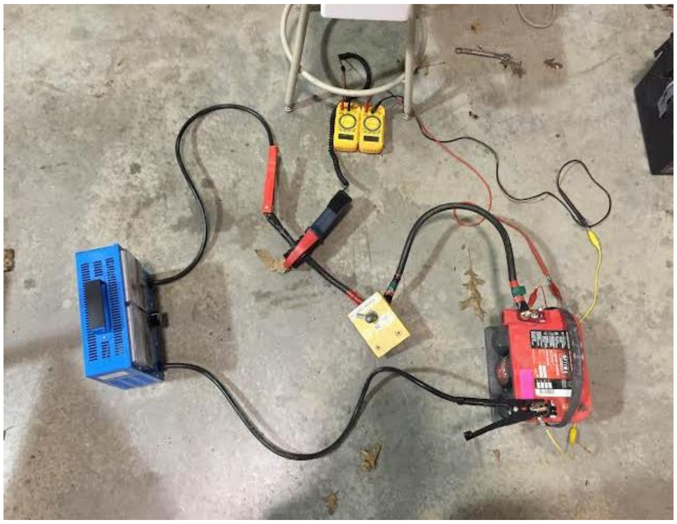


Fig. F.8 - Optima Sprint Simulation Test

Appendix G: Power Budget

The power budgets help to track the flow of power through the system. This allows for understanding of how closely each of the components is to its maximum and for a more accurate calculation of the power entering each stage of the system. Each stage of the power budget includes the power loss in that component as a way to find where the efficiency of the system is lacking and make improvements. The power budgets provide a concise way of listing the specification of each part of the system and whether the design goals are realistic based on the numbers it provides.

Sprint Power Budget						
Batteries						
Battery Impedance*	B_Z	0.003	Ω			Pull from Manufacturers Data
Nominal Battery Voltage	B_NV	36	V			Nominal Voltage
Battery Actual Voltage*	B_AV	27.5	V			Approximate Voltage Under Load
Battery Current*	B_I	550	A			Maximum Potential Current
Battery Power Addition	B_Pgain	15125	W	20.28	hp	B_Pgain= B_I*B_AV
Battery Power Output	B_Pout	15125	W	20.28	hp	B_Pout=B_Pgain
Wiring to Controllers						
Wiring Impedance*	W_C_Z	0.276	Ω/km			00 Welding Wire Resistance
Length*	W_C_L	1.83	m	6	ft	Approximate Length of Wire
Wire Voltage Loss	W_C_V_Loss	0.14	V			W_C_V_Loss= (W_C_Z/1000)*(W_C_L)*(W_C_I)
Wiring Voltage	W_C_V	27.36	V			W_C_V= B_AV - W_C_V_Loss
Wiring Current	W_C_I	275.00	A			W_C_I = B_I / 2
Wiring Power Loss	W_C_PL	76.34	W	0.102	hp	W_C_PL = 2*(W_C_I^2)*(W_C_Z/1000)*W_C_L
Wiring Power Output	W_C_Pout	15048.66	W	20.181	hp	W_C_Pout = B_Pout - W_C_PL
Cumulative Efficiency		99.50				
Controllers						
Controller Efficiency*	C_e	0.98				Controller Efficiency from Testing
Controller Voltage	C_v	27.36	V			C_V = W_C_V
Controller Current	C_I	275.00	I			C_I = W_C_I
Controller Power Loss	C_PL	300.97	W	0.404	hp	C_PL = (1-C_e)*W_C_Pout
Controller Power Output	C_Pout	14747.68	W	19.777	hp	C_Pout = W_C_Pout - C_PL
Efficiency		97.51				
Wiring to Motors						
Wiring Impedance*	W_M_Z	0.276	Ω/km			00 Welding Wire Resistance
Length*	W_M_L	1.83	m	6	ft	Approximate Length of Wire
Wire Voltage Loss	W_M_V_Loss	0.14	V			W_M_V_Loss= (W_M_Z/1000)*(W_M_L)*(W_M_I)
Wiring Voltage	W_M_V	27.22	V			W_M_V= C_V - W_M_V_Loss
Wiring Current	W_M_I	275.00	A			W_M_I = C_I
Wiring Power Loss	W_M_PL	76.34	W	0.102	hp	W_M_PL = 2*(W_M_I^2)*(W_M_Z/1000)*W_M_L
Wiring Power Output	W_M_Pout	14671.34	W	19.675	hp	W_M_Pout = C_Pout - W_M_PL
Cumulative Efficiency		97.00				

Fig. G.1 Sprint Power Budget (1 of 2)

Motor							
Motor Efficiency*	M_e	0.83				Pulled from Motor Curve
Motor RPM*	M_rpm	2100.00	rad/s	2100	RPM	Pulled from Motor Curve
Motor Power Loss	M_PL	2494.13	W	3.345	hp	M_PL = (1-M_e)*W_M_Pout
Motor Power Output	M_Pout	12177.21	W	16.330	hp	M_Pout = W_M_Pout - M_PL
Cumulative Efficiency		80.51				
Drive Train						
Number of Bearings*	DT_BN	5				Number of Bearings in Drive System
Bearing Efficiency*	DT_B_e	0.985				Gerr's Handbook Values
Gearing Efficiency*	DT_G_e	0.97				Machinist Handbook
Total Efficiency	DT_tot_e	0.90				DT_tot_e = DT_G_e*DT_B_e^DT_BN
Gear Ratio*	DT_GR	1.22				Gears Used
Drive Train RPM	DT_rpm	268.78	rad/s	2566.67	RPM	DT_rpm = DT_GR
Drive Train Power Loss	DT_PL	1225.03	W	1.643	hp	DT_PL = (1-DT_tot_e)*M_Pout
Drive Train Output Power	DT_Pout	10952.19	W	14.687	hp	DT_Pout = M_Pout - DT_PL
Cumulative Efficiency		72.41				
Propeller						
Prop Efficiency*	P_e	0.80				Approximate Propeller Efficiency
Prop Thrust	P_Thrust	783.98	N	176.246	lb	P_Thrust = P_Pout/(P_vel)
Boat Velocity*	P_vel	11.18	m/s	25	MPH	Speed Goal (Input in MPH)
Propeller Power Loss	P_PL	2190.44	W	2.94	hp	P_PL = (1-P_e)*DT_Pout
Popeller Power Output	P_Pout	8761.75	W	11.75	hp	P_Pout = DT_Pout
Cumulative Efficiency		57.93				
Hull						
Hull Drag	H_drag	783.98	N	176.246	Lb	H_drag = P_thrust
Hull Velocity	H_vel	11.18	m/s	25	MPH	H_vel = P_vel
Hull Power Loss	H_PL	8761.75	W	11.7497	hp	H_PL = H_PL - P_Pout
Hull Output Power	H_Pout	0.00	W	0.00	hp	Should Equal Zero - Sheet Check

Fig. G.1 - Cont. Sprint Power Budget (2 of 2)

Endurance Power Budget							
Solar Panels							
Max Solar Power Gain	SP_max	520	W	0.697	hp	Maximum Potential Power Under 1 Sun
Sun Condition Efficency*	SP_e	1				Fraction of 1 sun condition (0-1)
Solar Panel Power Gain	SP_P_in	520	W	0.697	hp	SP_P_in = SP_e*SP_max
Solar Panel Voltage	SP_V	16	V			Approximate Measured Panel Voltage
Solar Panel Current	SP_I	4	A			Approximated Measured Panel Current
Solar Panel Output Power	SP_Pout	520	W	0.697	hp	SP_Pout = SP_P_in
Peak Power Tracker						
MPPT Efficiency*	MPPT_e	0.96				MPPT Efficiency from Testing
MPPT Current*	MPPT_I	4	A			MPPT Current (Entered)
MPPT Voltage*	MPPT_V	24	V			Voltage Match Depending upon 24V or 36V
MPPT Power Loss	MPPT_PL	-20.8	W	-0.028	hp	MPPT_PL = MPPT_e*SP_Pout
MPPT Power Output	MPPT_Pout	499.2	W	0.669	hp	MPPT_Pout = SP_Pout - MPPT_PL
Batteries						
Battery Impedance*	B_Z	0.003	Ω			Battery Impedance as pulled from man. Specs
Nominal Battery Voltage*	B_NV	24	V			3 Pairs of 2 Batteries
Battery Actual Voltage*	B_AV	24	V			Battery Voltage Under Load
Battery Current*	B_I	24	A			Expected Current Drawn
Battery Power Addition	B_Pgain	576	W	0.772	hp	B_Pgain= B_I*B_AV
Battery Power Output	B_Pout	576	W	0.772	hp	B_Pout=B_Pgain
Combine Battery and Solar	Tot_Power	1075.2	W	1.442	hp	Tot_Power = MPPT_Pout + SP_Pout
Combine Current	Tot_I	28	A			Tot_I = MPPT_I + B_I
Wiring to Controllers						
Wiring Impedance*	W_C_Z	0.276	Ω/km			Impedence for 00 Welding Cable
Length*	W_C_L	1.52	m	5.000	ft	Approximate Length of Wire
Wire Voltage Loss	W_C_V_Loss	0.01	V			W_C_V_Loss= (W_C_Z/1000)*(W_C_L)*(W_C_I)
Wiring Voltage	W_C_V	23.99	V			W_C_V= B_AV - W_C_V_Loss
Wiring Current	W_C_I	28.00	A			W_C_I = B_I
Wiring Power Loss	W_C_PL	-0.66	W	-0.001	hp	W_C_PL = (W_C_I^2)*(W_C_Z/1000)*W_C_L
Wiring Power Output	W_C_Pout	1074.54	W	1.441	hp	W_C_Pout = B_Pout - W_C_PL
Controller						
Controller Efficiency*	C_e	0.98				Controlled Efficeny as Gathered from Testing
Controller Voltage	C_v	23.99	V			C_V = W_C_V
Controller Current	C_I	28.00	I			C_I = W_C_I
Controller Power Loss	C_PL	-21.49	W	-0.029	hp	C_PL = (1-C_e)*W_C_Pout
Controller Power Output	C_Pout	1053.05	W	1.412	hp	C_Pout = W_C_Pout - C_PL
Wiring to Motors						
Wiring Impedance*	W_M_Z	0.28	Ω/km			Impedence for 00 Welding Cable
Length*	W_M_L	1.52	m	5.000	ft	Approximate Length of Wire
Wire Voltage Loss	W_M_V_Loss	0.01	V			W_M_V_Loss= (W_M_Z/1000)*(W_M_L)*(W_M_I)
Wiring Voltage	W_M_V	23.98	V			W_M_V= C_V - W_M_V_Loss
Wiring Current	W_M_I	28.00	A			W_M_I = C_I
Wiring Power Loss	W_M_PL	-0.66	W	-0.001	hp	W_M_PL = (W_M_I^2)*(W_M_Z/1000)*W_M_L
Wiring Power Output	W_M_Pout	1052.39	W	1.411	hp	W_M_Pout = C_Pout - W_M_PL
Motor						
Motor Efficiency*	M_e	0.89				Must Be Enter Based on Position on Motor Curve
Motor RPM*	M_rpm	219.91	rad/s	2100.000	RPM	Pulled from Corresponding Position on Motor Curve
Motor Power Loss	M_PL	-115.76	W	-0.155	hp	M_PL = (1-M_e)*W_M_Pout
Motor Power Output	M_Pout	936.63	W	1.256	hp	M_Pout = W_M_Pout - M_PL

Fig. G.2 - Endurance Power Budget (1 of 2)

Drive Train						
Number of Bearings*	DT_BN	5				Bearings on Both Driveshaft and Propeller Shaft
Bearing Efficiency*	DT_B_e	0.985				Bearing Efficency (Gerr's Handbook)
Gearing Efficiency*	DT_G_e	0.97				Gearing Efficency (Machinist Handbook)
Total Efficiency	DT_tot_e	0.90				DT_tot_e = DT_G_e*DT_B_e^DT_BN
Gear Ratio*	DT_GR	0.33				Gear Ratio Used
Drive Train RPM	DT_rpm	73.30	rad/s	699.993	RPM	DT_rpm = DT_GR
Drive Train Power Loss	DT_PL	-94.22	W	-0.126	hp	DT_PL = (1-DT_tot_e)*M_Pout
Drive Train Output Power	DT_Pout	842.40	W	1.130	hp	DT_Pout = M_Pout - DT_PL
Propeller						
Prop Efficiency*	P_e	0.80				Enter Propeller Efficency
Prop Thrust	P_Thrust	158.69	N	35.674	lb	P_Thrust = P_Pout/(P_vel)
Boat Velocity*	P_vel	4.25	m/s	9.500	MPH	Expected Boat Velocity
Propeller Power Loss	P_PL	-168.48	W	-0.226	hp	P_PL = (1-P_e)*DT_Pout
Popeller Power Output	P_Pout	673.92	W	0.904	hp	P_Pout = DT_Pout
Hull						
Hull Drag	H_drag	158.69	N	35.674	Lb	H_drag = P_thrust
Hull Velocity	H_vel	4.25	m/s	9.500	MPH	H_vel = P_vel
Hull Power Loss	H_PL	673.92	W	0.904	hp	H_PL = H_PL - P_Pout
Hull Output Power	H_Pout	0.00	W	0.000	hp	Should Equal 0- Calculation Check

Fig. G.2 – Cont. Endurance Power Budget (2 of 2)

Appendix H: Hull Design and Modification

This section includes details and diagrams which have been discussed within the report regarding the hull modification.

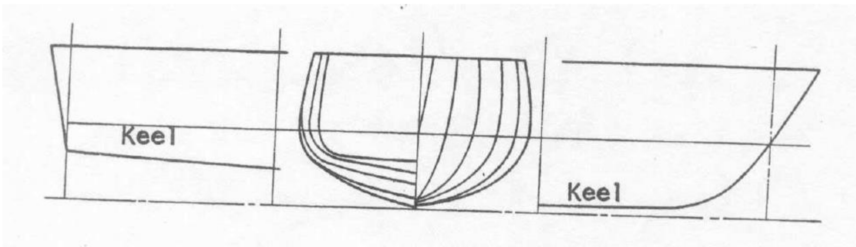


Fig. H.1 - Savitsky High Speed Displacement Hull

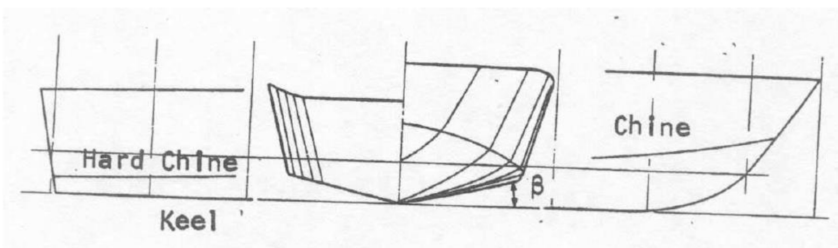


Fig. H.2 - Savitsky High Speed Planing Hull

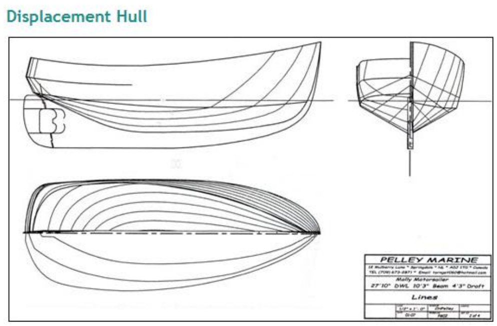


Fig. H.3 - Hull Classifications: Displacement Hull

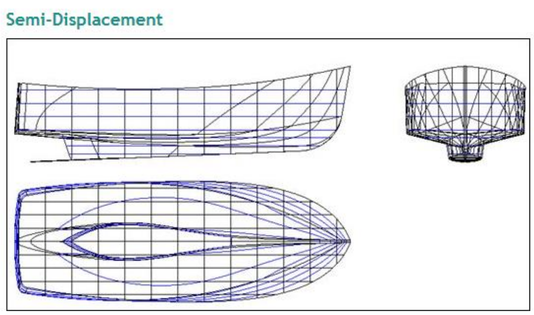


Fig. H.4 - Hull Classifications: Semi-Displacement Hull

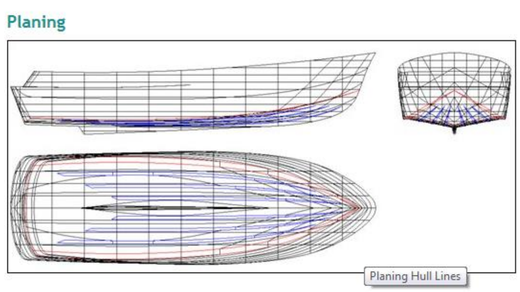


Fig. H.5 – Hull Classifications: Planing Hull

Fig. H.6 – Trim Tab Kit

Balsa Core - ProBalsa			2' x 4' sheets		
		thickness	3 / 8 in	1 / 2 in	3 / 4 in
Weight		cost	$31.28	$38.71	$48.38
lbs. per cu. Ft.			cost per cubic ft.		
10			$7.82	$12.89	$24.19

Fig. H.7 – Jamestown Distributors Material Costs – Balsa Wood

				1/8 in. thick sheets		
Corecell	A500			2 x 4	4 x 4	4 x 8
			cost	$33.84	$49.09	$130.18
Weight				1/4 in. thick sheets		
lbs. per cu. Ft.				2 x 4	4 x 4	4 x 8
5			cost	$47.11	$89.99	$158.08
				1/2 in. thick sheets		
				2 x 4	4 x 4	4 x 8
1/ 4 in	1 / 2 in	3 / 4 in	cost	$72.99	$154.04	$334.12
cost per cubic ft.				3/4 in. thick sheets		
$7.85	$24.33	$47.96		2 x 4	4 x 4	4 x 8
			cost	$95.92	$186.88	$336.66
				1 in. thick sheets		
				2 x 4	4 x 4	4 x 8
			cost	$131.59	$256.37	$338.12

Fig. H.8 - Jamestown Distributors Material Costs – Corecell Foam

Port side of the boat with proposed modifications in respect to the endurance waterline.

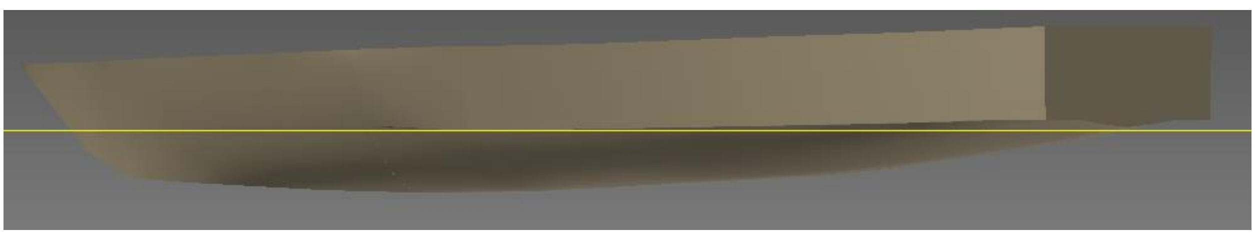


Fig. H.9 - Inventor model of the hull with proposed step-chine modification

Back view of the boat with proposed step chines with respect to the endurance waterline.

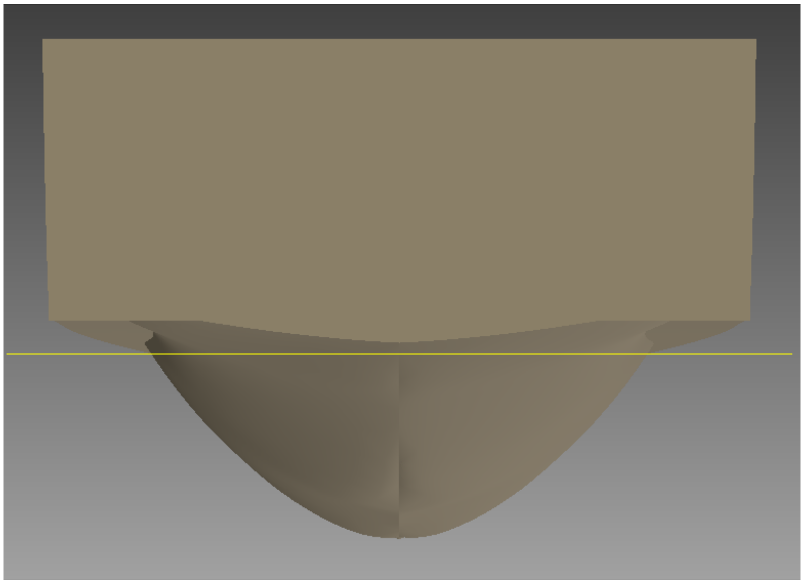


Fig. H.10 – View from the transom (back side) of the Inventor model for hull modification.

Qty	Unit of Measure	Item Description		Price
1	ea (1)	GUR-FGA500-0016-2/4 Core-Cell A500 .125"x 24"x 48" Plain Sheet Wish List Delete	Unit Price: $33.84 ea Availability: 4 In Stock	$33.84
1	ea (1)	GUR-FGA500-0023-2/4 GURIT CORE-CELL FOAM 1/2"X24"X48" PLAIN SHEET 24/CS Wish List Delete	Unit Price: $72.99 ea Availability: 4 In Stock	$72.99
2	ea (1)	GUR-FGA500-0026-2/4 CORE-CELL FOAM 3/4" X 24" X 48" PLAIN SHEET A500 Wish List Delete	Unit Price: $95.92 ea Availability: 3 AVAILABLE	$191.84
1	ea (1)	WSY-205B WEST 205B FAST HARDENER, 0.86 (QT) ***CONSUMER COMMODITY ORM-D (ORMD-AIR)*** *Hazmat product. Additional shipping and handling charges will be applied.* Wish List Delete	Unit Price: $40.00 ea Availability: 1123 AVAILABLE	$40.00
		HAZARDOUS MATERIAL HANDLING FEE		$4.99
1	ea (1)	WSY-406-7 WEST 406-7 COLLOIDAL SILICA 5.5 oz (CAB-O-SIL) Wish List Delete	Unit Price: $22.99 ea Availability: 487 AVAILABLE	$22.99
1	ea (1)	WSY-INTERNET-105B WEST 105B EPOXY RESIN, .98 GAL Wish List Delete	Unit Price: $81.99 ea Availability: 991 AVAILABLE	$81.99

To modify quantities, click Update Cart.

☐ **Empty Shop Cart**

Input zip code to calculate shipping cost: 15010		Original Subtotal	**$448.64**
Select ShipVia: Ground Shipping	Calculate	Shipping	**$24.45**
		Total	**$473.09**

Fig. H.11 - Jamestown Distributor's cost sheet regarding proposed modification order

The following has been obtained through Reference [9] of our “Reference” section.

PDS-Corecell A-10-1213 1 Gurit® Corecell™ A STRUCTURAL CORE MATERIAL

- ¬ **Exceptional impact tolerance**
- ¬ **Suitable for dynamically-loaded structures**
- ¬ **Superior styrene and temperature resistance to linear PVC foam**
- ¬ **Highly thermoformable**
- ¬ **Ideal for resin infusion**

Type	**Test Method**	**Units**	**A500**
Nominal Density	ISO 845	kg/m3 lb/ft3	92 5.7

Fig. H.12 – The following table density value was utilized in our hull weight calculations

Thermal Conductivity ASTM C518 0.04 W/mK

Dimensional Stability (HDT) DIN 53424 63°C / 145 °F

Intermediate densities may be available on request, subject to minimum order quantities.

E gurit@gurit.com

W www.gurit.com

Corecell is a registered trademark in the EU and in other countries.

Physical properties of cured epoxy

Specific gravity	1.18
Hardness (Shore D) ASTM D-2240	83
Compression yield ASTM D-695	11,400 psi
Tensile strength ASTM D638	7,900 psi
Tensile elongation ASTM D-638	3.4%
Tensile modulus ASTM D-638	4.08E+05
Flexural strength ASTM D-790	14,100 psi
Flexural modulus ASTM D-790	4.61E+05
Heat deflection temperature ASTM D-648	118°F
Onset of Tg by DSC	129°F
Ultimate Tg	142°F
Annular shear fatigue @ 100,000 cycles	10,600 lb

Manufactured for
WEST SYSTEM by:

Gougeon Brothers Inc.
P.O. Box 908
Bay City, MI 48707

866-937-8797

www.westsystem.com

March, 2013

Hull Modification Construction

Fig. H.13 – Forming/Adhering Corecell

The hull modification construction process is detailed next; visual support from the following figures should help to aid the reader through the steps. The boat hull was first placed upside down and was then leveled fore to aft. Next, sections from the Corecell foam sheets were first heated (160°F - 180°F) to its pliable range, quickly pressed into the shape of the hull at specific locations, and finally bonded to the hull using WEST system epoxy. Consecutive layers of the foam were added in certain sections of the hull due to the concave shape of the hull. The additional volume foam layers were shaved off, sanded down, and faired to shape for the step chines. After the step chines were formed using foam, a veneer of cedar strips were added on top of the foam to tie the modification into the existing structure. The cedar strips did not have to be purchased because a significant amount of the strips were left over from the initial hull construction. Matching each of the cedar strips, added as a veneer over the Corecell foam, placing them in line with the current strips of the hull was attempted with each piece, however the lack of time with the project limited the detailed craftsmanship of each individual strip. Each of the cedar strips were bonded to the other strip using wood glue, while the veneer was bonded to the foam using WEST system epoxy. The veneer of cedar strips over the foam core was faired down to the final shape for the step chines. The final shape was determined level and was prepared for the layer of 6mm fiberglass which would cover the added material. The fiberglass cloth was not purchased because two large rolls had been left over from the initial hull construction. The WEST system epoxy was used to bond the fiberglass to the cedar veneer. Additional coats of epoxy were added to fill in the cloth layer. The final coat of epoxy is shown in the picture below.

Fig. H.14 – Adding the veneer of cedar strips on top of Corecell

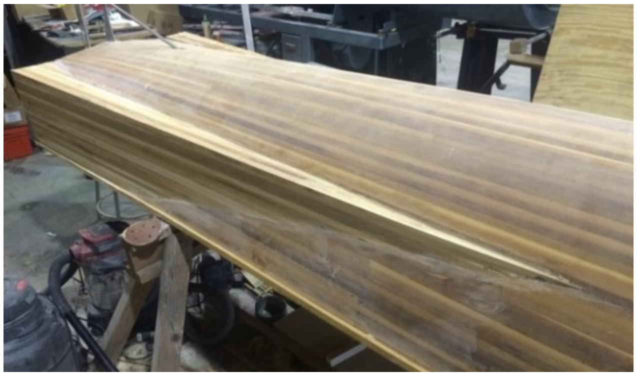


Fig. H.15 – Cedar veneer completed

Fig. H.16 – Final coat of epoxy completed.

After the final epoxy coat the hull will be sanded down and prepared for three coats of varnish. The varnish will protect the epoxy from UV degradation.

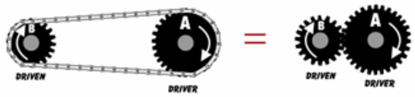
One of the intended characteristics for this modification of the hull, the step chine design, included increasing the surface area. The increase in surface area, parallel to the sprint waterline, was constructed to improve planing hull characteristics. The following side by side figures illustrate the increase in surface area, before and after the modification. Each figure is a view looking at the transom. The increase in surface area from the step chine modification is an increase of 4 square feet.

Fig. H.17 – Before picture of the hull

Fig. H.18 – Picture after modification

Appendix I: Gearing and Chains

Gear Selection



$$Gear\ Ratio = \frac{NumberOfTeethOnDriverGear(FromMotor))}{NumberOfTeethOnDrivenGear(DriveShaft)}$$

Speeds for Gear Ratio Calculation		
Motor Speed in Rotations Per Minute:	2155	rpm
Propeller 1 (13 Pitch 10 Diameter):	2500	rpm
Gear Ratio for set-up = 2500rpm/2155rpm=	1.16:1	

Aavailable Gears			
Motor Gears:		Driveshaft:	
18	teeth	12	teeth
21	teeth	18	teeth
22	teeth	20	teeth
24	teeth		

Based the Gear Ratios generated, using an 18 tooth gear on the Drive Shaft would generate Ratios that are closest to the desired ratio. Larger gear ratios than desired were selected based on past team's issues with lack of overdrive.

Theoretical Desired Ratio= 1.1:1			
BASED ON MOTOR GEARS		BASED ON DRIVE SHAFT GEARS	
18 teeth	Ratio	12 teeth:	Ratio
18-20:	0.9	18-12	1.5
18-18:	1	21-12	1.75
18-12:	1.5	22-12	1.833333333
21 teeth		21-12	2
21-12:	1.75	18 teeth:	
21-18:	1.166666667	18-18	1
21-20:	1.05	21-18	1.166666667
22 teeth		22-18	1.222222222
22-12:	1.833333333	24-18	1.333333333
22-18:	1.222222222	20 teeth:	
22-20:	1.1	18-20	0.9
24 teeth		21-20	1.05
24-12:	2	22-20	1.1
24-18:	1.333333333	24-20	1.2
24-20:	1.2		

Fig. I.1 – Gear Selection Table

Calculating the gearing ratio is accomplished by dividing the teeth number of the driver gear (motor gear) by the teeth number of the driven gear (drive shaft gear). The speeds for Gear Ratio Calculation show the motor speed based on the ME909 motor curve data, the propeller speed based on calculation from Crouch's Method, and the theoretically desired gear ratio which is calculated by dividing the propeller speed by the motor speed. The list of available gears shows the Sprint gears (chain size 40) available. Using the list all of the gear ratios were calculated for all possible arrangements.

The image to the right shows the gearing ratio chosen for Sprint. The gears in the drive train are Martin Sprockets. The pinion sprocket (22-teeth) is a Martin 40BS22 (7/8), and the driven sprocket is a Martin 40BS18HT 1. The dimensions were found on the Martin Gear Catalogue. The drive train set-up utilizes two motors spinning the larger sprockets which connect to a single drive shaft with the two smaller sprockets. The torque rotation is clockwise.

Martin 40BS22 7/8		
Material:	steel	
Pitch Type:	Single	
Bore Type:	Finished with Keyway	
Chain Number:	40	
Number of Hubs:	1	
Number of Strands Across:	1	
Number of Teeth:	22	
Pitch:	0.5	in
Bore Diameter:	0.875	in
Length Through Bore:	1	in
Outside Diameter:	3.78	in
Tooth Width:	0.284	in
Hub Diameter:	2.875	in
Keyway Size:	3/16 X 3/32	in
Pitch Diameter:	3.513	

Martin 40BS18HT 1		
Material:	steel	
Pitch Type:	Single	
Bore Type:	Finished with Keyway	
Chain Number:	40	
Number of Hubs:	1	
Number of Strands Across:	1	
Number of Teeth:	18	
Pitch:	0.5	in
Bore Diameter:	1.125	in
Length Through Bore:	1	in
Outside Diameter:	3.14	in
Tooth Width:	0.284	in
Hub Diameter:	2.3125	in
Keyway Size:	1/4 x 1/8	in
Pitch Diameter:	2.879	

Fig. I.2 & I.3 – Gear Specifications

The image to the right shows the calculations for the angular velocity, torque, and pitch circle diameter for the driver and driven gears selected for Sprint.

Gear Relationships

Angular Velocity (Driver)
$$\omega_1 = \frac{2\pi n_1}{60} = \frac{2\pi\,(2155rpm)}{60} = 225.67\ rad/s$$

Angular Velocity (Driven)
$$\omega_2 = \omega_1 \cos\left(\frac{180}{N}\right) = \left(\frac{225.67rad}{s}\right)\cos\left(\frac{180}{18}\right) = 222.242\ rad/s$$

$$\frac{T_1}{T_2} = \frac{dp}{dg}$$

Torque (input)
$$T_1 = \omega_1 \cos\left(\frac{180}{N}\right) = 230\ lb * in$$

Pitch Circle Diameter (Driver)
$$dp = \frac{p_{chain}}{\sin\left(\frac{180}{N_p}\right)} = \frac{0.5in}{\sin\left(\frac{180}{22}\right)} = 3.513\ in$$

Pitch Circle Diameter (Driven)
$$dg = \frac{p_{chain}}{\sin\left(\frac{180}{N_g}\right)} = \frac{0.5in}{\sin\left(\frac{180}{18}\right)} = 2.879\ in$$

Torque (output)
$$T_2 = \frac{T_1 dg}{dp} = \frac{(230lb * in)(2.879in)}{(3.513in)}$$

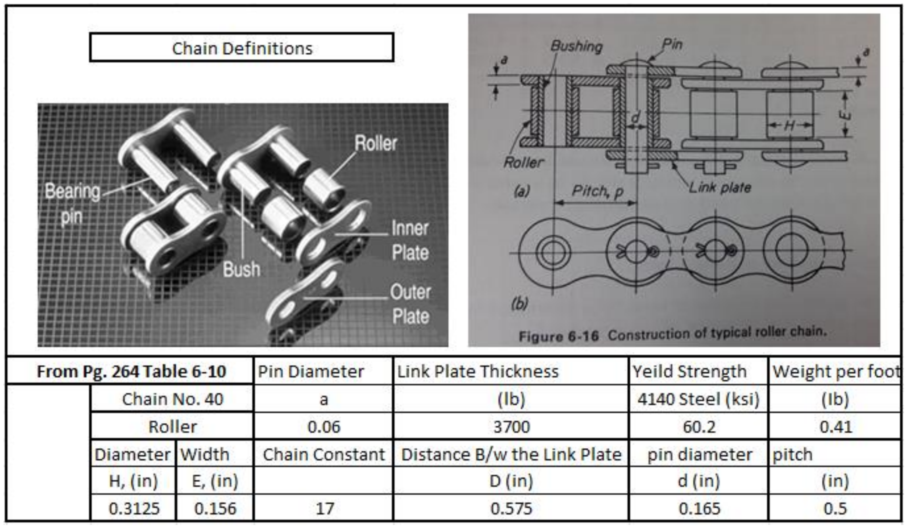
$$Gear\ Ratio = \frac{n_p}{n_g}$$

Fig. I.4 - Gear Relationships

Chain:

The image to the right displays the chain dimensions. The chain definitions and values for the chain used is taken from the Standard Handbook of Chains. The most important components of the chain are the Chain number (40), and the pitch (0.5in).

The image to the right shows the new chains cut due to the increase in the diameters of the gearing. The chains have 23 links, and are fastened together with spring clips.



From Pg. 264 Table 6-10			Pin Diameter	Link Plate Thickness	Yeild Strength	Weight per foot
	Chain No. 40		a	(lb)	4140 Steel (ksi)	(lb)
	Roller		0.06	3700	60.2	0.41
	Diameter	Width	Chain Constant	Distance B/w the Link Plate	pin diameter	pitch
	H, (in)	E, (in)		D (in)	d (in)	(in)
	0.3125	0.156	17	0.575	0.165	0.5

Fig. I.5 - Chain Schematic

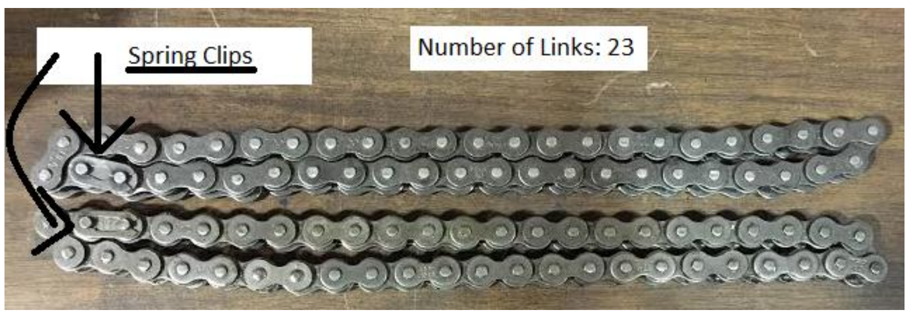


Fig. I.6 - Picture of the chain used in the drive trian

Appendix J: Motor and Motor Controllers

The motor system was not changed from the previous design. The vessel is equipped with two Motenergy MEE-909 brush type permanent magnet DC motors. Two motors are used in tandem during the spring, slalom, and qualifying events. Only one of the motors is operated during the endurance event. Each motor is capable of 300 Amps for 30 seconds and operate within a 12-48 Volt range. Each motor weighs 24.1 lbs. and are fixed within the vessel by mounting them upon the aluminum Gear/Motor Mounting plate (see Fig. J.1. below).

Fig. J.1 – View of our set up for the motors and motor controllers

Fig. J.21 – ME909 motor

This ME0909 is a Brush-Type, Permanent Magnet DC motor with very high efficiency. Capable of 4.8 KW continuous and 15 KW for 30 seconds. For voltages from 12 to 48 VDC input and 100 amps continuous (300 amps for 30 seconds). Designed for battery operated equipment.

Power	4.8 KW continuous 15KW for 30 seconds
Voltage	12 - 48 Volts
Speed	3,984 rpm at 48V Unloaded 83 RPM per Volt
Size	6.88" OD, 6.29" long (w/o shaft)
Shaft	7/8"x 1-5/8", 3/16" key
Weight	24.1 Lbs.

Fig. J.3. – ME909 Specifications

Each of the ME909 motors are controlled by Curtis 1204 motor controllers. Each Curtis motor controller is rated for 24-36 Volts, 275 Amps. Only one of the controllers is used for the endurance configuration, while both controllers (one for each motor) are used in the other competition events.

During testing in late April, one of the Curtis controllers was defective. The backup controller (Alltrax AXE4855) was tested, but upon reach half throttle burnt and was non-salvageable. At the time of this report replacement Curtis 1205 motor controllers have been purchased, and will be implemented for use at the competition.

APPENDIX C

APPENDIX C

SPECIFICATIONS

NOMINAL INPUT VOLTAGE	12V, 24–36V, and 36–48V
PWM OPERATING FREQUENCY	15 kHz
STANDBY CURRENT	less than 20 mA
STANDARD THROTTLE INPUT	5 kΩ ±10% (others available)
WEIGHT	1204: 1.8 kg (4 lbs) 1205: 2.7 kg (6 lbs)
DIMENSIONS	1204: 146mm×170mm×70mm (5.75"×6.75"×2.8") 1205: 146mm×222mm×70mm (5.75"×8.75"×2.8")

MODEL NUMBER	NOMINAL BATTERY VOLTAGE (volts)	CURRENT LIMIT (amps)	2 MIN RATING (amps)	5 MIN RATING (amps)	1 HOUR RATING (amps)	VOLTAGE DROP @ 100 AMPS (volts)	UNDER-VOLTAGE CUTBACK (volts)
1204-0XX	24–36	275	275	200	125	0.35	16
-1XX	24–36	175	175	130	75	0.50	16
-2XX†	24–36	275	275	200	125	0.35	16
-3XX†	24–36	175	175	130	75	0.50	16
-4XX	36–48	275	275	200	125	0.35	21
-5XX	36–48	175	175	130	75	0.50	21
-6XX	12	275	275	200	125	0.35	9
-7XX	12	175	175	130	75	0.50	9
1205-1XX	24–36	400	400	275	175	0.25	16
-2XX	36–48	350	350	250	150	0.30	21
-3XX	12	400	400	275	175	0.25	9

† Models for use with permanent magnet motors (no A2 bus bar provided).

Curtis PMC 1204/1205 Manual C-1

Fig. J.4. – Curtis Motor Controller Specifications

Appendix K: Driveshaft

The previous 2012-2013 team fabricated the vertical strut for the driveshaft. Three individual pieces of the strut were welded together. The base fastens to the hull and a second plate located inside the hull evenly distributes loads applied to the strut. The design minimized the area for lateral forces to act on and maximized the area for the strut to resist bending stresses. The strut was fabricated out of 1061-T6 aluminum.

The worst case scenario was used in calculations; as the boat conducts hard turns at high speeds during the competition events. At top speed, the strut creates drag determined to be 89 lbs. of force. At 3/16th inch plate the bending stress was determined to be 17,020 psi for a 3/16th inch plate. The 3/16” thick aluminum afforded a safety factor of 2. Of the common aluminum alloys, 1061-T6 aluminum plate was chosen since its yield strength is 40,000 psi.

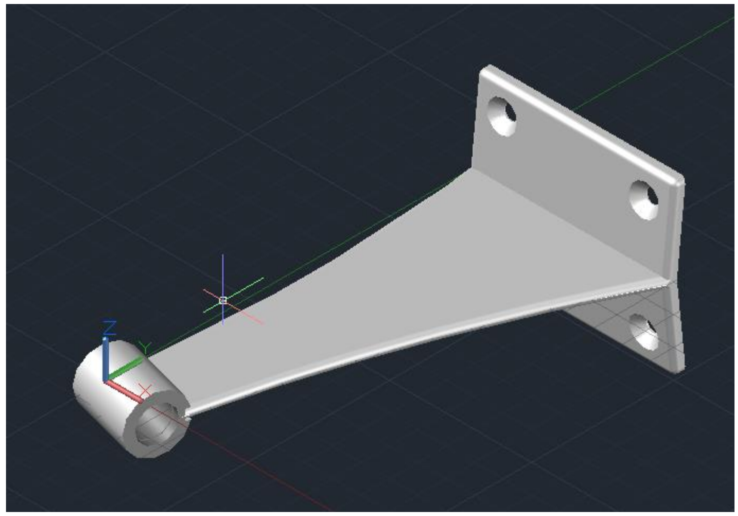


Fig. K.1 - Driveshaft support strut model

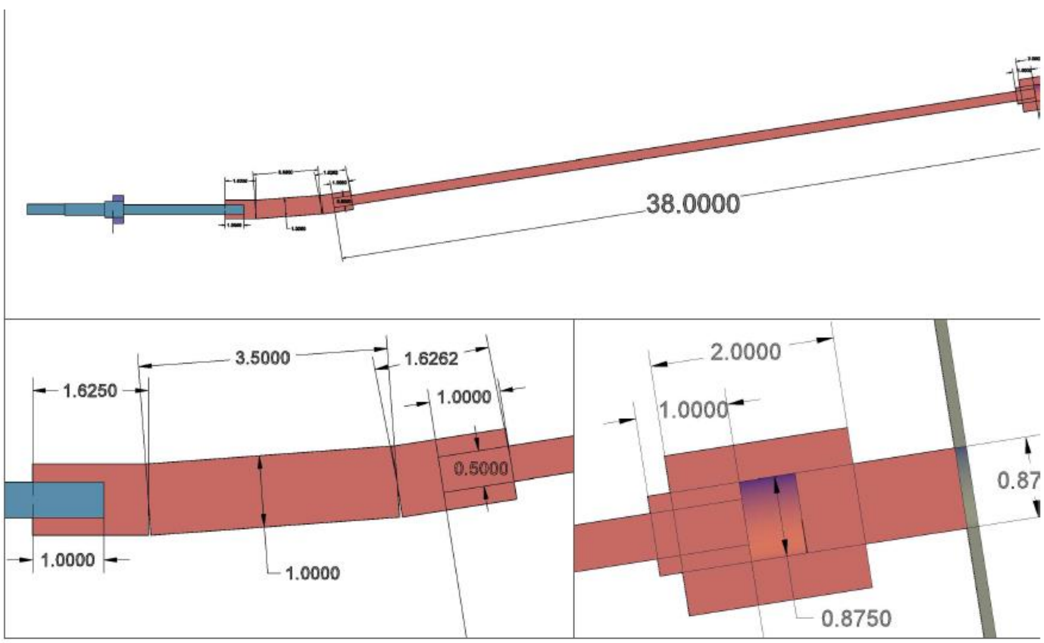


Fig. K.2 - Driveshaft drawing

Appendix L: Bearing Housing

In order to compare the design options for the bearing house analysis was completed in Autodesk Simulation CFD 2015 using finite element methods. Three housing options were each drawn in simplified form using Autodesk Inventor. The model of each housing was enclosed within a solid rectangle. Each model was imported into the simulation software. The parameters set for the analysis included: setting the inner housings material to aluminum, setting the enclosures material properties to water, giving the inlet face of the rectangle a known velocity, setting the outlet face of the rectangle to zero gage pressure, and setting all other faces of the rectangle equal to model symmetry, so that there was no wall effects. The fluid model used was k-epsilon, because of this application involving turbulent flow around a bluff body. The model were then meshed; a smaller meshing was applied to the bearing housing surface.

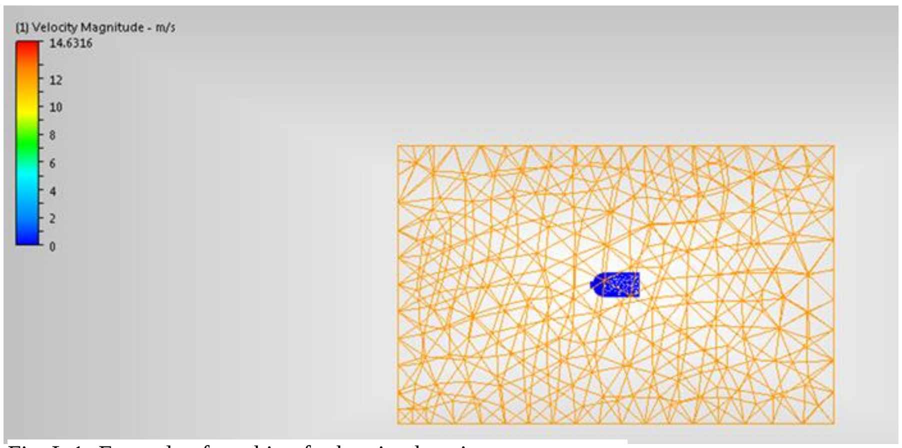


Fig. L.1- Example of meshing for bearing housing

The simulation software was solved and a velocity profile was created for each of the three housings.

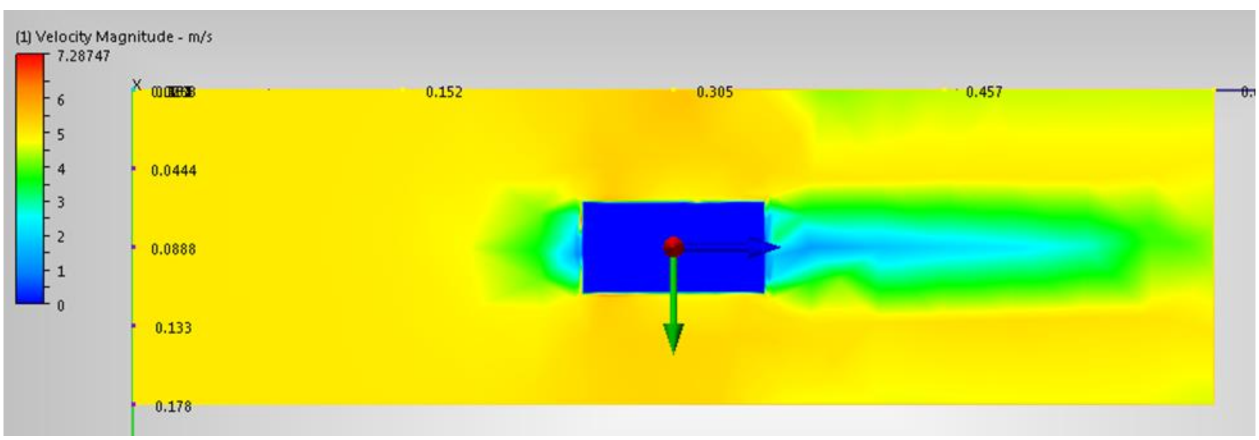


Fig. L.2- Velocity profile of old style bearing housing

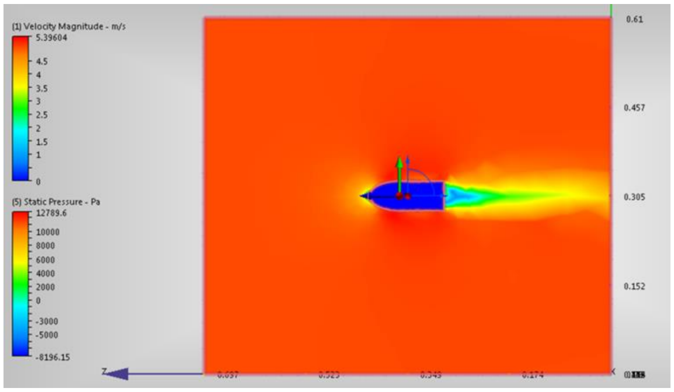


Fig. L.3- Velocity profile of elliptical housing

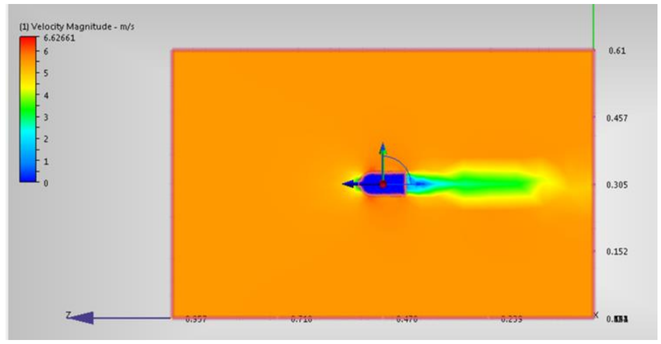


Fig. L.4- Velocity profile of semi-sphere housing

The velocity profiles show that the old housing causes a much larger disturbance in the flow of water compared to the two new designs. This flow is especially important, because it leads directly to the propeller. Figures K.3 and K.4 show that the disturbance caused by the elliptical housing is far less than the semi-sphere housing; that the elliptical housing results in the best flow to the propeller.

The drag force for each housing was calculated at different velocities, ranging from 3 m/s to 12 m/s. In order to verify the validity of the Autodesk Simulation CFD software for this application, the results of the old housing, essentially a cylinder. The drag force on the old cylinder was calculated by hand using the drag formula $F_D = \frac{1}{2}\rho v^2 C_D A$, the frontal area of the cylinder, and a drag coefficient of .85 for short cylinder. The results of the simulation software results and the hand calculations were plotted on Figure K.5.

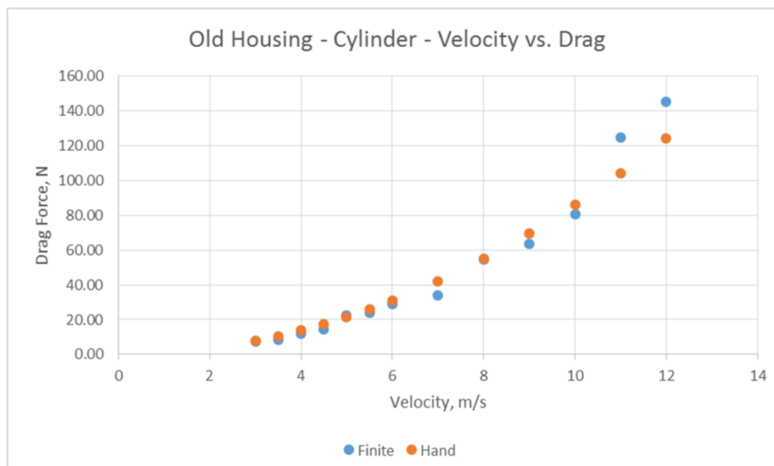


Fig. L.5- Comparison of results using hand calculations and Autodesk CFD

The results show that the hand calculations and the software results match closely for all of the speeds tested; thereby verifying the methods used for the drag analysis. The results show that the elliptical housing causes the least drag at every tested velocity. Both updated produced an approximately 33 percent reduction in drag force. These results do not fully represent the entire housing unit, lacking the propeller shaft and constant velocity joint; the results do serve as an effective comparison between design options.

	Old Housing		Elliptical	Semi-Sphere
Speed	Drag (Finite)	Drag (Hand)	Drag (Finite)	Drag (Finite)
m/s	N	N	N	N
3	7.30	7.75	3.55	3.18
3.5	8.35	10.55	5.06	3.86
4	11.99	13.78	7.57	6.97
4.5	14.25	17.44	10.46	9.17
5	22.41	21.54	13.03	10.08
5.5	24.03	26.06	14.31	15.27
6	28.77	31.01	15.71	16.06
7	33.81	42.21	21.08	21.06
8	54.31	55.13	32.28	30.06
9	63.42	69.77	42.47	56.47
10	80.61	86.14	54.07	57.00
11	124.51	104.23	57.01	79.75
12	145.23	124.04	89.70	91.40

Fig. L.6- Results of CFD drag testing of bearing housing options.

Final Design of the Bearing

Housing

The elliptical bearing housing was chosen for the simplicity of its design and improved shape. The housing is made of aluminum and is one solid piece, milled from a piece of round stock. The housing contains a thrust bearing at the front to carry the propeller thrust and a roller bearing to keep the shaft aligned at the rear. The setup involves plastic seals infront of and

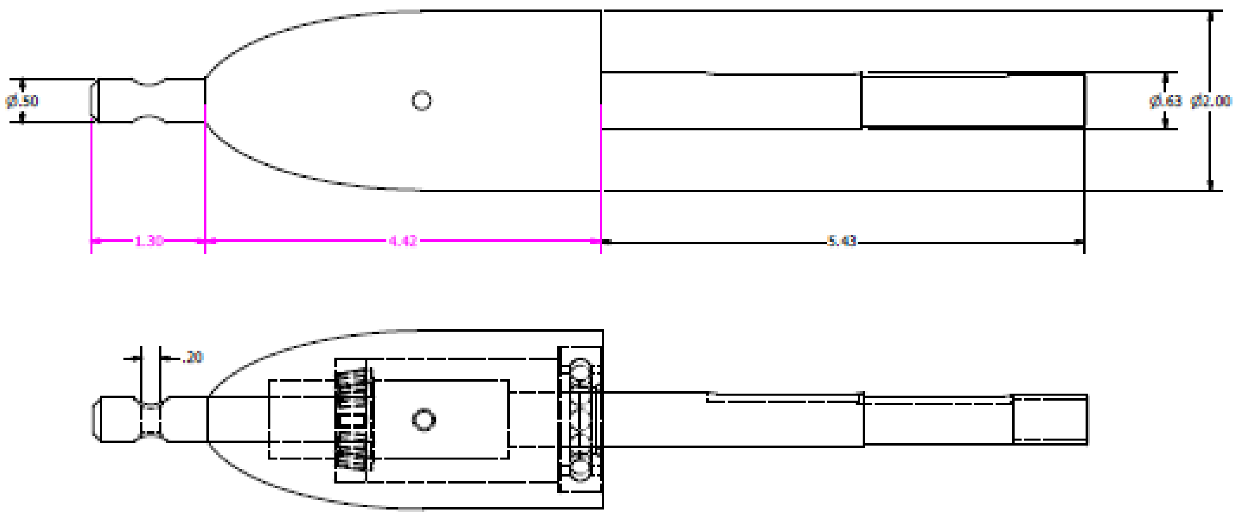


Fig. L.7- Bearing housing assembly drawing

behind the thrust bearing to make it water tight. The roller bearing has double plastic seals. The shaft is held in place by the connection to the constant velocity joint at the front and the propeller hub secures the roller bearing and shaft from the back.

The design requires a new shaft to be made. The new shaft will be made of steel and manufactured on the lathe. It contains a larger diameter section to support the thrust bearing, a hole for connection to the constant velcocity joint, a keyway for connection to the propeller hub, and threads to secure the propeller into position.

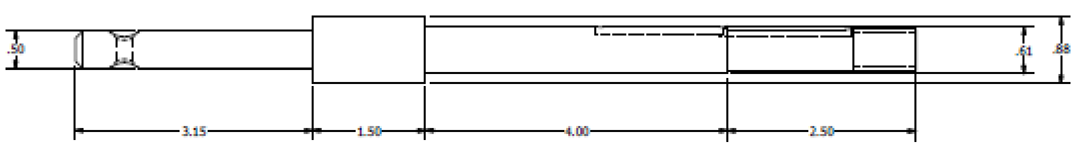


Fig. L.8- New propeller shaft drawing

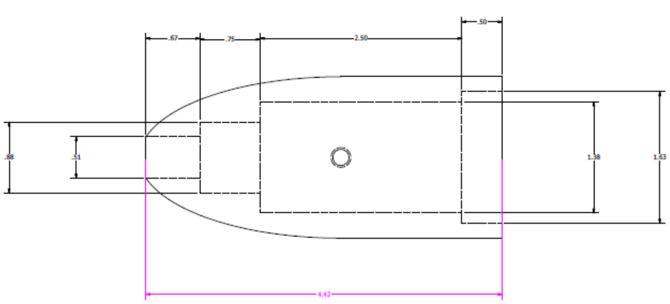


Fig. L.10- Bearing housing drawing

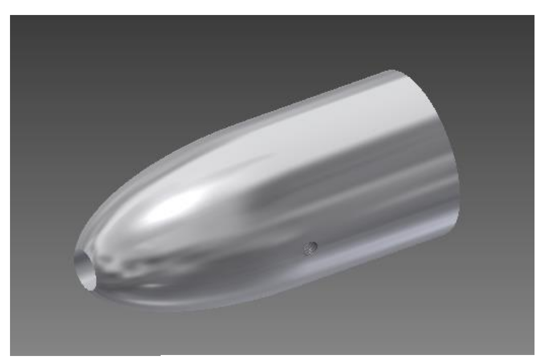


Fig. L.10- Bearing housing rendering

Appendix M: Propeller Manufacturing

A. Description

The detailing of the manufacturing process of the propellers and the steps taken to get the propellers from the design in JavaProp and OpenProp to using the Computer Numeric Control (CNC) to mill them out of aluminum stock and then to manually grind and remove material to obtain a finish on the propeller that will match the foil shape designed by the software.

B. G-Code Generation Software

Computer Aided Manufacturing (CAM) software is crucial to the work to be done in creating an optimized propeller. In the pursuit of an ideal program to generate the code for the propeller model there are a couple qualifiers that are deemed necessary for the software to be able to be used for generating the necessary code that would allow complex shapes to be accurately machined using the CNC mill. There are three qualifiers that the software would need to be able to fulfill. The software must:

- Generate G-code for complex curves
- Have rough and fine finish options for the machine to be able to accomplish a manual tool change
- Be able to use circular interpolation (G02 and G03) to machine arcs (preferred for timely milling times but nonessential)

The software used to generate code that is paired with the mill interfacing software is out of date and unable to use current 3D modelling files and makes the process difficult and generate adequate code. The next software that was used was MechCAM which is a freeware. This software is not able to create code that includes circular interpolation that is compatible with the FANUC style CNC mill that is used. So another software was desired. It was found that the Autodesk software: Inventor HSM was a more then capable program to allow the machining of the propeller using the CNC. This software is a plug-in to the Autodesk Inventor software which allows for ease of use with the propeller models created in AutoCAD.

C. Initial Trials with the CNC Machine and Software

The first successful attempt at generating G-Code for the propeller machining was done using Autodesk Inventor HSM which adds a tab in the ribbon of the main window of the software. This allows the user to seamlessly generate code from the solid model part file. A prototype milling was done using high-density, engineering foam and a solid model of a propeller that was created by a past Solar Splash team at Geneva. The prototype model is pictured in Figure M.1. The foam allowed for an increase in the feed rate and cutting speed for the propeller so that the prototype could be created quickly. With the machining of a propeller there are considerations that need to be made involving how a 3-axis mill and how it will cut both sides of the propeller. Mounting and size considerations were important so that propeller would be able to be fit on the CNC table and be milled. A support would need to be added at the end of the blade so that during the machining process the blade would not deform under the load from the tool cutting the stock. The prototype was made out of foam so the force exerted by the tool on the stock was greatly reduced using the foam so that support design was a simple strut that would allow the blade to be mounted to the table using double sided tape and be adequately supported from deformation. The final result of the prototyping attempt is shown in Figure M.2. This was a good proof of concept and test use of the CAM software to allow the team to proceed forward with the manufacturing of the propellers

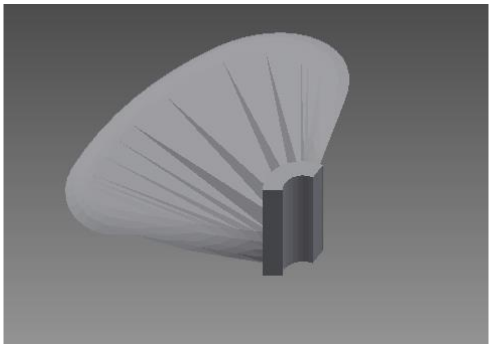


Fig. M.1 – Prototype Model

Fig. M.2 – Finished Prototype with support

D. Propeller Support Analysis

The 3D models of the sprint and endurance propellers have been previously made by past teams using a combination of different software, such as JavaProp. These models can be exported form their modeling software as different files to be used in generating code and interfacing with the CNC mill. The milling process will require some modifications to the base model as to allow for support structure to remain as part of the prop for the first half of the milling so that when the stock is to be flipped so that the mill can complete the milling process for the reverse side and it can be supported and not allow for a deflection that would cause a deformation in the prop by the force applied to the propeller by the tool. The force used for these calculations is the F_t force shown in Figure M.3.

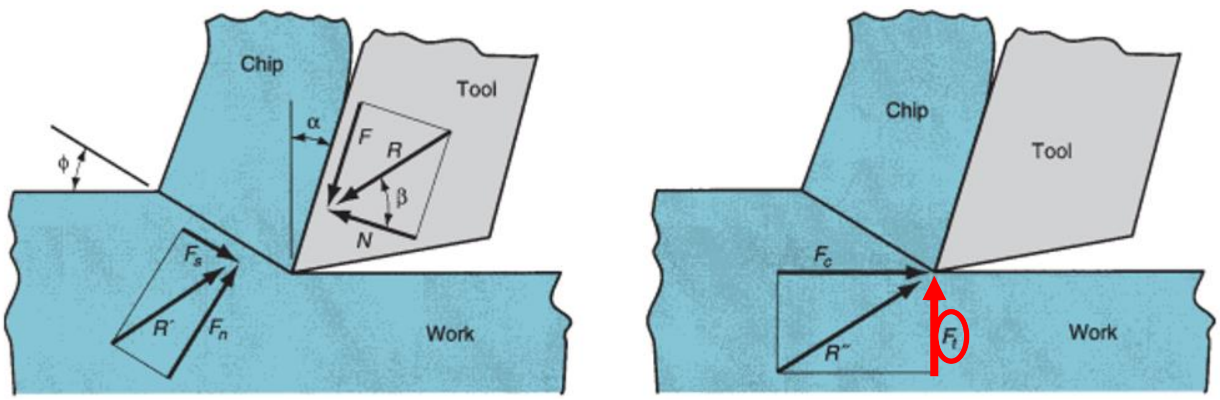


Fig. M.3 – Forces acting on the stock during milling[5]

the material. A resultant force for the tool upon the stock material is directed along the cutting angle. So to find the force that the mill tool places on the stock in the vertical direction the ultimate shear strength is set equal to F_t, making a generalization to simplify the problem and then simple trigonometry is used to solve for F_t. The forces are all geometrically related in Figure M.4.

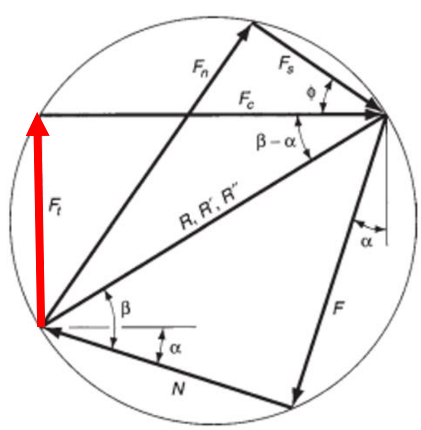


Fig. M.4 – Geometric relationships of the forces involved in a milling operation[5]

$$F_t = \frac{S_t w \sin(\beta - \alpha)}{\sin\phi \cos(\phi + \beta - \alpha)} = \frac{F_s \sin(\beta - \alpha)}{\cos(\phi + \beta - \alpha)}$$

$$F_s = S \cdot A_s$$

$$F_t = \frac{S A_s \sin(\beta - \alpha)}{\cos(\phi + \beta - \alpha)}$$

Using the force in the vertical direction found by the previous analysis, the calculations can be done to determine the size of a support needed to assure that there will be no deformation in the final product and there will also be no deformation in the beam section of the propeller shown in Figure M.5 that would cause misaligned cuts that would cause the specifications of the propeller to be inaccurate.

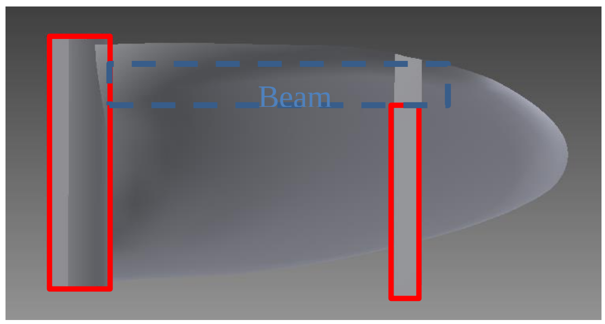


Fig. M.5 – Beam analysis of the support structure

The area of the support beam, can be specified using a simple deformation calculation:

$$\Delta X = \frac{F_t L}{EA}$$

$$A = \frac{F_t \cdot L}{\Delta X \cdot E}$$

These methods will allow the 3D models of the props to be prepared and accurately machined using the CNC mill. These are crucial steps to be taken in the analysis and fabrication of the propellers. The design used for the manufacturing of the propellers is shown in Figure M.6.

The sprint propeller had to be divided into sections for each blade because the designed diameter was too big for the table of the CNC. This caused for increased difficulty in the final assembly of the propeller but allowed for much more manageable sizes of stock to be machined into the propeller blades. As seen in Figure M.6, there are holes that are drilled and tapped to allow it to be fixed to a plate that will be

Fig. M.6 – 3D Model of the sprint propeller assembly mounted to the table. Double sided tape was again used for the first side of the blade stock because it had a significant amount of surface area which increased the tape's effectiveness.

The endurance propeller was able to be machined all at once because it is a two bladed design which can be set up on the table so it reaches the entire length of the blade in the x-axis of the CNC. There is also a support designed into the endurance propeller shape so that it can be mount in the same way as the sprint propeller.

E. The Assembly

The sprint propeller required extra finishing to allow the propeller blades to be assembled into one unit. Each blade went through a finishing step which required the support to be cut off and ground down so that the foil shapes would match that which was designed. After that was done the blades were all placed around a driveshaft substitute, a bolt with the same diameter, and pinched together using washers and a threaded nut so that the blades would be held tight and it would allow for welding to bond the three blades into one propeller.

After the welding was completed grinding and sanding was done to give a surface finish to the aluminum blade and it was then ready for on the water testing and the competition.

Fig. M.7 – Picture of the fully assembled prop ready to be finished

Appendix N: Steering

The current steering system was designed, fabricated, and installed in 2013. The current system, shown in Fig. N.1., will be utilized during competition. The material used to fabricate all components of the system is 6061 aluminum. The previous team utilizes an aluminum pivot rod until that component failed during testing in 2014. An incident occurred with the propeller kicking back up into the steering strut, hitting the strut with enough force to sheer one of the propeller blades from the main hub. Damage to the propeller, steering strut, steering pivot rod, drive shaft, and drive shaft strut was sustained. The previous team designed solutions for the damaged components. A new steel pivot rod was fabricated and was installed for the current system. The steel pivot rod is shown below in Fig. N.2.

Fig. N.1. – Steering system

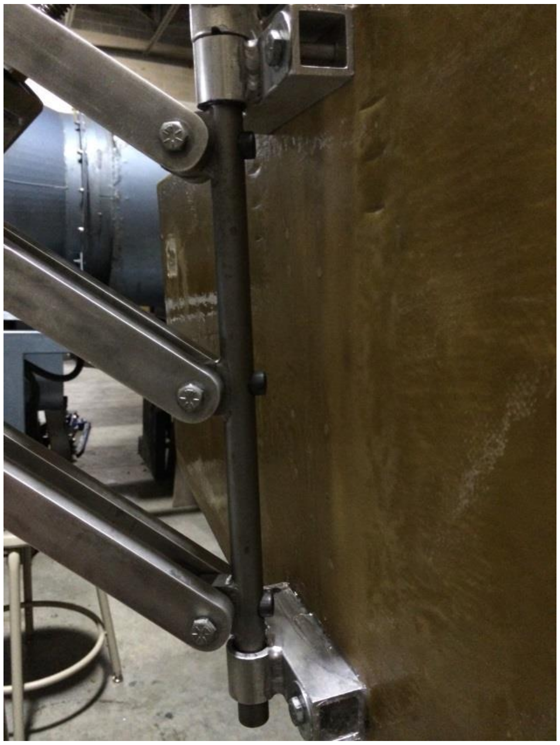
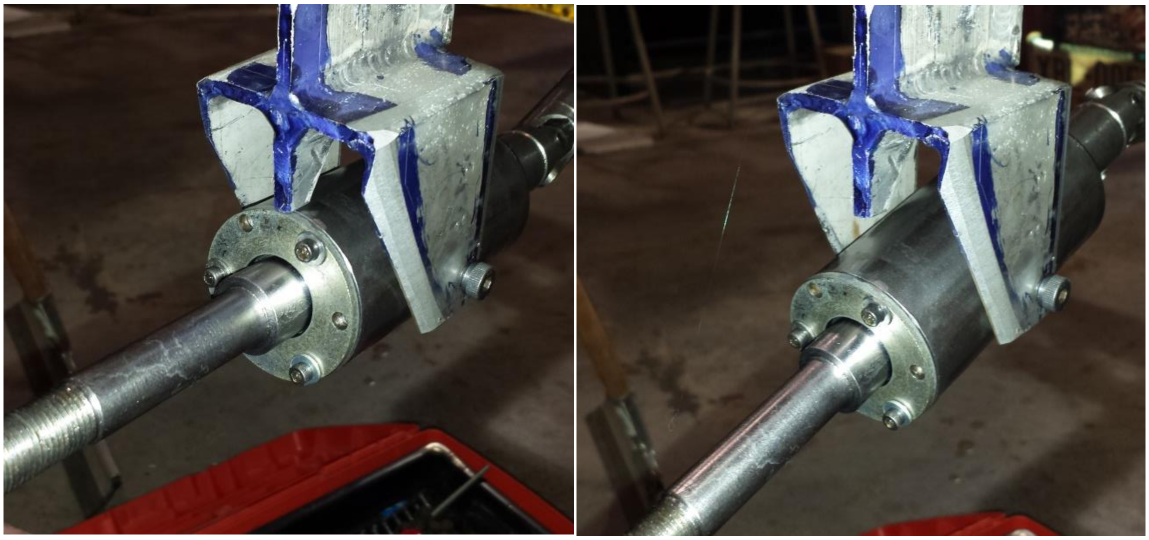


Fig. N.2. – Steel pivot rod, which replaced previous aluminum pivot rod.

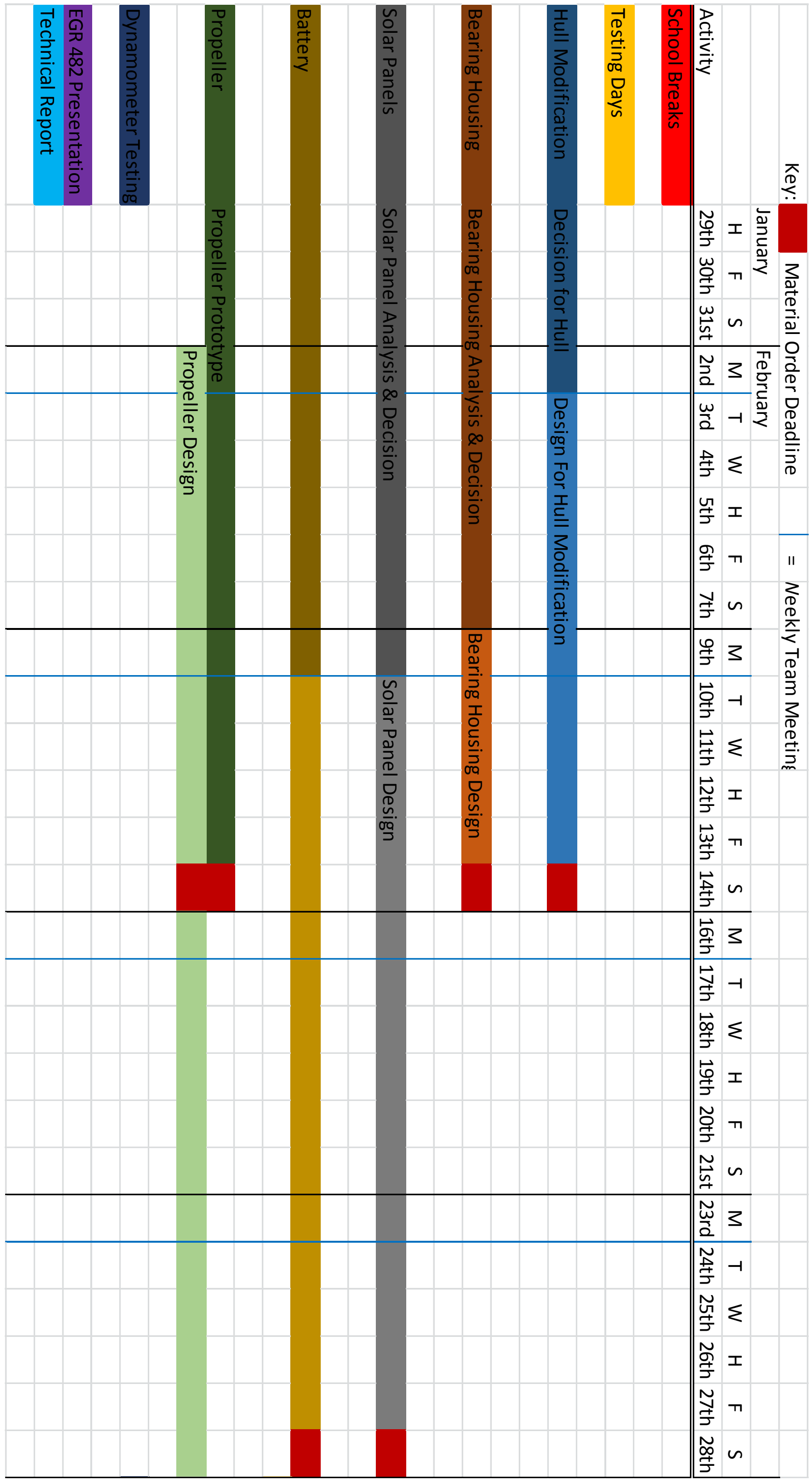
Our team installed an aluminum tab to prevent the propeller from coming into contact with the steering strut. The small tab was welded to the underside of the steering strut and contacts the thrust housing assembly, shown in Fig. N.3. below.

Fig. N.3. – Views of how the trim tab restricts vertical movement of the thrust housing

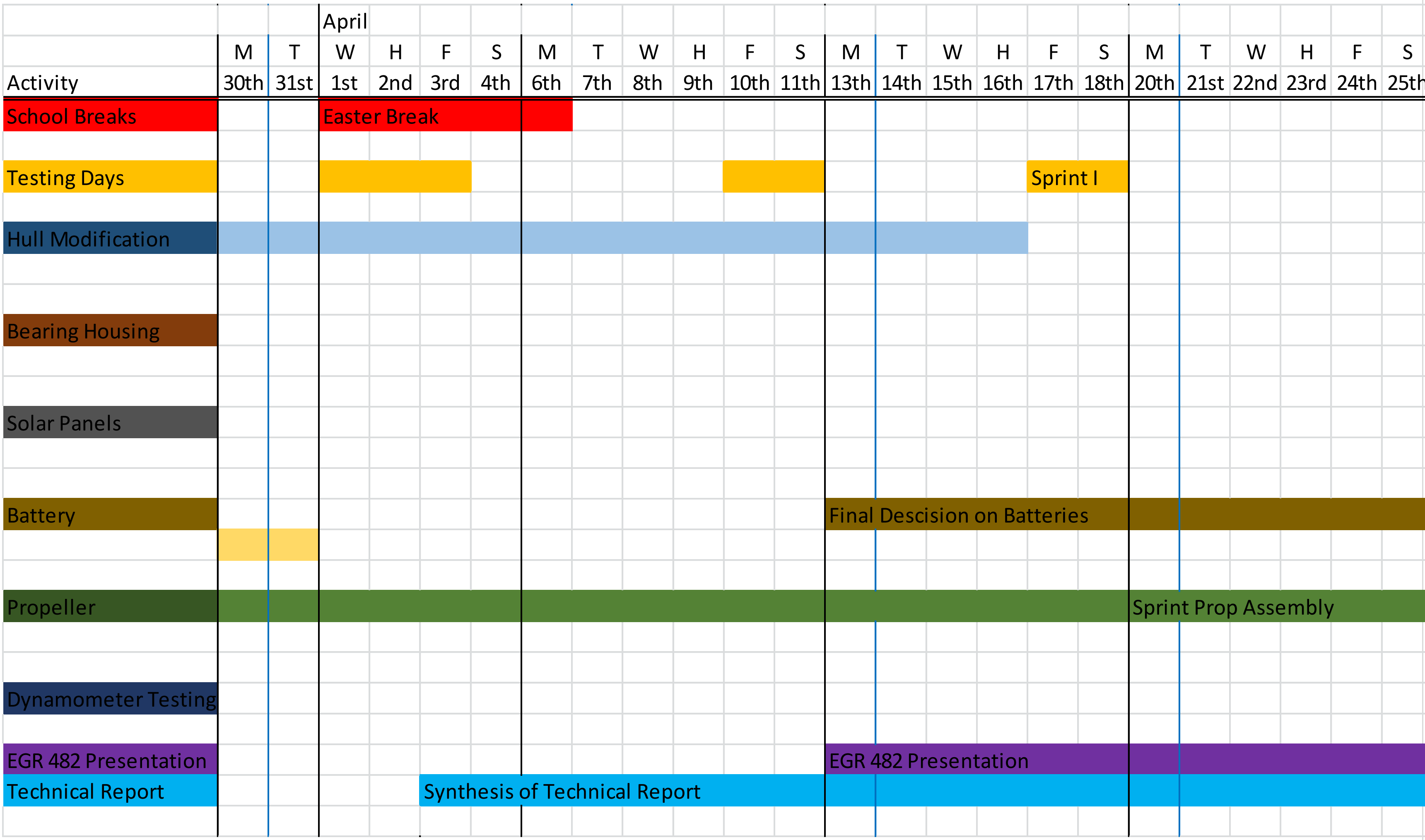


Appendix O: Gantt Chart

The schedule for the sprint semester of the senior design team was made into a gantt chart and is as follows for dates from January 29th through the wekk of the competition (June 13th).



	March																							
	M	T	W	H	F	S	M	T	W	H	F	S	M	T	W	H	F	S	M	T	W	H	F	S
Activity	2nd	3rd	4th	5th	6th	7th	10th	11th	12th	13th	13th	14th	16th	17th	18th	19th	20th	21st	23rd	24th	25th	26th	27th	28th
School Breaks							Spring Break																	
Testing Days																								
Hull Modification							Modify Hull																	
Bearing Housing																								
Solar Panels																								
Battery																								
	Battery Mount Design & Modifcation																							
Propeller							Sprint Prop Manufacturing																	
Dynamometer Testing	Test Direction & Curve of Motors																							
EGR 482 Presentation																								
Technical Report																								


April
M T W H F S M T W H F S M T W H F S M T W H F S
Activity
30th 31st 1st 2nd 3rd 4th 6th 7th 8th 9th 10th 11th 13th 14th 15th 16th 17th 18th 20th 21st 22nd 23rd 24th 25th
School Breaks
Easter Break
Testing Days
Sprint I
Hull Modification
Bearing Housing
Solar Panels
Battery
Final Descision on Batteries
Propeller
Sprint Prop Assembly
Dynamometer Testing
EGR 482 Presentation
EGR 482 Presentation
Technical Report
Synthesis of Technical Report

					May																			
	M	T	W	H	F	S	M	T	W	H	F	S	M	T	W	H	F	S	M	T	W	H	F	S
Activity	27th	28th	29th	30th	1st	2nd	4th	5th	6th	7th	8th	9th	11th	12th	13th	14th	15th	16th	18th	19th	20th	21st	22nd	23rd
School Breaks							Finals Week						Post Graduation											
Testing Days																						Sprint II		
Hull Modification																								
Bearing Housing							Bearing Housing Fabrication																	
Solar Panels													Solar Panel Fabrication											
Battery																								
	Battery Mount Design & Modifcation																							
Propeller	Endurance Prop Manufacturing																							
Dynamometer Testing																								
EGR 482 Presentation																								
Technical Report																								

							June											
	M	T	W	H	F	S	M	T	W	H	F	S	M	T	W	H	F	S
Activity	25th	26th	27th	28th	29th	30th	1st	2nd	3rd	4th	5th	6th	8th	9th	10th	11th	12th	13th
School Breaks																		
Testing Days				Endurance I														
Hull Modification																		
Bearing Housing																		
Solar Panels													Competition Week					
Battery																		
Propeller																		
Dynamometer Testing																		
EGR 482 Presentation																		
Technical Report																		

Appendix P: Hull CFD Analysis

One way of checking the validity of the hull modification was to perform CFD analysis on the hull with and without the hull modification. The hull was modelled in its original state in Autodesk Inventor and then modified to include the chine line. The hull was then rotated about its center axis to create two trim conditions for the boat; one of the trims representing the hull position in sprint and one representing the hull position in endurance. The four hull models used for the CFD analysis are included below.

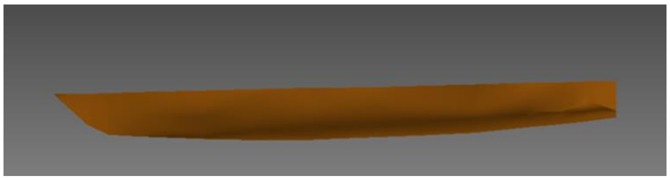


Fig. P.1 - Inventor model – original hull - endurance

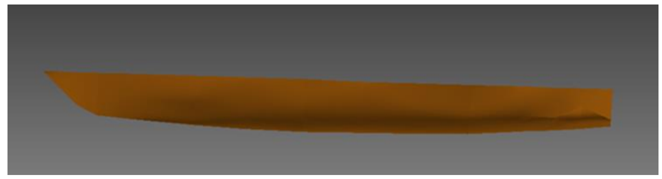


Fig. P.2 - Inventor model – original hull - sprint

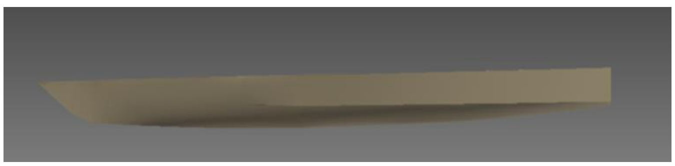


Fig. P.3 - Inventor model – modified hull - endurance

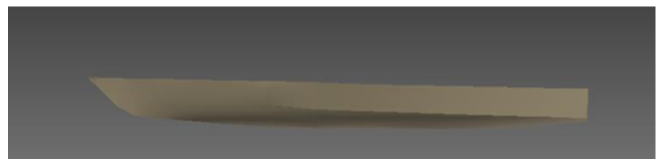


Fig. P.4 - Inventor model – modified hull - sprint

Only a small portion of the hull is actually in contact with the water during use. Therefore, only the portion of the hull in contact with the water was needed for this analysis. In order to determine the water line; a plane was created parallel to the neutral axis to represent the waterline. The portion of the boat about this line was removed from each model and the remaining slice of the model was weighted using the properties function in inventor.

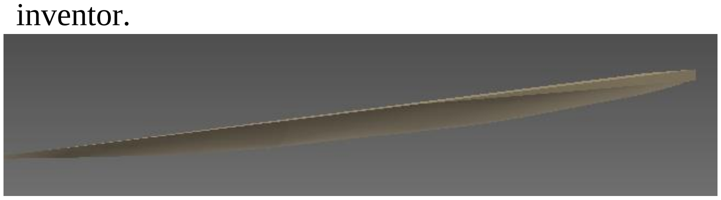


Fig. P.5 - Example of slice of hull

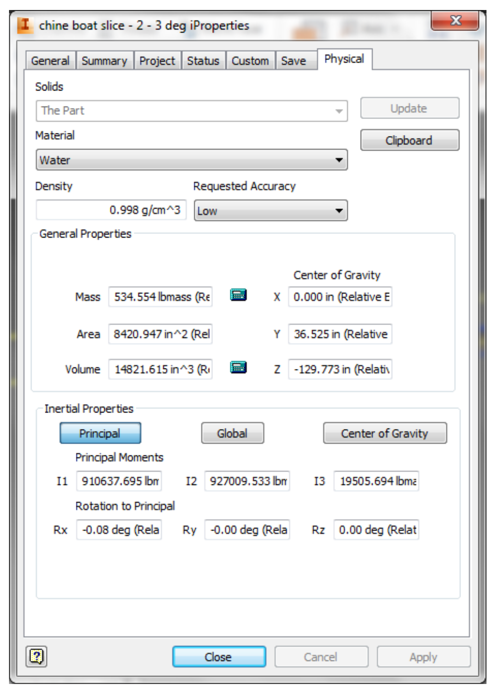


Fig. P.6 - Inventor iProperties Window

The height of the waterline was adjusted until the buoyant force was equal to the weight of the boat. In order to accomplish this the density of the boat was set to that of water and the mass of the boat was compared to that of the weight of the actual boat. This process was completed for each model. The top of the model was selected as a drawing plane and a rectangle extruded downward creating the fluid flow volume around the bottom of the hull.

The models were imported into Autodesk Simulation CFD. K-epsilon was select as the fluid to model turbulent external flow. The panel facing the front of the hull was select as an input velocity and the output panel was selected as a pressure. The input velocity was modified based on the boat speed and the output pressure was set to zero. The model was meshed as shown below.

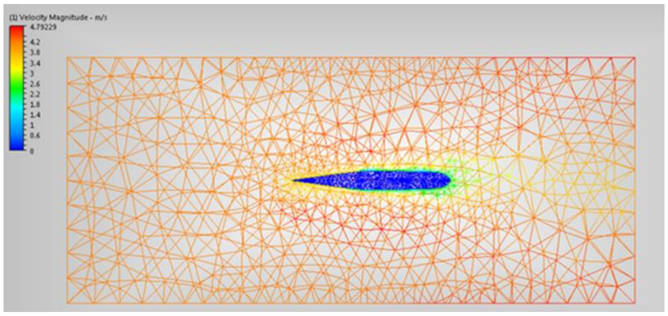


Fig. P.7 - Example of Mesh

The endurance trim of the boat was examined at four different speeds: 3, 4.2, 5, and 10 m/s. The trim of the hull and the waterline was not varied for any of the speeds. This testing ignores the other features of boat such as the steering and makes the assumption that the hull would not be changing its angle or depth in the water depending on speed. Both of these assumptions cause error in the actual drag force on the boat from the CFD results, but the CFD results are valuable in their ability to compare the hull before and after modification. The CFD modeling showed the effect the shape of the hull has on the flow of the water around the hull as shown by the velocity magnitude profiles.

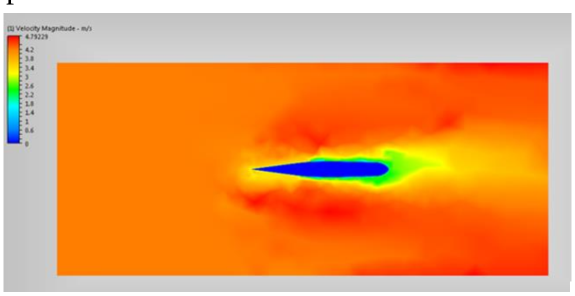


Fig. P.8 - Original hull top view - Endurance

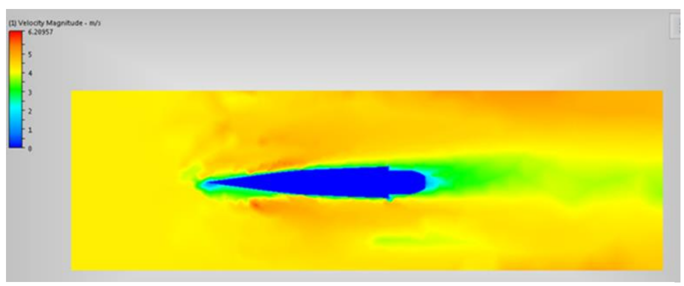


Fig. P.9 - Modified hull top view - Endurance

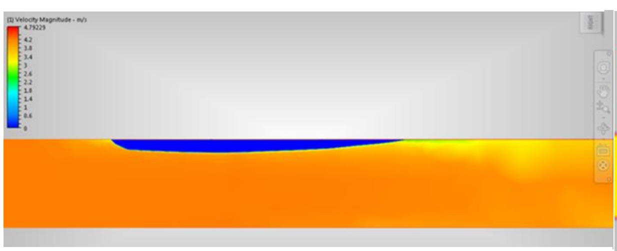


Fig. P.10 - Original hull side view - Endurance

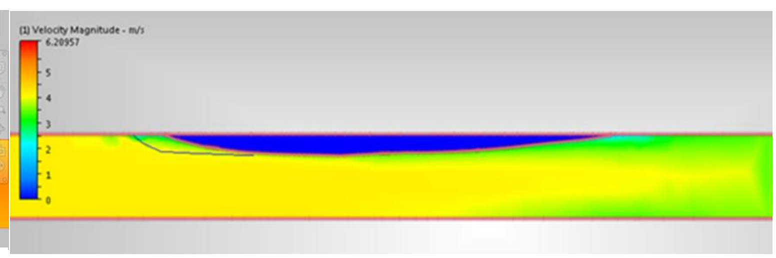


Fig. P.11 - Modified hull side view - Endurance

Endurance Mode				
	Original Shape		With Chine Lines	
Velocity	Drag	Lift	Drag	Lift
m/s	N	N	N	N
3.0	36.31	56.58	33.43	107.11
4.2	69.04	79.04	62.11	216.97
5.0	81.19	184.10	85.90	237.28
10.0	283.02	875.93	321.63	1483.61

Fig. P.12 - Endurance simulation results

The simulation shows that the addition of the chine lines had little to no impact on the drag force on the hull in endurance; when ignoring the 10 m/s, which is much faster than the boat trails in endurance. An added benefit is that the addition of the chine lines provided an increase in lift, meaning the boat should ride higher in the water and experience less drag, because of the addition.

The graphs of the amount of drag and lift compared to the speed through the water clearly shows the trend of a much larger increase in lift than increase in drag from the additional material.

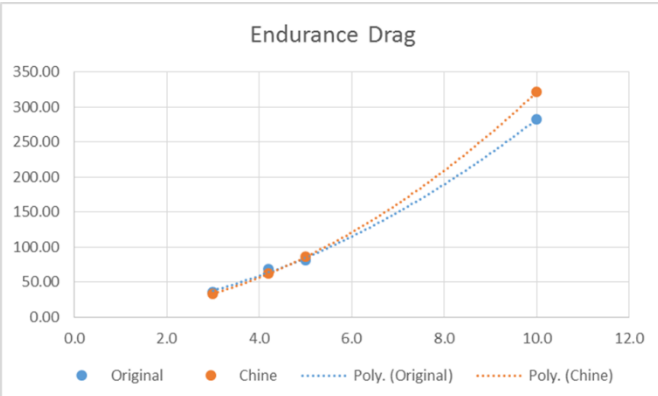


Fig. P.13 - Endurance hull drag

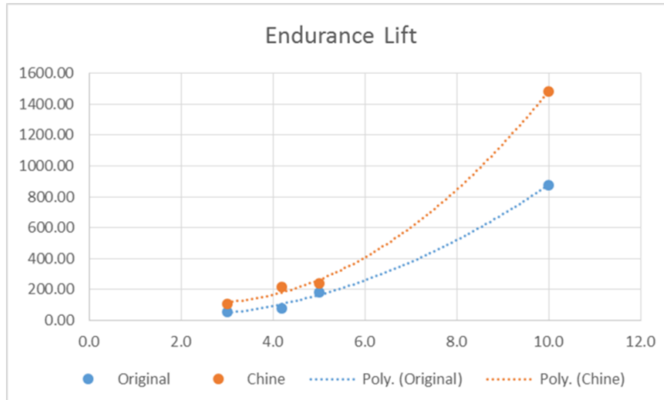


Fig. P.14 - Endurance hull lift

The sprint analysis was performed at 4.2, 7, and 12 m/s. The tilt was modified for this testing so that the hull was at angle similar to that it experiences in its transition phase between endurance speed and top speed. The velocities profiles show the impact of the chine lines on the velocity of the water around the hull.

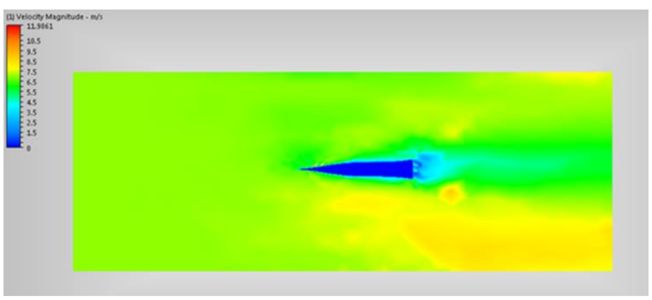


Fig. P.15 - Original hull top view - Sprint

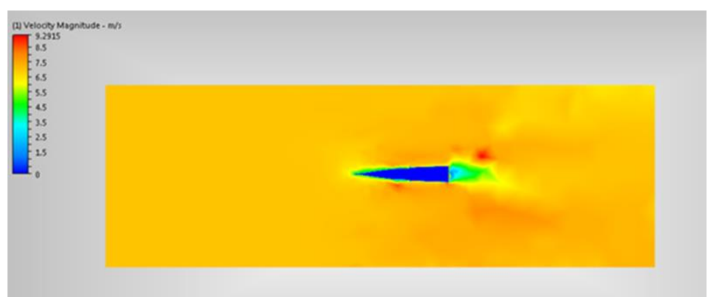


Fig. P.16 - Modified hull top view - Sprint

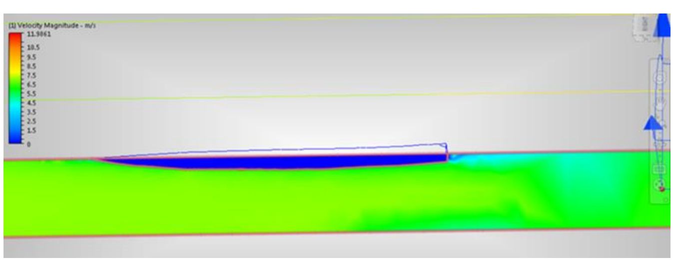


Fig. P.17 - Original hull side view - Sprint

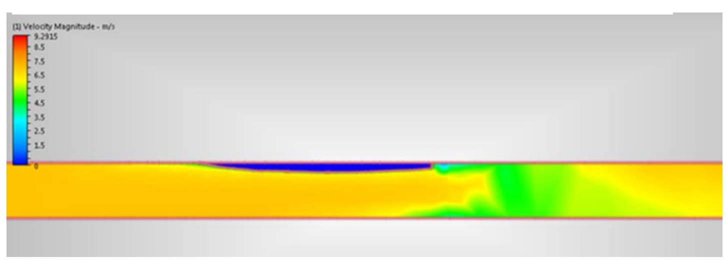


Fig. P.18 - Modified hull side view - Sprint

The results of the sprint CFD analysis show that at sprint speeds (7-12 m/s) the drag increased by up to 50 percent after the hull modification, but the lift force increased by over 100 percent. This trend is exactly the goal of the hull modification. This increase in lift force should allow the boat ride higher out of the water and plane, while not substantially increasing the amount of drag it experiences. This trend can clearly be seen in the graphs of the drag and lift force versus boat speed for both the modified and unmodified hull.

Sprint Mode - 3 Degrees Tilt Upwards				
	Original Shape		With Chine Lines	
Velocity	Drag	Lift	Drag	Lift
m/s	N	N	N	N
4.2	121.19	263.33	119.01	280.68
7.0	230.81	419.43	315.27	957.64
11.0	532.05	1108.61	751.98	2315.88

Fig. P.19 - Sprint simulation results

The results of the CFD analysis correlate with the goals of the modification. Based on this

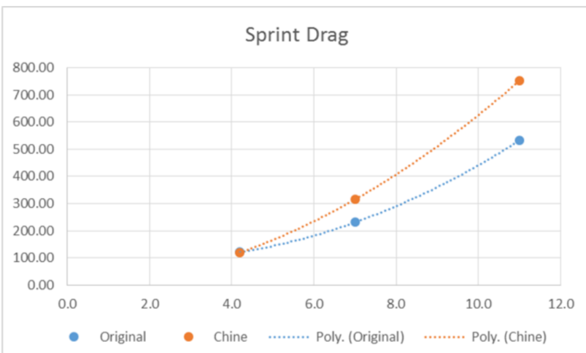


Fig. P.20 - Sprint hull drag

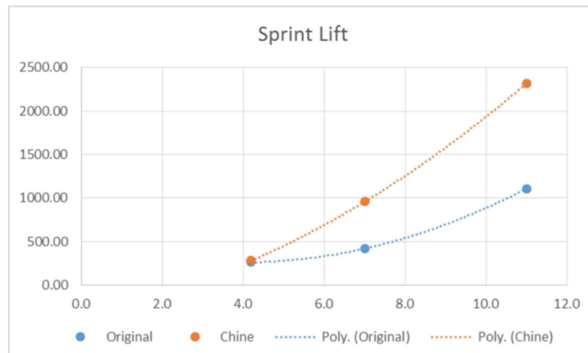


Fig. P.21 - Sprint hull lift

analysis the chine lines has minimal negative effects on the endurance performance of the hull, while adding significant lift force in the sprint competition.