Mechanical Report

Submitted to:

Metropolitan Water District

Solar Cup Challenge 2019

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Lennox Academy, Solar Cup Team

Lennox Math Science and Technology Academy

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Introduction

Lennox Mathematics, Science and Technology Academy is a school in Lennox, California. We are a public charter school that correlates its coursework specifically in the STEM field. Our school has previously participated in the Solar Cup three times. Our first year of participation, we exceeded expectations and performed exceptionally by placing first in our district in 2015 and placing first in the sprint races in 2017. Although in 2016, a lack of proper communication and "lack of initiative," caused the team not to place in the competition. Our third year, Lennox Academy placed first in the sprint, but a problem with the steering mechanism caused our boat to barrel against another team's boat during the endurance race and costing us 30 minutes in the race.

Compared to previous years, where the solar boat project was a class for our capstone course in engineering, solar boat now is an official school club open to all grade levels. Using the Solar Cup as a vehicle, our main goals are to gain hands-on experiences in different career fields, including art, design, engineering, nautical sciences, and water conservation. In addition, we aim to get all students to develop soft skills such as time management, creativity, communication, and engagement. Furthermore, we want underclassmen participants to receive mentorship from older well-versed students to maintain the club in future years.

In addition to the development of personal skills and career exposure, our goal is to create awareness towards our county's water conservation problems. As Californians, we have all experienced some shortcoming from a drought that has harshly impacted the state in the past decade. Drought.gov reports that "approximately 80 percent of the state's population, about 29,866,000 people," is still experiencing this phenomenon. As a result, our team is determined to learn more about how to conserve water, and actions we can do to make a difference. Beyond teaching students, our long-term goal is to help our community learn more about the small things they can do to save hundreds of gallons of water through our Instagram account @lmstasolarcup. Besides our public service announcement, we will post all of West Basin's tips to preserve water in short and captivating animations, and direct our followers to bewaterwise.com to learn more.

Hull

According to Archimedes' principle, the buoyant force is equal to the weight of the displaced water caused by an object. In order for the boat to float, the buoyant force must be equal or greater than its weight for the boat to float at the surface of the water. This section will focus on the different components and physics behind this year's boat, such as the center of gravity, buoyancy, the waterline, and floatation.

Hull Preparation

During the construction of the hull, our team ran into an obstacle were seams appeared after the hull of the boat was nailed down. In result, water could seep into the boat and increase the mass, thus increasing friction and reducing speed. As a solution, we used a microballoon epoxy mixture consisting of chopped chives, epoxy resin, and a fast hardener, which acted as a "putty" to fill in the seems which were then sanded down, as shown in Figure 1.

Figure 1: Seems being filled with microballoon epoxy mixture

Buoyancy and Floatation

In the years Lennox Academy has participated in, our school has demonstrated growth in improving and understanding the buoyancy and flotation of the hull. Since 2015, the team’s flotation device has evolved from using foam to small and large plastic bottles, and then a kayak float bag. Although the 2015 team’s solution seemed practical, it proved to be ineffective as it added an unnecessary weight of 10 pounds and their decision behind the device lacked justification. Figure 2 demonstrates the 2015 team’s flotation device.

Figure 2: 2015 Flotation device

In 2016, the team researched new efficient and effective options to approach the buoyancy of the boat. In effect, they improved by using small water bottles held by a fishnet, which was much lighter, more effective, and easy to construct. Later, the team reconfigured the idea and changed the device to use larger bottles for less weight and more volume. Figure 3 demonstrates the water bottle device inside their boat.

Figure 3: 2016 Water bottle floatation device

In 2017, the team continued to focus on how to further improve the buoyancy of the boat by continuing to decrease the weight of the flotation device. Through further research, the 2017 team found and used a kayak float bag which had the least weight while still obtaining the required amount of buoyancy. Looking back at the website for the kayak balloon, the float bag weighs 10 ounces (small) and 16 ounces (large).

This year, we decided to continue using the kayak balloon in our boat since it proved most effective and successful in 2017. Figure 4 illustrates the 2017 team's installation of the kayak balloon into their boat, similar to how we plan to do so this year.

Figure 4: 2017's Installation of kayak balloon on the boat's bow

In 2017, the team performed calculations using measurements of the kayak balloon that can be found on the product's website as shown below in Table 1 to determine whether the kayak balloon created enough buoyancy to make their 215-pound boat float and have a 20 percent displacement margin to meet the tech manual requirements.

Boat Type	Kayak
Material	10-gauge urethane material
Dimensions Large	47” Length x 14” Depth x 24” Width x 3” Width at end
Inflation Tube Length	38”
Features	Lifetime warranty
Notes	Sold Individually

Table 1: Specifications of the Kayak Balloon compiled from the manufacturer

Buoyancy Calculations:

The following are the calculations performed to size the flotation balloon. Table 2 shows the results of the calculations and conversions used.

Kayak Balloon Conversion Table	
Cubic Feet	Weight (lbs)
1 cubic foot	62.42 pounds
3.78 cubic feet needed for the boat	236 pounds of the boat

Table 2: Kayak Conversions

This year, our boat’s weight is estimated at 236 pounds, which was then converted to cubic feet to represent whether enough buoyancy will be provided from the kayak balloon. Compared to the previous year, our buoyancy has increased from 3.44 cubic feet to 3.78 cubic feet, an improvement from last year’s success.

Similar to the 2017 team, our team was able to input our measurements and confirm the previous year's values for the volume of the kayak balloon by using an online frustum calculator to solve the volume, which uses the formula: $V = h\left(\frac{\pi}{3}\right)(R^2 + Rr + r^2)$. Figure 6 below shows the values inputted into the volume calculator.

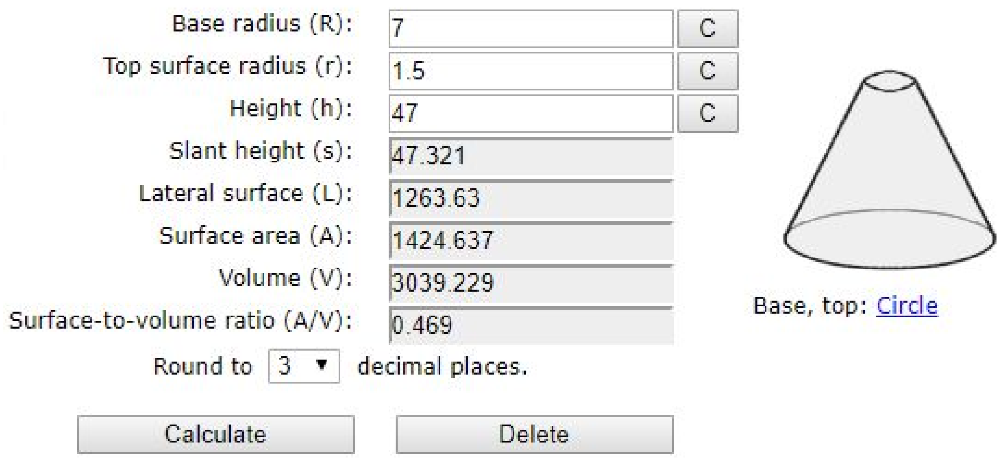

Figure 6: Frustum calculator

Illustrated in Figure 7, the variables of the formula include: R is the base's radius, r is the top surface radius, and h is the height. Furthermore, this formula is originally derived from the formula for the volume of a cone: $V = \pi r^2(h/3)$ In result, the calculator outputted a volume of 3039.229 cubic inches or 1.758 cubic feet, thus allowing our team to safely determine the object will fit in our boat to provide a buoyant force.

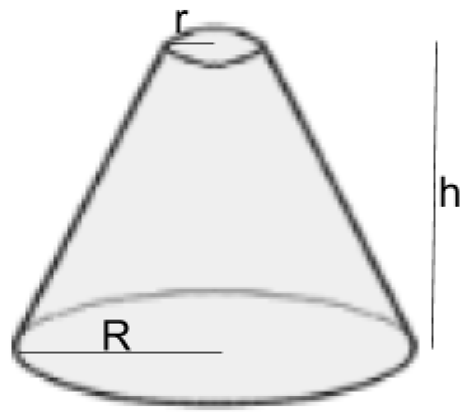

Figure 7: Labeled frustum

Center of Gravity

The center of gravity is a vital component in understanding where the downward gravitational force is experienced on the boat and how to position it in the water. In previous years, the 2015 and 2016 teams lacked the experience to successfully calculate the center of gravity of their boat. The 2015 team underestimated the size of the boat, resulting in miscalculations of buoyancy. The 2016 team was able to understand buoyancy more than the last team, but had incorrect calculations and were unable to determine the center of buoyancy and the trim line. Finally, the 2017 team were able to calculate the center of gravity and found that the previous teams forgot to consider the weight of the skipper and the drag created while the boat moved.

This year, our team wants to build upon 2017's information and determine the most accurate center of gravity while considering the skipper's position. According to the criteria presented in the 2019 tech manual, the criteria includes: the skipper can be no further than 40 inches forward of the bulk head and a skipper weight "limit" of 150 pounds. Considering the criteria, this year we would like to accurately calculate the center of gravity by weighting each object being used, including the new and previous years' components including the skipper, then placing each component relatively the same as 2017's boat while moving the center of gravity forward and keeping the boat planar to the surface for the least drag.

Referencing to former teams, the 2015 team did not have the calculations to determine the center of gravity. Later, the 2016 team addressed the center of gravity and attempted to determine it using a modeling program as shown below in Figure 8. Although they created a digital 3D replica of their boat, there were incorrect measurements performed and they forgot to consider the weight that would then be placed on the boat with the motor, the skipper, and the other components.

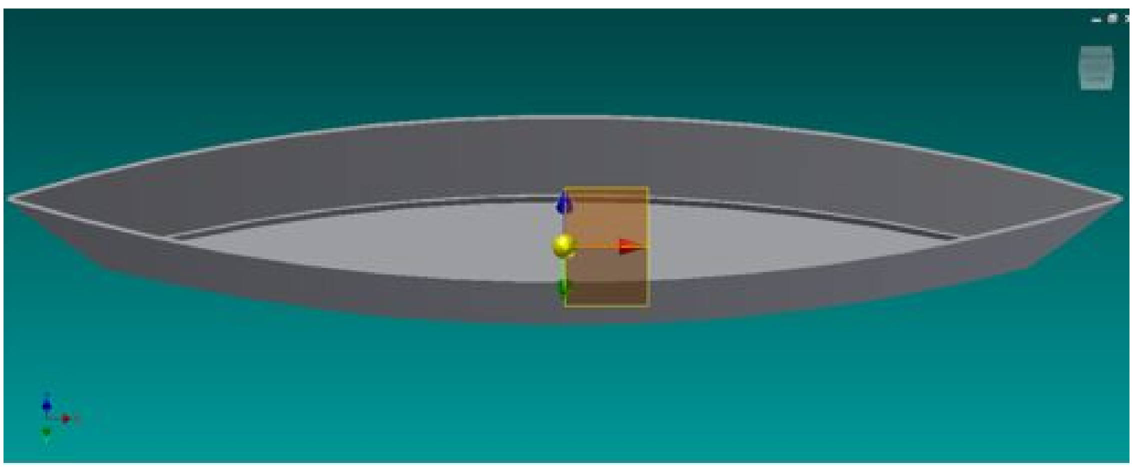

Figure 8: 2016 3D model used to find center of gravity

In order to find the center of gravity of this year's boat, we referenced the information found in the previously in 2017 to figure out how to determine the total weight and total moment shown below in Table 3.

Components on Boat	Weight (lbs)	Distance (in)	Moment (in*lbs)
Solar Panel	14.5		14.5
Bilge Pump	4	55	220
Batteries	26	73	1890
Motor	24	75	1800
Fire Extinguisher	7.4	108	799.2
Seat	3	94	282
Speed Controller	3	84	252
Skipper		94	94
Rudder	1	3	3
Propeller	3.4	24	81.6

Table 3: 2017 Center of Gravity data table

This year, most of the boat will stay the same as 2017 as most components from the boat will be reused or will be ordered new with the same specifications. Also, the distance from the stern for all components will stay relatively the same. However, changes for this year will include new and lighter solar panels, and the possible purchase of a lighter and more comfortable skipper seat. Additionally, there will be the possible modifications made to the steering system and rudder.

For the solar panels specifically, our team has decided on purchasing two new solar panels as shown in Figure 9, which weigh 4.7 pounds each, about half the weight of the 2017 solar panels, according to the product's specifications Additionally, these new solar panels allow us to decrease our total number of solar panels from four to two, while still providing the solar energy required to recharge the batteries.

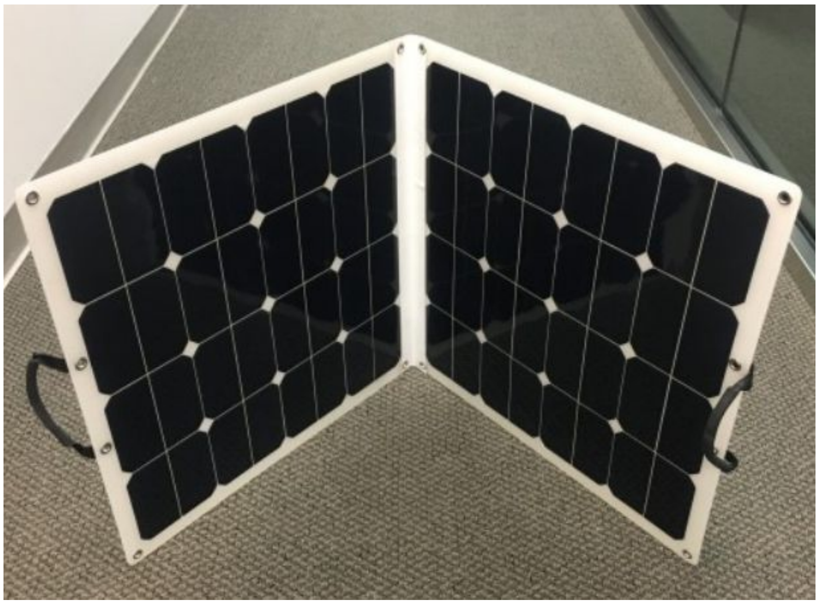

Figure 9: Solar panels our team is considering purchasing this year

As for the seat, it has evolved each year our school has participated when considering weight and comfortability. In 2015, a class room chair without legs was used, shown in Figure 10. That year, the team solely focused on installing a seat into the boat and never considered how it may factor into the center of gravity and buoyancy. In 2016, the team empathized with the fact that the skipper will be seated for long periods of time. Therefore, it was decided to purchase a new lightweight and comfortable chair that would be nailed in place, as shown in Figure 11.

Figure 10: Classroom chair used in 2015

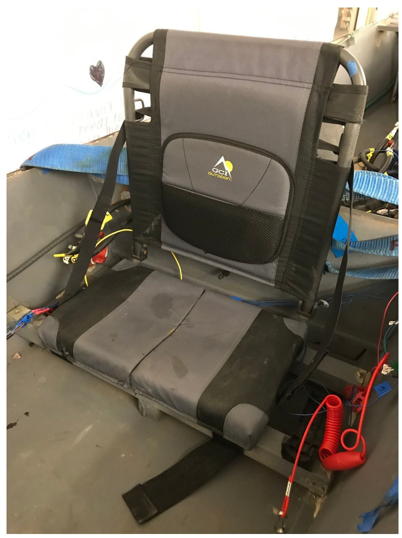

Figure 11: Chair used in 2017

The table below illustrates this year's calculations for the center of gravity. The table includes the weight of each component, including the skipper, and their distances from the stern. Then, the total moment is divided by the total weight of the boat, resulting in the center of gravity being seven feet and ten inches from the stern.

Component	Weight (lbs)	Distance from Stern (inches)	Moment (inch*lbs)
Motor	24	75	1800
Batteries (2)	52	73	3796
Speed Controller	3	84	252
Solar Panel (Bow)	4.7	142	667.4
Solar Panel (Stern)	4.7	59	277.3
Bilge / Pump	4	55	220
Rudder	1	3	3
Propeller	3.4	24	81.6
Seat	3	94	282
Fire Extinguisher	7.4	108	799.2
Skipper	150	94	14100
Total Weight:	236	**Total Moment:**	22278.5

Table 4: Current Center of Gravity measurements

Center of Buoyancy and Waterline

Another aspect that makes the center of gravity vital is the center of buoyancy, which is the upward force on the hull that is caused by the displaced fluid. The importance of the center of buoyancy is to understand and locate the buoyant force that acts upon the hull of the boat. As for the waterline, it is the line at which the hull meets the surface of the water, which factors into the drag forces that act on the hull. This year, we determined that by understanding these concepts, we can maintain the alignment of the center of gravity to the center of buoyancy while assembling our boat throughout the year.

In order to determine the center of buoyancy, our team understands that the mass placed on the boat must be balanced so that the buoyant force aligns with the center of gravity as close as possible and is located across the center of the hull from the bow to the stern. The center of buoyancy is also responsible for explaining why a small watercraft like ours will experience roll caused by unbalanced movement of objects or the skipper, as shown below in Figure 12. This year, our team wants to prevent an imbalance of mass by distributing the mass across the boat.

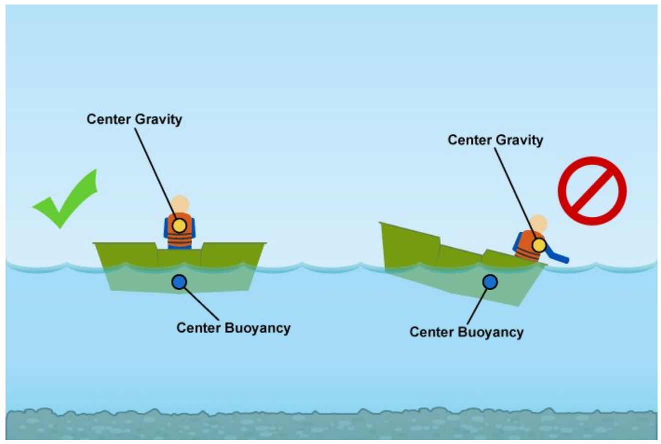

Figure 12: Illustrates the connection between center of gravity and buoyancy

The waterline indicates the location in which the hull and the surface of the water make contact, affecting drag forces that ultimately affect speed. Additionally, it serves the purpose of ensuring that the boat has sufficient freeboard to reserve buoyancy to float on the surface of the water. For this competition, using our mechanisms purposefully, it allows us to maximize the speed and efficiency of our boat during both the endurance and sprint race.

Mechanical

The objective of this year is to develop and innovate the designs from previous years, in regards to the mechanical components. These components include the motor mount, the steering mechanism, the tiller mechanism, and the possible redesign of the rudder. In order to perfect our boat's mechanisms, we will also be attempting to test new propellers and optimize the entire mechanical system while ensuring the boat can still perform basic movements with an optimal reaction time.

Motor Mount

Consideration of durable and lightweight material is essential for the construction of the motor mount. While improvements have been made since the first year of the competition, a new design that weighs less but still maintains durability would allow the boat to move faster. As the motor mount must support the motor and reduce the vibration created from the drive system, verifying the consolidation of the structure is vital in keeping the motor system in place during the competition. Figure 13 below shows the digital design of the motor mount used for the 2016 Solar Boat competition.

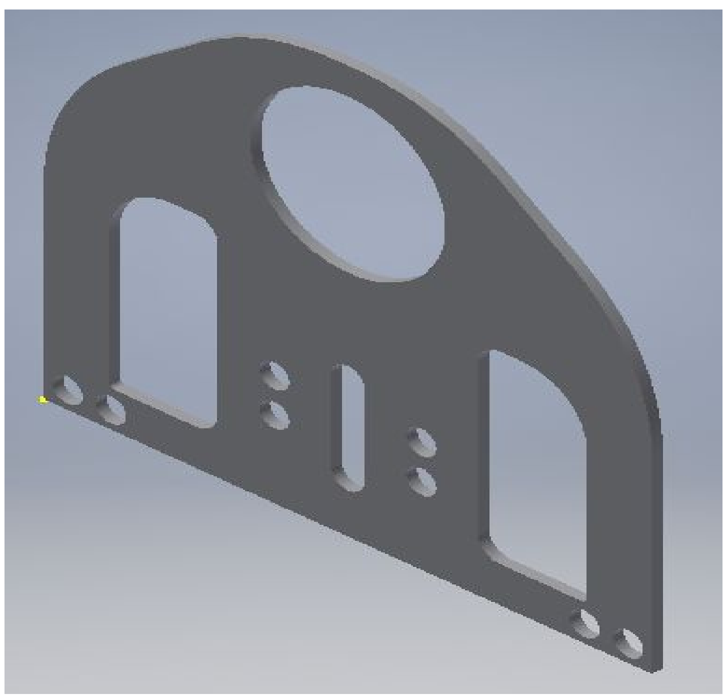

Figure 13: Initial motor mount design

The motor mount design used for the 2015 boat incorporated a ¼ inch aluminum plate that serves as lighter design replacement compared to the design they initially used in the first year. In 2016, adjustments were made which included bolting the motor mount onto the boat using aluminum arms, which replaced the wooden boards used in the first year of the competition. Replacing the wooden boards with the aluminum arms proved to be more optimal as the new design reduced the weight created by the wood. However, the new goal for 2018 is to construct a more superior method of attaching the motor mount that would decrease the negative factors affecting the boat. In other words, the primary objective is to alter the current design or create a new motor mount that would weigh less to avoid excess weight onto the boat, while still having a consolidated structure to support the motor system. In Figure 14, the physical current design of the motor mount is shown.

Figure 14: 2017 Motor Mount

While the motor mount design for 2016 created a solution to reducing weight, this year's goal is to create a new design that would be lighter yet still contains the same durability.

Moreover, the new material must be within the same cost of aluminum. The initial idea was to reconstruct the motor mount with a stronger material that weighs less. While materials like carbon fiber weigh 50 percent less than aluminum and possess greater strength, the price of carbon fiber per pound is far more expensive. Thus, the solution to this dilemma would be to reduce the weight of the existing motor mount by removing excess from the top edges while still ensuring the same durability. Another plausible solution would be to find another stronger and cheaper material to replace aluminum.

Motor

A motor is a type of mechanism that converts electrical energy into mechanical energy. It is commonly found in all types of vehicles like cars, boats and aircrafts. In our boat, it is the source of movement, therefore it is one of the most important pieces. When choosing the best motor, the specifications have two factors that should be considered. The first is revolutions per minute (rpm), or the amount of turns the motor can complete in a set period of time while running at a nominal voltage. The nominal voltage of a motor, is any acceptable voltage value that the motor needs to run. In order to increase efficiency and speed, the rpm of the motor should be matched with the rpm of the propellers. Otherwise, the motor would be overworked if its rpm is too high, and underworked if it is low. Ensuring that the boat has enough endurance to reach the end of the track is pivotal. Weight is another factor that should be considered when finding the right motor for a boat. A motor that is too heavy will slow down the boat because it takes more power to move heavier boats at the same speeds of a lighter boat, therefore a lighter motor that produces the necessary power output would be more optimal.

In 2015 and 2016 the solar boat teams used a ME0909 motor which can be found in Figure 15. Additionally the motor weighed 24 lbs. Using the curve shown in Figure 16, it was determined that the motor had an efficiency level of 86 percent when ran at 1600 rpm, and produced 1.2 kW of power.

Figure 15: The ME0909 motor used in 2015 and 2016 competition

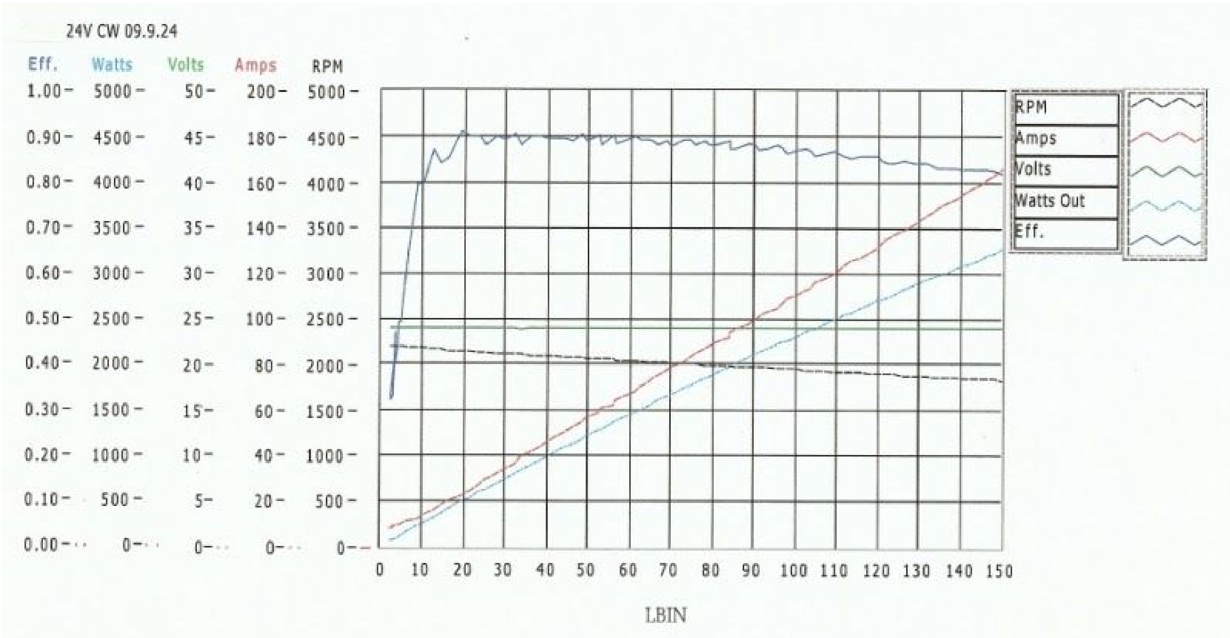

Figure 16: Illustrates the efficiency curve of the ME0909 motor

Due to the fact that the motor was old, bulky and inconsistent, in 2017, the solar boat team decided to invest in a new motor, the Saietta 95R as shown in Figure 18. Compared to its precursor, this motor was a dramatic improvement. On the efficiency found below in Figure 17, it had an efficiency level of 93 percent, produce 4kW of power at 1600 revolutions per minute, and only weighed 24 pounds.

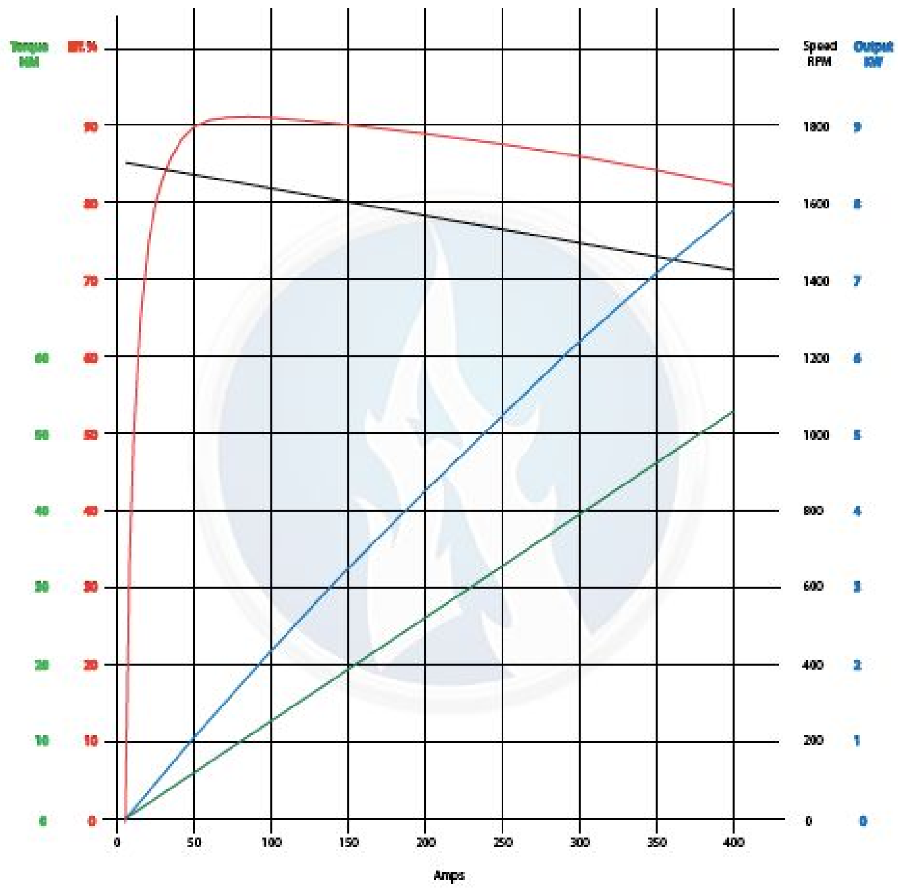

Figure 17: Displays the efficiency curve of the Saietta 95R

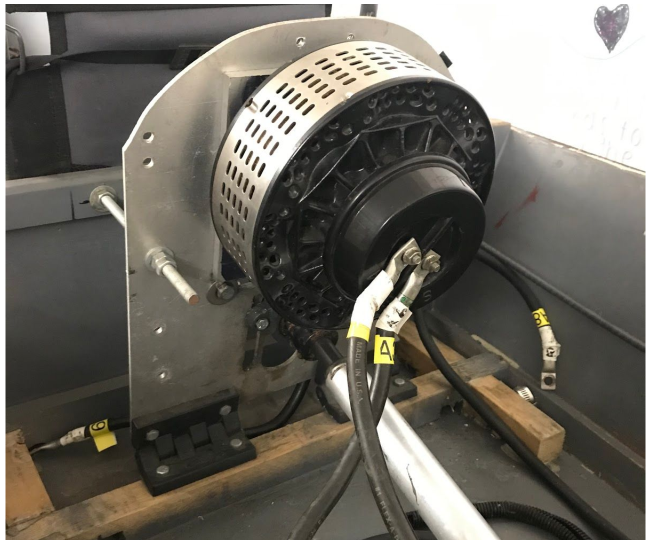

Figure 18: Saietta 95R motor used in the 2017 competition

To improve the boats performance in the endurance race, we are strategizing to use the Alltrax software. This program can be used to adjust the motor in terms of power, speed and throttle type. During the endurance race, if a skipper were to hold down a throttle to its maximum position, the boats energy would be wasted on speed. Therefore, it is important that the skipper maintain the throttle at the appropriate level to keep the motor's performance as close as possible to the efficiency curve. Using the Alltrax software we will set the maximum throttle position to a certain velocity. During the endurance race the skipper completely holds down the throttle, which decreases the workload of the skipper and increases the boats performance for the race.

Propeller

The propeller is the driving force of the boat. The two factors that determine the utility of the propeller are diameter and pitch. All propellers have a diameter that is twice the distance from the tip of the blade to the axis. This measurement dictates the amount of power the propeller can receive and the output. Therefore, the greater the diameter of a propeller, the more efficient it is, but at the cost of speed. When a propeller is larger, the boat experiences slower speeds because the blades are harder to turn compared to the blades of a propeller with a smaller diameter. Another measurement of propellers is pitch, the linear displacement of each rotation. The higher the pitch the greater the speed but this comes with the loss of efficiency. Increases in pitch equate to decreases in revolutions per minute by the motor, which is an energy loss.

In 2015, the team used a three blade plastic propeller, as seen below in Figure 19, with a pitch of 7 inches and a diameter of 8 inches for both races. The propeller was matched with a gear ratio of 1:1 and produced a maximum speed of 14 miles per hour. This has been the only team so far to use a three blade propeller.

Figure 19: Propeller used for Solar Boat 2015

Then in 2016, the team used a 2 blade aluminum propeller, found below in Figure 20. The propeller had a pitch of 12 in, the diameter of 10 in, and was matched with a gear ratio of 1:2. Under these conditions, the boat was able to reach speeds of 12 to 15 miles per hour.

Figure 20:Aluminum 2 blade propeller used in 2016. This had a pitch of 12in.

Most recently in 2017, the team came up with the idea to find the best propeller using a test tank. However, constraints on time led the team to reuse 2016's propeller. This was matched with the same gear ratio of 1:2 with a new motor and resulted in one of the best performances of the two prior teams in terms of speed. The boat finished the sprint race within 26 to 28 seconds and won first in speed for its region.

Propeller Calculations

The process of finding the best propeller begins with a simulation called CAD for Automated Shape Optimization (CAESES), shown in Figure 21. Within the model, a propeller's dimensions such as pitch and diameter are input to calculate speed and revolutions per minute. Using this program, multiple designs can be tested without the need to purchase. From there, the list of propellers will be narrowed down to those that are the fastest and most efficient.

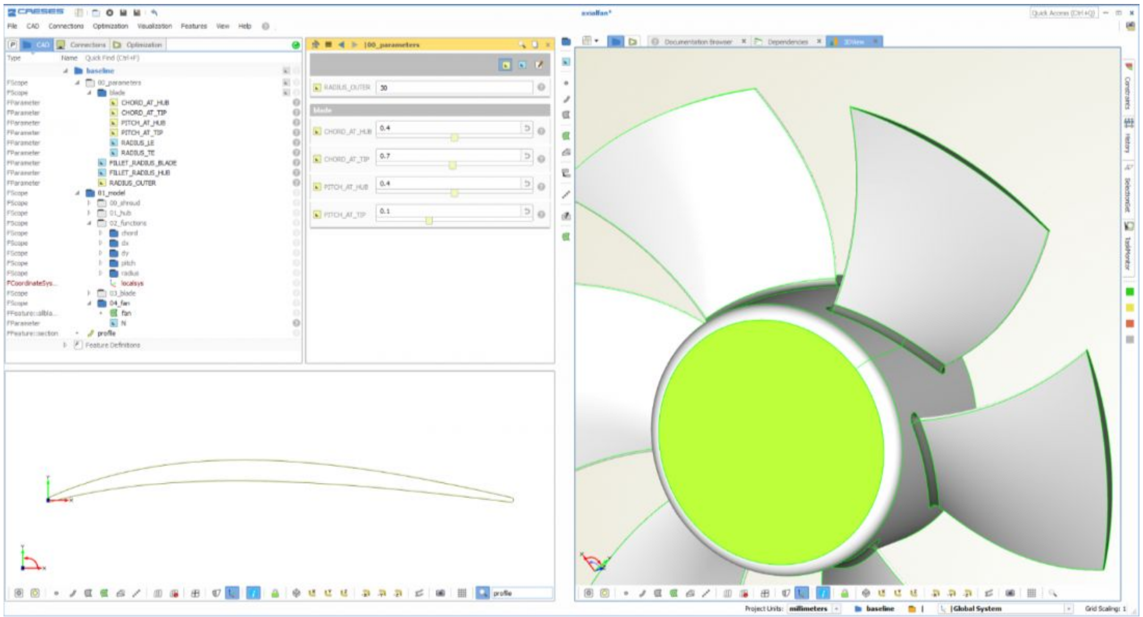

Figure 21: Shows a screenshot of the propeller simulator CAESES

From the results three propellers will be tested in the water tank, they can be found below in Figures 22 through 24. The three that will be tested are a high pitch, low pitch, and two blades. The two criteria that the propellers will be tested on is speed and efficiency.

Figure 22: This is a high pitch, 3 blade, plastic propeller. This has a pitch of 10.8in

Figure 23: This is a low pitch, 3 blade plastic propeller. This has a pitch of 8.5in

Figure 24: Propeller used in the 2017 competition

Within the tank, the propeller is attached to a shaft that moves forward when a force is applied. The components of the water tank can be seen below in Figures 26-28. On the other side of the shaft, a force plate will be set up to measure thrust. This data is then transferred and graphed through lab quest. Using the equation $a = F/m$, it is understood that for every increase in force, there is an increase in acceleration. Since the speed race is short, the boat needs to accelerate to its top speed in as little time as possible. In summary, the propeller with the largest thrust will be the best for the speed race.

For the endurance race, the propellers will be running at a constant velocity, for ninety minutes. The factors that are used to calculate a propellers efficiency are turbulence, the motor's rpm, and thrust. A propeller that produces a large amount of turbulence produces cavitation which reduces the speed of the boat. The graph that is produced by the sensor in the test tank will tell us the motor's rpm and voltage compared to the thrust of the propeller. The best propeller will maximize both rpm and thrust while maintaining sufficient voltage to complete the 90 minute endurance race.

Gearing

The gear ratio is the amount of revolutions the motor has to turn for one revolution of the propeller. The lower the gear ratio, the faster propeller will turn. However, there is a limit to the output speed due to the hull and propeller. Hull speed tells us that any boat can only go so fast. Therefore, it is important to find a gear ratio, that provides the best speed without being inefficient. Previous Solar boat teams have used gear ratios of 1:1 and 1:2. So far the one with the best results is a 1:2. An example can be found below in Figure 25.

Figure 25: Shows the 1:2 gearing ratio of 2017's boat

This year, different gear ratios will be tested with the propeller and motor to find the most efficient match between all three components. A high gear ratio means that the propeller shaft will be turning slower, but produces more torque. On the other hand, a low gear ratio will turn the propeller shaft faster but produces a smaller amount of torque. In terms of speed, a low gear ratio is optimal because it gives the boat a greater top speed. This is best for the speed portion of the competition because the sprint races are short, so the boat needs to reach its maximum speed in as little time as possible. On the other hand, endurance requires a high gear ratio because it provides faster speeds for the same number of engine revolutions. The endurance

race is all about efficiency, so we need to make sure that we are using all the potential power of the motor.

In order to find the best ratio we will be testing different propellers with the motor set at different ratios, in the test tank. In this test, the data that is collected will be the rpm of the motor, thrust of the propeller and voltage. The gear ratio that provides the best results for endurance and speed.

Water Tank Procedures

In 2017, the Solar Boat team came up with the idea to use a water tank to test the mechanical portions of the boat such as the motor, propellers, and gearning. Due to limitations on time, they were not able to use the water tank before the competition. However, this year we have set up procedures on collecting data for the three components mentioned above. We will be using the water tank to improve the speed and efficiency of our boat as a whole.

First off, we will be testing different combinations of propellers sizes and gear ratios. In this portion, we will be looking for the largest thrust. To measure this, the propeller will be placed on a shaft that moves forward when the propeller is turned on, the shaft can be seen below in Figure 26. When the propeller moves the shaft, we will find the thrust of the propeller by measuring the force applied on a force plate, found below in figure 28. This data will then be transferred and graphed through a lab quest, which is seen below in figure 27. Once we have tested the best combinations, we will compare the graphs to find the propeller and gear ratio with the largest thrust. This will give us the best combination for the speed race.

Figure 26: The shaft that the propeller is attached to

Figure 27: Force Plate and Labquest

Figure 28: Force Plate put in position to measure the force of the shaft

To test for the endurance of the boat we will be using the same procedures above, but instead of thrust, we will be looking at how closely a combination follows the efficiency curve of the Saietta 95R motor. In the endurance race, the boat should complete as many laps as possible before the batteries run out, which we estimated is 90 minutes. Using the water tank, we will be able to improve the performance of the boat.

Stuffing Box and Driveshaft

A stuffing box is designed so that the boat does not have any leakage while competing. This works by connecting the bottom of the boat to the motor in a watertight seal that prevents the components of the stuffing box from getting wet. If a leak were to occur, many of the electrical components would be affected and damaged by said leak. Throughout the years, modifications have been done to the stuffing box in regard to its constructions. This ranged from starting with a kit designed for its creation to the current design.

Students from the third year competing changed the design from using the Donovan kit to its current design, which includes an aluminum tube and waterproof bearings. Their reasoning was that the Donovan kit created too much drag due to its weight and extra components used to build it. In order to reduce the friction, the students created an aluminum tube that houses the driveshaft. This was mounted using epoxy, a mounting plate, bolts, and silicone as seen in Figure 29.

Figure 29: Stuffing box of last year's design

As a team, it was decided there would be no change to this design given that it was at peak efficiency. We noticed that the design did indeed decreased friction after the boat's speed increased dramatically.

In 2015 and 2016, the teams initially used a thrust bearing that was attached to the bottom of the hull, as shown in Figure 30.

Figure 30: Thrust bearing used in 2015 and 2016

Although it seemed practical, it was not since it weighed 3 pounds and led to loss of energy due to friction. Therefore, in 2017, the team moved away from the bearing and designed a new driveshaft and bearing as shown in Figure 31. These bearings was made of watertight plastic with teflon coating allowing the team to vastly reduced friction and loss of energy. This year, our team will continue to use the driveshaft and bearings to prevent the same issues.

Figure 31: Improved stuffing box and drive shaft

Steering

Control over a vehicle is vital as the skipper relies on the steering to control the movement of the boat. The rudder, control cable, and tiller allow the skipper to control the boat's motion, and during the endurance and sprint races certain characteristics are favored, like sturdiness or smoothness. In this section, the steering mechanism of our boat will be explained and discussed, including the components mentioned before. Moreover, modifications were made this year to the tiller to improve efficiency and durability of the steering design from 2017.

Innovated Steering Design

The main focus for the new design was something that solved all the flaws of the old design while conserving its main design and simplifying controls for the skipper, for example we wanted to avoid the tiller getting stuck with the rust, avoid constant maintenance, and make it easier to find the neutral state of the rudder. As seen in Figures 32 and 33. The new design kept the horizontal handle that the old tiller design had while simplifying it.

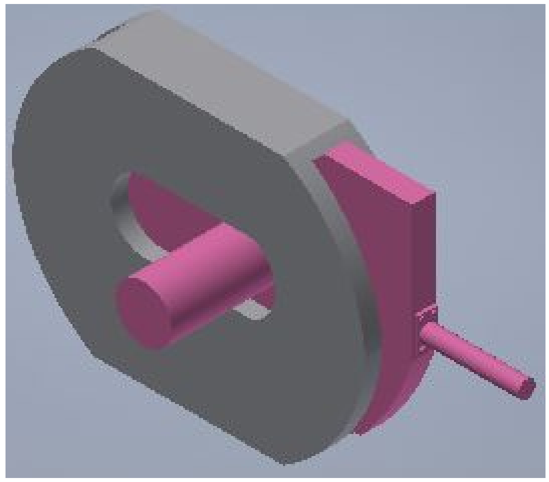

Figure 32: New tiller design 2019

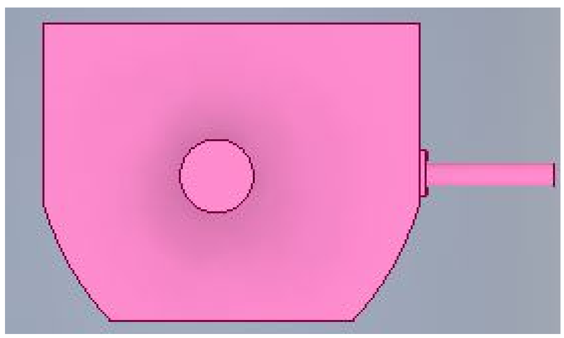

Figure 33: Interior of new tiller design 2019

Overall, we want to lower the weight of the heavy metal parts by exchanging it with plywood. That being said, our new design would be customized to fit our boat. We will use an interior part made of high-density polyethylene (HDPE), which has properties well suited such as high strength, low weight and resistance to moisture. Because of its smooth surface, it has the ability to glide back and forth with minimal friction against the plywood. The end of the interior, shown in Figure 33, will connect with the control cable and an exterior part, the gray part shown in Figure 32, that is attached to the boat which helps keep the handle steady. This design keeps the control cable steady while maintaining a low movement resistance between the two parts. Without the use of a metal ball bearing drawer, it reduces the risk of oxidation or it getting stuck. Other advantages that come with this design are the position of the control cable because it is directly attached to the handle making it move without getting stuck. Additions that we plan on making are to hollow out areas in the exterior and interior blocks to eliminate mass and reduce weight.

Tiller Design

For this year's design the mechanical team concluded that 2017 sliding tiller design for steering was the best option, however there were still some improvements that were required. This year, aspects such as unwanted movement due to ocean currents from the tiller arm, unnecessary weight, and rusting will be taken into consideration while making improvements.

Last year's tiller design worked adequately, skippers enjoyed and were comfortable with the control they were granted. Simple and securely bolted onto the starboard side of the boat, the sliding tiller offered a straightforward solution for steering. As the skipper pushes forward on the tiller, the control cable pulls on a piece of metal attached to a tube that's holding the rudder in place with ball bearings for minimal resistance, as shown in Figure 34, this movement causes the rudder to turn clockwise, and vice versa causing the boat to turn. Figure 35 shows the simplicity of the sliding tiller. Using two ball bearing drawer slides, parallel from each other, to achieve the sliding motion, it was creative, quick thinking, and economically resourceful idea. Additionally, the two parallel wooden slabs offer a stable anchor for the tiller to rest on giving confidence to the skipper to tug without worrying about any shaking. The bicycle handle, a small detail, provides that extra grip and comfort for the skipper.

Figure 34: Depicts 2017’s steering mechanism at the stern while fully pushed forward

Figure 35: Depicts 2017’s sliding tiller

All in all, the 2017 design was well made but the rusting of the sliders could not be ignored as it would sometimes jam the tiller in place, and maintaining it clean was an active chore. This dilemma sparked ideas for using a different material that wouldn't rust. Our ideas ranged from wood to HIPS (high impact polystyrene). Our solution to the rusting was to build the sliding tiller out of plywood instead, making it lighter. We also plan on spraying the wood with a sealant to prevent it from damaging, be it water or scratches.

As for the control cable we plan on mounting it identically to the 2017 design as seen in Figure 36. We're going to attach the cable to the starboard side of the boat where the main steering is located. In order for the steering to be as smooth and efficient as possible, we are going to place the control cable as straight as possible. If the control cable is not straight that will make the steering stiff and the cable will have more resistance. The control cable is attached to the steering handle and the rudder. When the control cable is pushed by the steering handle it moves the rudder and the boat to the right. Similarly if the steering handle is pulled, the boat moves to the left.

Figure 36: Depicts 2017's steering mechanism at the stern

Rudder

The rudder's primary function is to manage the water flow at the stern of the boat. Rudders play a vital role in the movement of the boat because they control the hydrodynamics of the entire boat by directing the boat in a specific direction. Overall, the rudder's performance can be affected by different factors such as its material and shape. In 2015 and 2016, the rudder from the Donovan kit was used. In 2017, the team moved away from the Donovan rudder and created their own overall rudder design and developing two rudders for the different events at the Solar Cup. Each rudder was 3D printed with a different profile to improve performance in the sprint and endurance races. Figure 37 shows the rudder used for the endurance race in 2017. Our main goal is to optimize the rudder design for each race type. This will be based on visual data collected using a test tank allowing us to look for flow patterns created and if the design creates air bubbles which effectively create drag. For now, we will be using the the rudder from the 2017 competition as we will research and test new designs and modifications as necessary.

Figure 37: 3D printed foil

Conclusion

Our goal as the 2019 Lennox Academy Solar Boat team is to continue from the success of 2017 by enhancing ideas and focusing on components to minimize drag and improve performance. We hope to maximize efficiency through redesigning mechanisms from previous years, such as the rudder, propellor and tiller. Overall, our team focused on solving the center of gravity, buoyancy, and floatation, and understanding and modifying the mechanisms responsible for controlling the boat. Additionally, this year's ultimate goal is to put 2017's test tank in use to optimize the gear ratio and rpm of the motor to the propellor.

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