Drive Train and Steering Technical Report

Los Altos Academy of Engineering

Team Members: Ruben Acosta, Tobiloba Adenugba, Benjamin Aguilar, Pedro Aguirre, Elias Conchas, Gabriel Estrada, Michael Garcia, Erika Gomez, Joseph Gonzalez, Samantha Gonzalez, Matthew Heredia, Dominic Huerta, Justin Kuoch, Ryan Lau, Melissa Lopez, Christian Mariscal, Kareem Mosalamy, George Ore, Fernando Padilla, Scott Pan, Anthony Parra, Alejandro Quesada, Isaac Ramirez, Gustavo Rangel, Nathaniel Ronquillo, Cesar Sanchez, David Sandoval, Issac Santana, Jacob Santana, Amy Tam, Joel Torrico, Isaac Treguboff, Reo Tseng, Rigoberto Valadez, Valeria Villalvazo, Leandro Wong, Jimmy Wu, Pedro Zepeda, Ruiqi Zhai

Advisor Contact:

Edward Richter
(626) 934-5514
erichter@hlpusd.k12.ca.us
www.lasv.org

Team Member Contact:

Leandro Wong
Mechanical Team Member
(626) 485-9648
leandrowong172@gmail.com

Dominic Huerta
Mechanical Team Member
(626) 774-4309
dominichuerta8745@gmail.com

Ryan Lau
Mechanical Team Leader
(626) 586-5776
RylabsUnit1@gmail.com

Amy Tam
Design Team Leader
(626) 617-1001
amytam01@gmail.com

Vicky Zhai
Project Manager
(626) 435-5776
vrzhai@gmail.com

Issac Santana
Electrical Team Leader
(626) 893-6629
issacsantana1@gmail.com

Table of Contents

Introduction

The Los Altos Academy of Engineering is diving back into the Solar Cup challenge once again for the second consecutive year. Our last season could be described as our transition back into Solar Cup after a six year hiatus. In Solar Cup 2019, we aim to do much better than our previous placement at 28th place. We hope to score in the middle of the pack. But more so than the placement, our program's main goal is to allow for our fellow students to achieve a solid experience and a grasp of engineering. For this reason, the returning veterans of our program have prioritized educating and preparing the underclassmen as we navigate through the boat design and build process.

Our team has reflected upon the experiences and lessons from last year and planned improvements accordingly. These reflections became our steering force for this year's competition. A huge improvement that we plan on making this year is reducing the total weight of our boat. This weight reduction will lower our waterline, ensuring that less water enters the boat, as well as increasing our speed in order to perform better in the sprint challenge.

We want to gain real design and fabrication experience, and for that reason have opted to rule out pre-built kits. We are extremely fortunate to have access to a fully capable machine shop, equipped with mills, lathes, drill presses, welding machines, and much more, so there is no need to use these kits. Even though they are considered as being the simpler route, we strongly believe that these will hinder our own ability to learn, to experience, to grapple and to solve problems in terms of design and fabrication.

We will also focus on improving the overall functionality of the boat. During competition last year, our steering system was far too heavy, and far too sensitive. This sensitivity led to major difficulties in steering for our skipper. We now know that we must significantly overhaul our steering system, both in weight and changing from a steering wheel to a lever. Additional improvements include factors such as rudder placement, which was misplaced last year and failed to lay in the wash of the propeller. Through these improvements on the overall function of the boat, we intend to improve our placement in Solar Cup 2019, and gain experience along the way.

Flotation and Center of Gravity Calculations

The longitudinal center of gravity for our boat was observed to be right below the bulkhead, moving slightly forward from that of our previous boat, in the centerline of the hull. This is due to a reduction of weight in the back of the boat, with the lighter steering system, shaft log, and materials. This means that our bow will ride parallel to the water. According to the Technical Manual, there is "difficulty steering if any of the bow stem is under the waterline" (Technical Manual, 2018, p.53), so having a boat which rides parallel to the water is favorable for our boat.

Batteries and Boxes	56.6 lbs.
Drive Train (Hardware)	20.8 lbs.
-Motor	24.0 lbs.
Steering	7.0 lbs.
Electrical Systems	12 lbs.
Solar Panels	7 lbs
Miscellaneous	10.8 lbs.
Total non-buoyant weight	138.2 lbs.
Displacement with safety factor of 20%	165.8 lbs.
Displacement needed / 62 lbs per foot	**2.67 cf**

The plan is to shave our boat weight down as much as realistically possible, in order to have a lower waterline and increase speed. According to the calculations on page four, the sum of every sinkable object in the boat came out to 138.2 lbs, improvement of 12.1 pounds from last year's boat. After taking the safety factor of an additional 20% into account, we will need a total of 2.67 cubic feet of buoyant material in the ballast.

Motor

For the motor, our current choice is the ME0909 Permanent DC Brush Motor. Our electrical report will go into detail on our methodology behind our motor selection.

Motor Mount

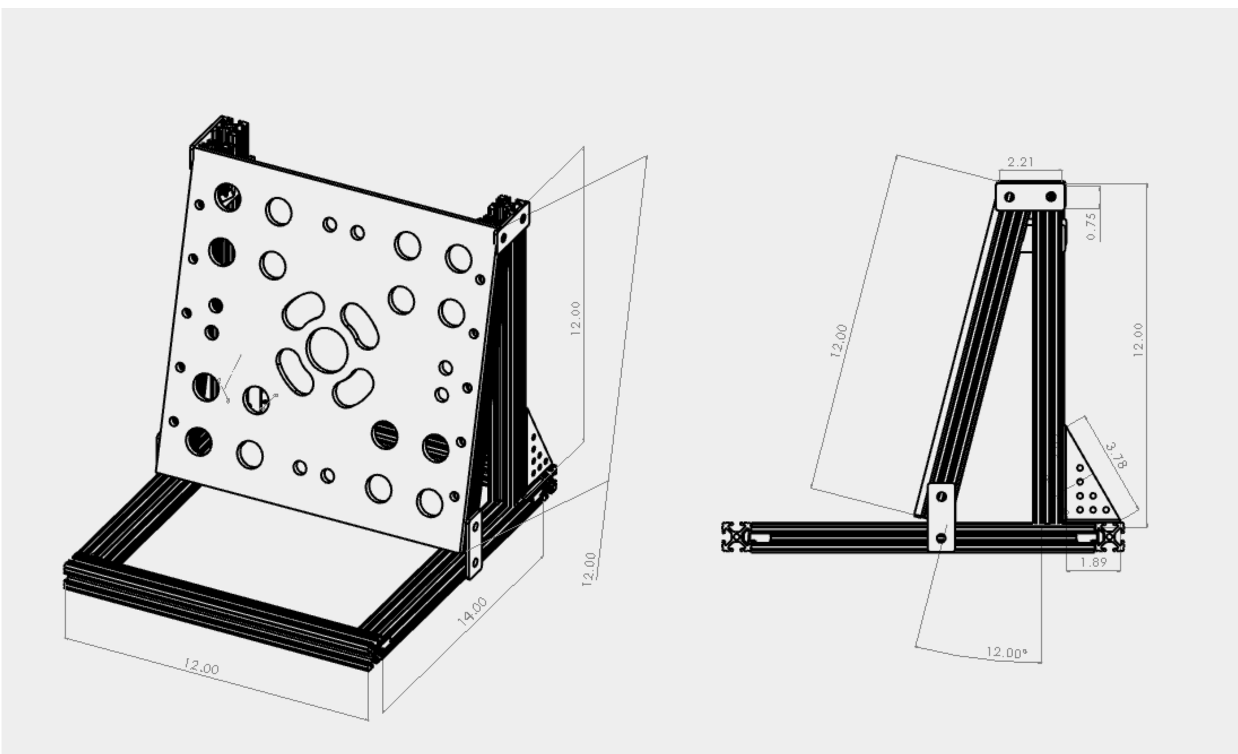


Figure 1: Multiple angles of the motor mount.

The frame of our motor mount will be made of 80/20 1010 Series 1" T-Slot aluminum extrusions. We had three considerations for frame materials. Our first consideration was hollow steel tubing. Our second consideration was hollow aluminum tubing. Our third consideration was these aluminum extrusions. While price would normally be a significant factor in material choice, we had all of these materials stocked in the shop, reducing our costs.

1” hollow steel square tubing was not chosen based on factors including weight and strength. Steel was superior to the two other materials in terms of yield strength, however; it was 2.8 times the weight of the other metals, meaning that it was unnecessarily heavy (Figure 2). In the name of keeping the boat as light as feasibly possible, steel was ruled out from being used on the boat.

Our second and third considerations were 1” aluminum square tubing and 1” T-Slot aluminum extrusions. Both essentially identical in both yield strength and weight. Additionally, the machinability between the two was satisfactory. Although the price of the T-Slot aluminum is nearly double that of the square tubing (Figure 2), versatility provided by 80/20 anchor fasteners in the T-Slot aluminum led to its selection. There is no need to weld together these aluminum extrusions, saving time which can be budgeted to improve other parts of the boat.

Material	Price (per ft)	Yield Strength (psi)	Weight (per ft, lb)
1” T-Slot Aluminum Extrusions	$3.48	35,000	1.21
1” Aluminum Square Tubing, ⅛” walls	$5.81	35,000	1.20
1” Low-Carbon Steel Square Tubing, ⅛” walls	$4.02	46,000	3.36

Figure 2: Comparison of strength between materials. Yield strength and price taken from the official websites of both 80/20, Inc. and McMaster-Carr Supply Co.

The front panel of the motor mount will be secured with 10 ¼”-20 hex bolts. To keep this angle we will place extrusions running at an angle of 12° (seen in Figure 1). These additional aluminum extrusions will be bolted to the principal frame with plates of aluminum and hex bolts. The front panel, on which the motor sits, is to be made with a ¼” thick aluminum panel, with multiple holes milled across its face in order to save weight.

The motor mount will weigh in at approximately 6.8 pounds, compared to the mount of last year that weighed 8 pounds. The footprint of this year’s motor mount is also significantly smaller than before- sitting at 14” by 12” rather than last year’s 18.5” by 15”. A smaller footprint allows for us to have more space inside the boat.

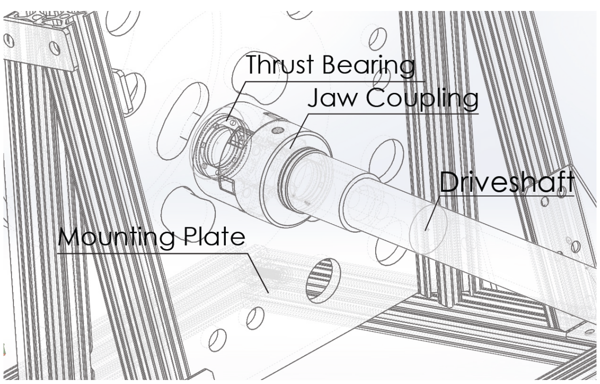
We will affix the motor to the bottom of the boat hull, screwing onto ¾” thick plywood risers which will be epoxied to the plywood bottom. This ensures that the motor mount will have a strong surface to mount onto, rather than solely screwing into the original ¼” plywood.

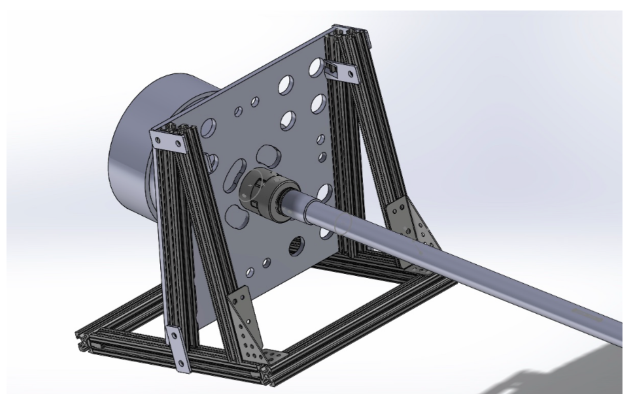
Through the conservation of both weight and space, we view our motor mount this year as a significant improvement from that of last year.

Thrust Bearing

The thrust bearing serves an important purpose: to ensure that the strong rotary force produced by the thrust of the propeller does not damage the motor and interfere with its efficiency (AST Bearings, n.d.).

Our ball thrust bearing will be held in with Loctite #603 Bearing Retaining Compound on the front panel of the motor mount, in the very same hole that the shaft of the motor resides. The bearing will protrude by ⅛”, making contact with the Lovejoy Jaw Coupling adjacent to it. After observing how the jaw coupling rides up against the motor mount when pushed into position, we found that the area immediately behind the Lovejoy coupling is the part of the drive train which experiences the greatest force from the propeller. This will be the most effective spot to place this bearing.





Figures 3 and 4: Wireframe and realistic drawings of the thrust bearing, motor mount, and drive shaft, respectively.

Transmission

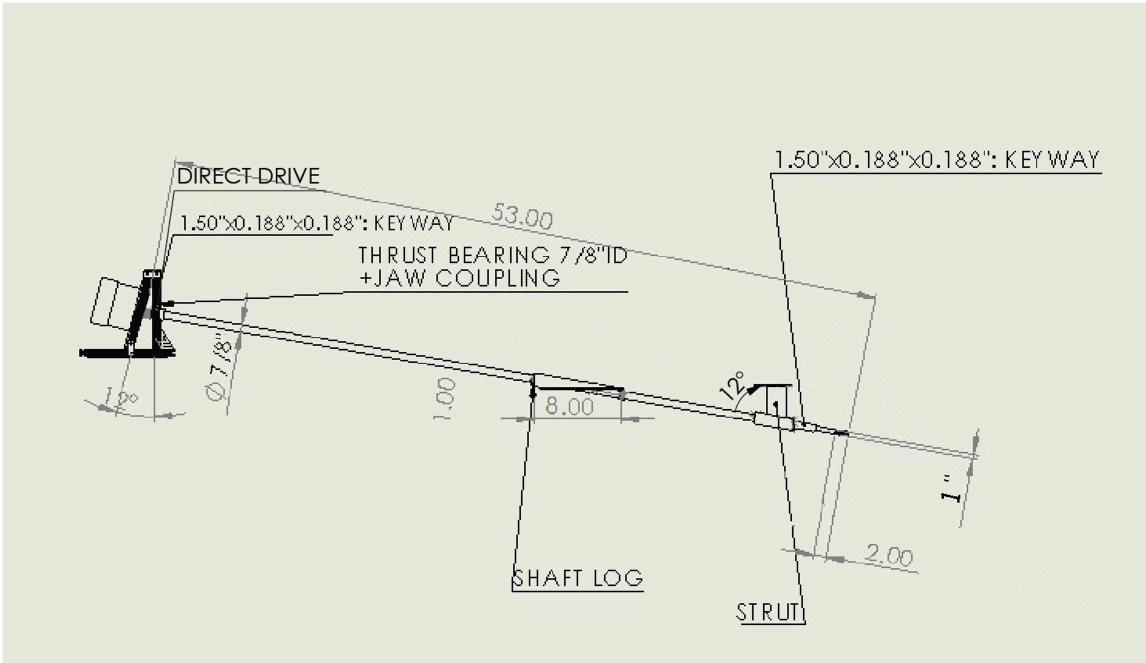


Figure 5: Side view of our drive train.

For our transmission, we considered both variable transmission and direct drive transmission. Consideration number one was a chain and sprocket system, consideration number two was a gearbox transmission, and consideration number three is a direct drive system.

Consideration number one was a chain and sprocket reduction system. One positive trait of this system would be its ability to change revolutions per minute and torque in order to see which works best with each race. However that would require many more moving parts, being overall an unnecessarily complex and time-consuming system. The fabrication process would be countless hours of testing and development, which at the end would likely not amount to a large enough gain, in the form of a multiple torque and speed transmission.

In addition, there would be a loss in efficiency of the motor. As a significant portion of the power exerted by the motor would be diverted to the chain and reduction system, rather than get sent down the shaft straight to the propeller as it would in a direct drive. In the name of time and overall motor efficiency, this reduction system idea was scrapped, as again there are no massive gains through this system.

Consideration number two was a gearbox system. With a gearbox system, we would be able to shift between gear ratios in order to make the boat propeller provide more torque or more speed, changing this depending on the conditions. A reputable transmission that would fit our boat would be ZF 15M marine transmission, mounting with a parallel offset. It was found to cost far too much; sitting at $1,821 on fredwarner1.net, an online marine supply, at the time of writing this report (Fredwarner1, 2018). For only the ability to change torque and gear ratio, this price is not within the parameters of our budget. Aside from cost, the gearbox weighs in at 31 pounds: which is far too heavy for this year's design.

We viewed consideration number three, a direct drive system, as the best candidate for our transmission for Solar Cup 2019. Assembly will be with Lovejoy Jaw Couplings, whose attachment will be detailed in the next Drive Shaft section. Alignment of these will be a challenge, but the low weight, low cost, time-efficiency, and overall simplicity offered by these couplings lead us to use it in our boat.

Drive Shaft

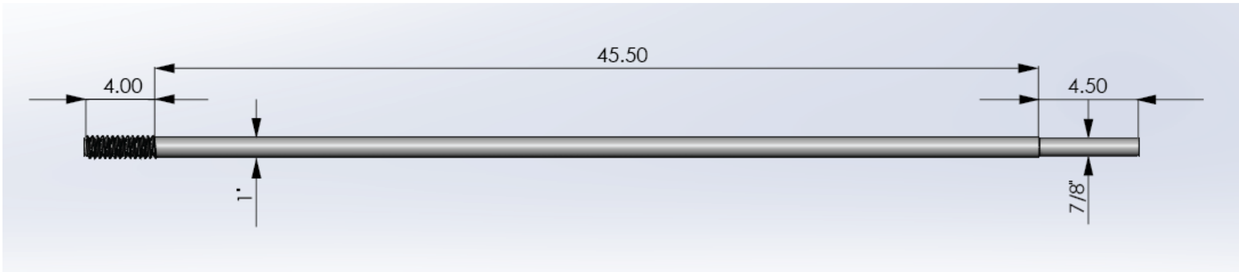


Figure 6: Our steel drive shaft.

Our boat's drive shaft will be made out of 1" round chromoly steel hollow tubing. We arrived at this decision after considering three different candidates. Our first option was titanium, the second option was aluminum, and third option was steel tubing.

In an effort to align our design choices with our goal of saving weight, we looked into utilizing considerations number one and two, titanium and aluminum. These materials were two and three times less dense than steel respectively (Benes, 2017). However, we chose not to use either one of them. To start, consideration one, titanium, is substantially more difficult to work with than steel, in addition to being significantly more expensive.

Even with the fact that we have a fully capable machine shop in our school, we currently do not possess the experience or knowledge to mill or fabricate titanium. If we did set out to create this drive shaft, it would take hundreds of hours of collective machining experience in order to be able to fabricate a metal with such a high strength and rigidity. In a perfect world, we would be more than happy to fabricate titanium, as the products can be far superior to steel and aluminum, however it is simply out of our reach at the moment.

Additionally, titanium is expensive. For a four foot long piece of grade two titanium tubing, at a diameter of 1", it costs $122 (TMS, 2018). A piece of steel with the same dimensions costs $48 on McMaster-Carr. In terms of both difficulty in fabrication and price, titanium was ruled out from being utilized on the boat.

Aluminum is relatively lightweight, easy to fabricate, and extremely abundant. However its difficulty to weld eliminates it as an option. According to Lincoln Electric, “even for those experienced in welding steels, welding aluminum alloys can present quite a challenge” (Lincoln Electric, n.d., p. 1). In the name of durability and ease of welding, aluminum was ruled out.

Consideration number three, which was steel 1” round hollow tubing. We selected this material for the drive shaft. Despite it being the most dense metal considered, its ease of welding, high strength, and ability to be fabricated lead to its selection.

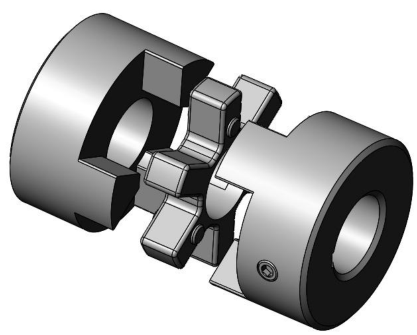


Figure 7: Lovejoy Jaw Couplings. The two jaw couplings (left and right) attach, with the elastomer “spider” linking the two together (center).

The selected 1” alloy steel hollow tubing will extend to approximately fifty three inches, and have two solid steel caps welded onto either side: One with a diameter of ⅞”, and one with a diameter of 1”.

The ⅞” side attaches to the motor with a Lovejoy ⅞” L-Type Jaw Couplings (Figure 7). The elastomer “spider” insert ensures that jaws both on the drive shaft and motor do not grind on each other, creating unnecessary friction. It is important to note that we utilized these couplings last Solar Cup, and they did a great job of delivering the power of the motor directly to the drive shaft.

These couplings are extremely simple to mount. The motor and both Lovejoys have pre-milled keyways, so we will mill a small 3/16” x 3/32” keyway into one cap and secure the coupling with a steel key. This ensures that the couplings will always rotate in sync with the motor and drive shaft. Lastly, we will tighten the set screw to ensure that the jaws do not move out of place up or down the drive shaft or motor shaft.

The opposite 1” cap of the drive shaft goes inside the water, and holds the propeller. 2 inches of this cap will be threaded, allowing for a large 1” nylon locknut to screw on behind the propeller, securing it in place. A cotter pin mounts behind the locknut onto the stainless steel cap, so that the nut does not manage to slip off of the drive shaft. All of this is done to not let the propeller fall into the water.

Another keyway will be milled here in order for a steel key to sit between the propeller and the shaft.

In order to propel the boat forward, a propeller tends to pull itself and the drive shaft in the opposite direction, the direction away of the boat assembly. For this reason, we plan to use three shaft collars at different parts of the drive shaft so that the shaft does not slide out of the boat and into the water.

Shaft Log and Stuffing Box

The main objective for a shaft log is to ensure that water does not enter the boat through the shaft hole. Last year, our purchased shaft log was made of solid brass, but it was heavy and expensive. According to an online boating supply, a similar shaft costs around $150.00, and weighs in at close to five pounds (Great Lakes Skipper, n.d.). We seek to circumvent these two negative factors through this use of PVC rather than brass.

We will utilize a piece of 14” long PVC, with a 1” internal diameter, cut to an angle of 12° in order to match that of the motor and drive shaft. We will bond it to a ½” plank of solid wood with marine adhesive sealant. In addition we will coat the wood with layers of epoxy (similar to that in Figure 8). This ensures that water does not enter the wood and lead to warping, cracking from expansion, and overall weakness.

Figure 8: A PVC shaft log taken from solarcup.org. The PVC is attached to the piece of wood here with a type of “plastic welder”.

For the stuffing box, we could have opted for a shaft log with an integrated stuffing box inside of the shaft log itself, however that would greatly increase weight. The assembly would require multiple bearings at both ends of the shaft log, in order to lower the interference and resistance at hand when it contacts the drive shaft. With two bearings inside of this shaft log, we would be adding an extra one or two pounds to the boat.

The stuffing box will be at the top of the shaft log, which points towards the motor. It is comprised of a PVC conduit bushing and a hose, which fastens tightly with two hose clamps. This is so that no water makes its way up the shaft log. We are still considering the use of rotary seals inside the shaft log, and will determine their necessity once we get the boat out into the water.

Strut and Shaft Angle

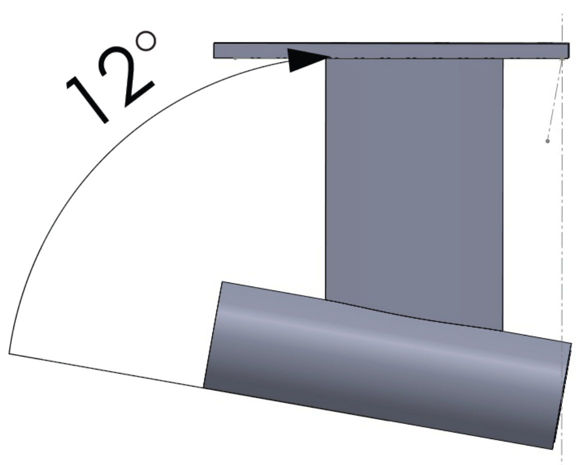


Figure 9: The design of the strut.

The strut serves the vital purpose of providing additional support for the drive shaft under the boat, and maintaining its alignment to the motor. Our purchased strut will be made of out brass, at an angle of 12°. While we could have fabricated the strut out of wood or a composite material, time-efficiency and rigidity are the two most important factors of the strut. As it will need to ensure the alignment and rigidity of the boat, we will prefer to use metal, in order to be able to cope the the stresses created during steering. In addition, the onset of not having to fabricate a strut from PVC, wood, or even metal will save us time that can be budgeted elsewhere on the boat. Brass will weigh more than if we used these other considered materials, but the positives of a brass strut outweigh its negatives.

As for our shaft angle, according to Rice Propulsion, a propeller “parallel to the waterline is the most efficient in theory”, however that is both unreliable and impossible to achieve with a direct drive transmission (Rice Propulsion, 2006, p.1). Limiting the extent of the angle, on the other hand, is possible.

Shaft Angle	Performance Loss
3°	0.14 %
5°	0.39 %
10°	1.52 %
15°	3.41 %

Figure 10: A table taken from www.ricepropulsion.com. This depicts the performance of propulsion lost solely to shaft angle.

With a simple proportion calculation based on the table provided by Rice Propulsion, the approximate loss in performance from a shaft angle of 12° is about 2.73% (Figure 11). This is preferred to a much deeper angle, such as 19°, needed to use a large propeller for the sprint race. These have a performance loss of nearly 4.55%, in addition to the “significant variable loading to the propeller blades”, which results in “vibration and/or cavitation”, lowering the overall efficiency of the drive train (Rice Propulsion, 2006, p.1). During cavitation, our propeller will not be solely treading through water, but also through the air agitated by the vibration of the propeller. This poses major problems for efficiency as these propellers are not designed to gain thrust in air.

$$\frac{3.41}{15} = \frac{x}{12}$$

$$\frac{\cancel{15}x}{\cancel{15}} = \frac{40.92}{15} \qquad x = 2.728$$

Figure 11: By using the given ratio between one shaft angle and its performance loss, it is possible to calculate the performance loss an additional shaft angle. Numbers taken from Figure 10.

Propeller

We are using one three blade polymer propeller for this year's competition, with a pitch of 6”. Some initial considerations for propellers included two blade propellers and propellers with a greater pitch.

We found that two blade propellers vary too much in thrust: at low and medium speeds they struggle in terms of delivering thrust, but at high speeds they deliver far too much thrust (Solas Propellers, 2017). We seek a stable and predictable acceleration in our boat, so for that reason a two blade propeller was not chosen.

Additionally, most two bladed propellers need to be significantly larger than their three blade counterparts. We found that if both the blades on a two bladed propeller were the same size as their three bladed counterparts, the speed of the motor would need to increase to compensate for the lower surface area. Put simply, an effective two blade propeller would simply be too large to fit under the boat, at designated our shaft angle of 12°.

It is important to note that we used this same model of propeller last year. While one of these larger two blade propellers would be excellent for the sprint challenge, we are focusing on the reliability of our smaller three fin propeller. Due to the fact that we were out for one heat in the sprint race last year, we still do not know the propeller's maximum potential in the sprint, and still seek to find out its maximum capabilities.

Steering

Our steering system this year will be radically changed, being based on a push-pull lever system, rather than the drum and pulley system of last year. This year's overhaul of the steering system had to deal exclusively with the largest issues with our drum and pulley system last year, which were weight, fragility, and sensitivity.

Our steering system of last year came close to about twelve pounds, mostly due to the steering wheel itself, weighing in at approximately seven pounds. This is too heavy. We seek to free up as much weight as feasibly possible, so this previously heavy steering system will need to be redesigned and scrapped.

In terms of fragility, the main issue was with two lathed aluminum posts attached under the dashboard. These guided the steering cable around the skipper and across to the pulleys. At competition, the stress from the steering cable was far too great for one of the posts. One snapped off, and needed to be reattached. This was unacceptable, and must be changed.

Lastly, the steering wheel was far too sensitive for the competition. Even with only a quarter turn of the steering wheel, the rudder would rotate nearly 50°. In addition, it was inconsistent during use. This caused multiple issues for our skipper, who even had difficulty gauging whether the rudder was straight or not, and had to be far too careful with the steering system. We will need a method to adjust the sensitivity and responsiveness of the system.

Our goal for steering this year is to ensure that the aforementioned issues related to weight, fragility, and sensitivity are minimized, and we believe that they will be minimized with a push-pull steering system.

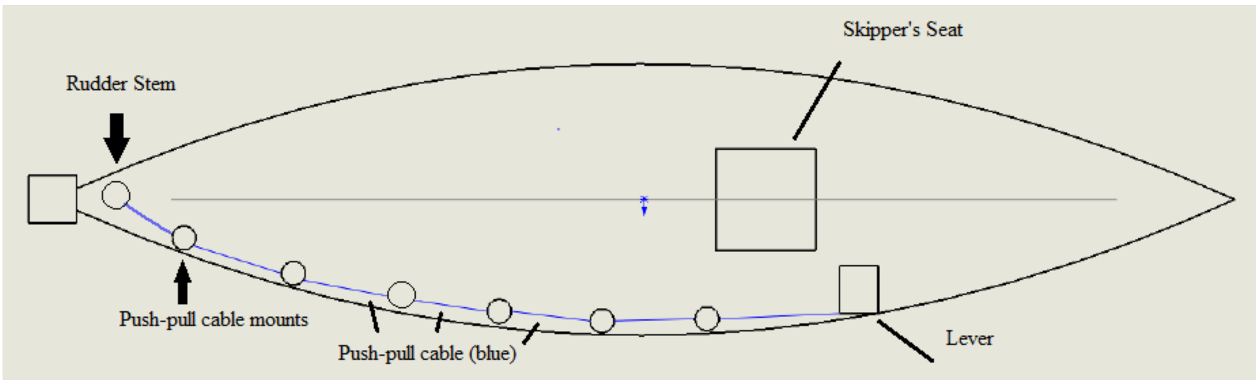


Figure 12: Top/bottom view of the steering system. The lever will be at the side of the skipper's dominant hand, who has yet to be selected.

The push-pull steering system redesign will consist of three new important parts: a lever, which is to the side of the skipper, the push-pull cable, and a rudder control arm which attaches to the rudder stem.

The lever will be the method in which the skipper interacts with the steering system. We initially considered keeping the steering wheel in the boat design, because the idea that levers could cause more fatigue for the skipper surfaced, leaning us more to side with the steering wheel. However, the truth of the matter is that one does not spend their whole time in the race steering. It is, certainly, in significant use, but not to the point where its use would tire the skipper. In addition, the lever will be much lighter than the steering wheel, sitting at no more than two pounds compared to our previous steering wheel. For these two reasons a lever was selected to be our skipper's method to interact with the steering system.

The 12" lever will be placed to the side of the skipper, which connects to the push-pull cable (Figure 12). This lever will move forward and backwards, where pulling or pushing would turn the rudder left or right.

We will most likely use aluminum for the lever. As presented by Figure 2 in the motor mount section, aluminum is much less dense than steel. In our effort to reduce weight as much as possible this year, we opted to use aluminum. The ability to easily weld steel does not specifically apply here, as we will not need to weld steel with the lever. We can use the clevis fasteners in Figure 12 to attach it to the rest of the system.

Solid plastic was initially taken into consideration for this lever as well; but there was simply no durable method to mount the push-pull cable. Although its extremely light weight and ease of fabrication are two favorable qualities, its negative aspects outweigh its positives. The stresses that the cable experiences and the need for a thin lever worked in aluminum's favor. Plastic can wear down quickly, especially when in contact with metal parts. This low durability is not favorable for this steering system.

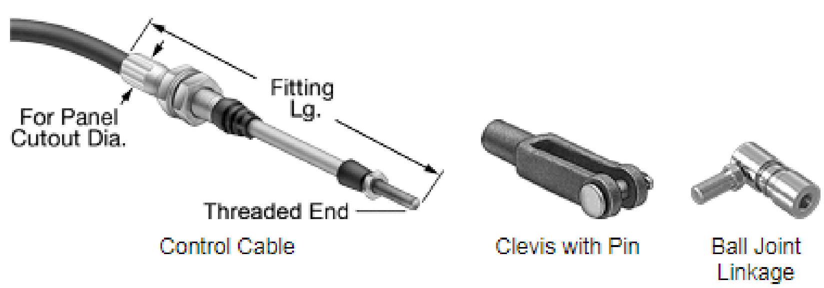


Figure 13: The end of a sample push-pull cable and compatible parts. Supplied by McMaster-Carr Supply Co.

We chose a push-pull cable lever system in contrast to a steering cable-based joystick system, like that detailed in the technical manual, due to simplicity (Technical Manual, 2019, p.100). Both the steering cable and push-pull systems would be effective, however the steering cable based system utilizes a whole loop of cable, which travels on a set of multiple pulleys. From first hand experience, we know that working with a loop of this type of cable is cumbersome. It can come loose from the pulley system as a whole quite easily, creating a situation where we would need to constantly put back onto the pulleys. A turnbuckle certainly will improve with putting the cable back on its pulleys, but it will not rival the simplicity of a push-pull cable. Push-pull cable simply has to be firmly mounted as one line to a side of the boat and will carry out its function effectively.

In addition, several moving parts at different portions of the boat restrict our ability to place things throughout the boat, in fear of affecting these cables. Last year, we opted to push the cable to the bottom of the boat and allow for more real estate in the boat. In doing so, we gained more space to freely place batteries, pumps, and the motor mount, but placed massive stress on our cable mounts. This is why the one cable mount on the dashboard broke free of the steering system. With push-pull cables, we will have more room in the boat to place the pump, electrical systems, and batteries, and not severely stress pulleys or cable mounts.

This 6' push-pull cable will runs along the side of the boat, spanning from the side of the skipper to the stern of the boat (Figure 12). It will be mounted to the lever and rudder control arm with proprietary clevis fasteners, available from McMaster-Carr along with the push-pull cable itself (Figure 13). These are semi-permanent solutions that will mount simply and effectively.

The cable as a whole must be held to the side of the boat with fabricated aluminum mounts. As the cable consists of an outside rubber protective layer and a steel core, the mounts will exist to ensure that when utilizing the lever, one will be able to move solely the steel core on the inside rather than the outside cable as a whole.

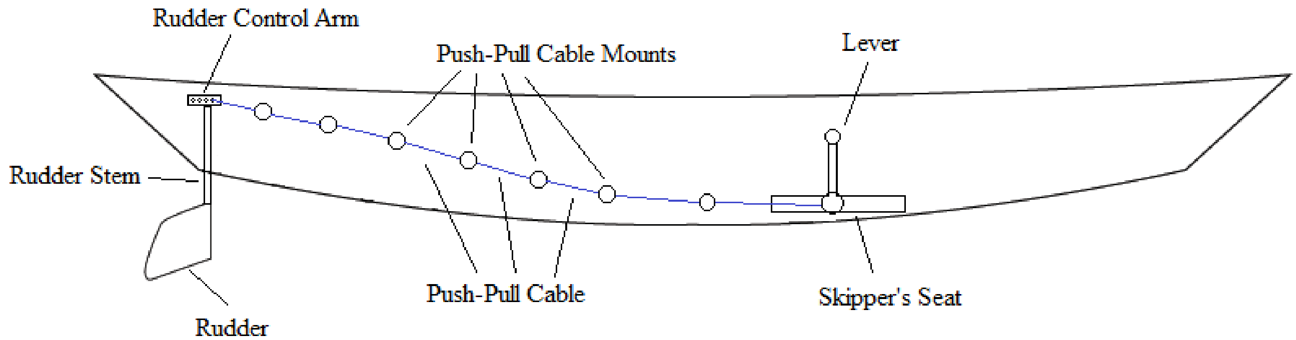


Figure 14: Side view of the steering system.

The final portion of the steering system is the rudder control arm, which serves as the link between the push-pull cable and the rudder stem. This control arm will simply slide over the rudder stem, and be secured by set screws and an additional shaft collar on top. These ensure that the rudder stem does not come loose and fall into the water. The control arm will be fabricated out of steel, in contrast to the aluminum of the lever. It will be in the shape of a rectangle, and have several holes milled across its span. This part will need to endure significant amounts of stress, as it is a small piece which will see constant use. Its small size means that weight difference between materials will make an insignificant impact on the total boat weight.

The push-pull cable will attach to any one of these small holes on the control arm. As these holes will progressively move farther away from the rudder stem, we will be able to calibrate the sensitivity of the steering (Figure 14). This inability to calibrate the steering sensitivity last year was a major flaw and issue in our previous boat.

Altogether, further testing will be needed to ensure that we will have an effective and improved steering system. Nevertheless, with our current design considerations we feel that our steering system will outperform that of last year.

Rudder

Our rudder this year will be a composite rudder. It will be made out of a fiberglass panel in between two panels of carbon fiber. These components will be bonded together with multiple coats of West Systems Epoxy, for rigidity and waterproofing. An aluminum strip with holes on the back of the rudder will ensure that there is a solid surface for the rudder to attach to the rudder stem.

The main advantage to a composite rudder is the weight. An aluminum rudder or steel rudder would weigh more than twice as much as a composite rudder (Griffiths, 2006). It may not be as strong as made one of a metal, but in our experience last year, the rudder worked perfectly. It did not crack of fail under stress, concluding that a composite rudder is perfectly adequate for a rudder material.

The rudder stem, which is the underwater rudder mount, will be fabricated from a solid piece of steel in the name of strength. It will rust, but the strength of the material has supremacy over its weight. The rudder will screw onto drilled holes of the stem, holding it in place firmly.

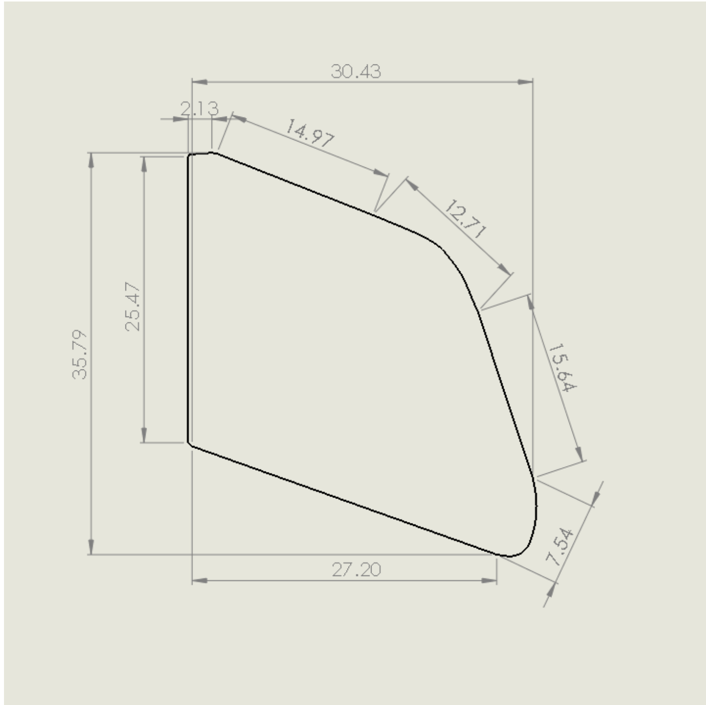


Figure 15: The rudder design.

Conclusion

Through improvements on multiple parts of the boat like the motor mount and shaft log we seek to lighten up our upcoming boat to increase speed and lower our waterline. These, along with our overhauls to the steering system, are in our crosshair for this upcoming year. The completion of all of these improvements grants us a positive vision into the future of our place in Solar Cup 2019. We hope that through a reasonable and methodical approach to boat building and design, Solar Cup 2019 will play out better than 2018, and we cannot wait for it to unfold.

References

AST Bearings, LLC. (n.d.). What is a Thrust Bearing? Retrieved from https://www.astbearings.com/thrust-bearings.html

Benes, J. (2007, December 20). Cool Tips for Cutting Titanium. *American Machinist.* Retrieved from https://www.americanmachinist.com/features/cool-tips-cutting-titanium

Fredwarner1 Marine Parts & Supplies. (n.d.). ZF 15M 1.9:1 Marine Boat Transmission Gearbox Hurth HBW150 3306002004. Retrieved from https://www.fredwarner1.net/product/zf-15m-1-91-marine-boat-transmission-gearbox-hurth-hbw150-3306002004/

Great Lakes Skipper. (n.d.). Marine Hardware Boat Shaft Log SL-14 | Malibu Boats 13 x 3 Inch Bronze. Retrieved from https://www.greatlakesskipper.com/malibu-sl-14-marine-hardware-bronze-13-3-4-inch-boat-propeller-shaft-housing

Griffiths, B. (2006, August 1). Rudder Gets New Twist With Composites. *CompositesWorld.* Retrieved from solarhttps://www.compositesworld.com/articles/rudder-gets-new-twist-with-composites

Lincoln Electric Holdings, Inc. (n.d.). Aluminum: A Guide to Aluminum GMAW Welding. Retrieved from https://www.lincolnelectric.com/en-us/support/welding-how-to/Pages/guide-aluminum-welding-detail.aspx

Rice Propulsion, S.A. (2005). Shaft Angles. Retrieved from http://www.ricepropulsion.com/cartas/TNL49/Tnl49.htm

Solas Propellers. (2018, May 11). *Propeller 101: 3 Blade or 4 Blade* [Video file]. Retrieved from https://www.youtube.com/watch?v=j5xoVM0U8Yo

Metropolitan Water District of Southern California. (24 September, 2018). Technical Manual for the MWD Solar Cup 2019. Retrieved from http://www.mwdh2o.com/PDF_In_The_Community/Solar_Cup_Technical_Manual.pdf

TMS Titanium Supply, Inc. (n.d.). Titanium Tubing. Retrieved from https://store.tmstitanium.com/products/6903/titanium-tubing/cp-grade-2/0.073-wall-0.999-diameter-47.800-long