Stony Brook University

Senior Design Project

Fifth Progress Report

Solar Boat Propulsion System

Group Number: 6

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Project Summary

Powering a boat by an electric motor is not the mainstream solution for boat propulsion, however with recent advances in battery technology and more efficient electric motors this type of system may become more common with the rising trend of electrification. The general design premise of this project is to depict and produce a propulsion system for a solar powered boat.

Electric propulsion is currently not a very common solution due to the higher costs and the lower range compared to conventional gas or diesel engines. However, they do provide benefits including noise and vibration reduction, as well as a large reduction in the general maintenance necessary for the consumer as they are often much simpler in design.

Ensuring that the boat is efficient without resulting in power loss is a main priority of this project. The final prototype of the propulsion system must be able to function for the Stony Brook Solar Racing team and dominate against their competitors.

The overall goal is to create a new system that is most efficient and significantly faster than the current propulsion system, which is not performing to the necessary standards.

Our team plans to coordinate our design with three other teams that are working on the solar panels/batteries, and the steering system. These three systems will work together to improve the efficiency and top speed of the boat. We will also collaborate on a transmission that can be used to further enhance the efficiency of the boat for different events such as endurance races.

Revision Table

September 19, 2023

Revision Letter	Date	Written by:	Description of Change in the Latest Revision
A	9/20/2023	SS	Initial release, chapter 1, 2, and 3.
B	10/24/2023	KR	Revise chapter 1, 2, and 3, addition of 4 & 5
C	12/22/2023	CE	Addition of chapter 6,7
D	03/08/2024	SS	Addition of Chapter 8
E	05/10/2024	AK	Addition of Chapter 9

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Nomenclature or List of Symbols

- IC: Internal Combustion Engine

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Chapter 1. Introduction

1.1 Preface

This project report provides an overview of the design and implementation of an outboard propulsion system for a solar racing boat. Chapter 1 of this report provides insight into the problem that is being addressed, the challenges faced, and a timeline for the project. The second chapter focuses on market research and preexisting solutions/patents as well as listing the project design requirements for the customer. In Chapter 3, we discuss the product design specifications including descriptions of users, system constraints, and design requirements.

1.2 Problem and Objective

Traditional gas-powered motors, although widely used for many watercrafts, have environmental issues associated with them. The largest issue is the burning of fossil fuels resulting in harmful pollutants being released into the atmosphere. Combustion engines are well known as the largest contributor towards our carbon footprint. Not only do they affect the atmosphere, but they also release hazardous substances such as oil and fuel into the water as well, which is extremely harmful to aquatic life. In recent years, there have been limitations placed on the amount of combustion engines produced in both the automotive and boating industries. However, the pollution rate in large bodies of water has continued to steadily increase. With an electric propulsion system, these consumer issues can be addressed. The use of solar panels allows energy to be generated solely through the sun, replacing the previous method of internal combustion, and releasing high levels of carbon dioxide into the atmosphere and water.

While electric power plants certainly contribute less to emissions, they prove to be a challenge to design when trying to deliver a large amount of thrust for long periods of time. In this project, we will need to focus on balancing power delivery, efficiency and weight of our propulsion unit. Our design needs to be desirable for a consumer when compared to traditional combustible motors, providing enough speed to be considered 'fun' for enough time to be useful. This will be achieved by minimizing drive system losses, motor efficiency, hydrodynamic drag and overall size of the product. In turn, we will produce a competitive unit which can be raced against other solar boats. In the end our goal is to develop an efficient and powerful propulsion with the purpose of winning the 2024 solar splash competition. The propulsion system has to be faster than the previous design and provide a more efficient output with the updated batteries and solar system that is also being installed.

1.3 Societal Factors

Compared to a traditional gas-powered motor, the use of electric motors in our solar boat design is significantly more environmentally friendly and promotes a safer, more enjoyable user experience. Air pollution has become an emerging threat that motor companies are struggling to address. The switch to electric motors has become the predominant method of reducing our carbon footprint. Energy generated from the solar panels produces zero direct carbon emissions/air pollutants. For a typical gas-powered boat, around 2.5 kilograms of CO_2 is emitted per liter of fuel

burned. As for a solar-powered boat, they can save about 25 kilograms of CO_2 emissions for every 10 hours of operation. They also contribute towards a more comfortable.
user experience. Our solar boat design drastically reduces noise given the gas-powered motors (70-80 dB) have been replaced by solar-powered motors (50-60 dB). The design promotes driver safety with no combustion processes taking place to produce a fire hazard. Additionally, the proposed design will improve overall energy efficiency. The solar panels directly convert sunlight into electricity while a gas-powered motor requires numerous processes to burn fuels and generate mechanical power. Our electric motors will be able to last up to 10,000 hours of use, significantly higher than 1,000-2,000 hours before a gas-powered engine needs to be replaced. Not only can they operate longer, but they also dramatically reduce fuel costs, making long-term savings significant.

1.4 Challenges

The main challenge in our design is generating efficient propulsion that can exceed speeds of other boats in competition while also balancing the weight. Our group must consider factors including motor efficiency, frame design, propeller design, and shell material in order to achieve optimal power and sustainability. Additionally, the group must ensure that the outboard system is lightweight and avoid impacting the boat's buoyancy and stability. However, this can become difficult while attempting to increase power output. The group must determine a suitable power to weight ratio to achieve this balance.

To ensure our group meets all requirements by the deadline, we have assigned tasks to each member. Once a task is completed, it will be reported to the group leader for approval. These tasks include selection of material, dimensioning, propeller design, hydraulic installation, CAD modeling, etc.

Our knowledge from Machine Design (MEC 310) is applicable when discussing boat kinematics. Design of Machine Elements (MEC 410) will be used for determining gear ratios and performing torque/power calculations. Additionally, Mechanics of Solids (MEC 363) will be useful as we can refer to stress/strain analysis and bending moment calculations. As far as chemistry courses, our knowledge from Material Science (ESG 332) will help us choose appropriate materials, for example, anti-corrosive metals such as aluminum and stainless steel.

Our team lacks experience with hydraulic steering systems, an essential component of our project. Although another team specializes in steering, we must determine the most efficient method of connecting our outboard system with the hydraulic system. We will cooperate with the other team members and have weekly meetings where we will exchange information and discuss the progress made.

1.5 Timetable

Table 1.1 Project Timetable

Deliverable	Deadline
Project Proposal	9/12/2023
Determine type of propulsion (Inboard or Outboard)	9/19/2023
Progress Report 1	9/29/2023
Coordinate preliminary designs with steering team	10/09/2023
Complete the product design specification (PDS)	10/19/2023
Finalize general requirements for steering and propulsion joint functionality	10/25/2023
Progress Report 2	11/03/2023
Develop preliminary design sketches	11/10/2023
Finalize a design and constraints	11/18/2023
Final design and constraints	12/15/2023
Progress Report 3	12/23/2023
Purchase all necessary items	01/29/2024
Finish all machining of initial prototype	02/20/2024
Test prototypes and fix any issues	03/02/2024
Progress Report 4	03/08/2024
Final prototype finished	03/25/2024
Fully mounted and operational in conjunction with steering and solar teams	04/10/2024
Final testing of prototype before competition	04/28/2024
Progress report 5	05/10/2024

1.6 Skills, Perspectives and Resources

Soroush has experience in coding and CAD modeling software. He has experience in CAD software such as Fusion360. He also has some experience in coding platforms such as Python, MATLAB, and C++.

Cole has experience in machining and has worked in a machine shop. He has an extensive background in the troubleshooting and repair of machine systems, and confidence with mechanical assembly. In addition to that, he has knowledge in circuitry and understanding of motors from prior experiences.

Kai has experience in machining and electrical circuitry. In addition to that he has knowledge of boating and has worked on boats prior to this project.

Alex has prior experience in 3D part design and fabrication as well as the assembly/fabrication of parts. He also has experience in the mathematical calculations for design parameters and tolerances.

Table 1.1.2 Resource Matrix

Task	**Soroush**	**Cole**	**Kai**	**Alex**
Market Research	X	X		
Report Writing	X	X	X	X
Technical Research	X	X		
3D CAD	X	X		X
Simulation (FEA et al.)			X	X
Design Calculations	X			X
Circuit Design		X		
Coding	X	X	X	X
Wiring			X	X
Machining		X	X	
Building or obtaining 3D parts			X	X
Prototype Assembly	X	X	X	X
Prototype Testing	X	X	X	X

Chapter 2. Background Research Background Research

2.1 Market Research

In our market research we found a large variety of patents that were similar to that required by our project. While generally speaking the majority of these patents are similar to many preexisting boating products, some have features that make them more innovative and differentiate them from the competition. The main difference between these products and the general market is the energy source for these, electric power. While electric powered boats are still a relatively new sector of the boating industry, they provide certain advantages to the conventionally powered boats. The most notable benefits of this powertrain are the reduction of emissions and reduction in routine maintenance necessary to operate the boat. Using an electric motor greatly simplifies the overall design of the system and therein creates a simple to operate system for any user. Out of the few designs we discuss below there are two that are most similar to what our project entails. The Torquedo Travel 1103 CS and the Newport NT300 are two outboard electric propulsion systems with the prior being very similar to our project as that can also be powered by solar energy and the overall design is very similar to our proposed designs. While outboard systems are generally more expensive than their inboard counterparts, the benefits such as higher top speed of the outboard are more desirable for the cost difference.

2.2 Project Requirements

- Must maintain the bearing that is pressed into the hull.
- System must have improved efficiency compared to the existing system.
- System must be able to run at a minimum of 4 mph for the endurance race and a minimum of 12 mph for the sprint.
- The components in the system must be shielded to prevent the skipper from being injured.

2.3 User Needs

Our product is designed to fit into the Stony Brook Solar Racing Team boat. The boat will compete in SOLAR SPLASH, the world championship of Collegiate Solar Boating. We must create an efficient and powerful propulsion system with a limited amount of voltage and amperage. The system must be able to withstand saltwater and several hours of continuous use. SOLAR SPLASH consists of a Sprint, Endurance, and Slalom race so the boat must be fast and maneuverable. It is also necessary to have a transmission system so gearing can be adjusted for the Sprint and Endurance race.

Our customer base also extends to those interested in a petrol alternative to power their boat. They may be attracted to the zero emissions of our system or the ultra-quiet operation. In certain lakes and water basins petrol motors are banned to keep emissions down, an electric propulsion system is necessary in these environments. Automobiles have already begun the switch to electric while boats are not far behind.

2.4 Existing Models

2.4.1 Torqeedo Travel 1103 CS

Figure 2.1 Torqeedo Travel 1103 CS

Key Features:

- Integrated 915 Wh high-performance lithium battery
- Onboard computer with GPS-based range calculation and charger
- Ultra-quiet (33db)
- Waterproof Design (IP67)
- 3 HP equivalent
- Solar chargeable
- Total weight: 17.3 kg (S) / 17.7 kg (L)

The Torqeedo Travel 1103 CS made by Torqeedo is an electric outboard marketed as an alternative to a 3 HP petrol outboard. It can do everything a 3 HP petrol outboard can while also being environmentally friendly, quieter, lighter and more convenient. At half throttle (3.4 mph) the motor has a run time of 6 hours with the integrated 915 Wh battery. It can be charged with solar panels while in use. The Torqeedo Travel 1103 CS utilizes tiller steering.

Table 2.1 Pros and Cons of the Torqeedo Travel 1103 CS

Pros	Cons
• Less maintenance than its internal combustion competitors • Zero emissions • Silent direct drive • Clean and compact • 5-year warranty	• Limited range • Must use the integrated battery. • Cost more than a comparable IC engine • Lithium batteries have a capacity loss of approximately 4% per year

2.4.2 Newport NT300

Figure 2.2 Newport NT300

Key Features:

- Power: 1300W (3 HP equivalent)
- Range: 7 Miles - 66 Miles
- 36V Battery required for operation.
- Ultra-quiet (40 db.)
- Motor Weight: 23.8 lbs. (S) / 24.3 lbs. (L)
- Brushless DC Motor

The Newport NT300 electric outboard motor gives users freedom from the gas pump, the boat ramp, and the constant need for maintenance. Unlike many of its competitors any 36V battery or series of batteries can be used, allowing users to take advantage of future battery innovations without buying a new outboard. With a longer range than competitors, the motor's run time keeps anglers on the water longer. The sound level is greater than many of its electric competitors, but still far less than 3 HP internal combustion outboards.

Table 2.2 Pros and Cons of Newport NT300

Pros	Cons
● Maintenance-free reliability ● Choose between different battery options to power the motor. ● Lightweight and compact ● Digital throttle and LCD screen offer easy operation	● 36 V battery required for operation (can be expensive) ● Motor must be flushed after each use. ● Less durable compared to its internal combustion competitors. ● Lithium batteries have a limited life span

2.4.3 Elco EP-6 Electric Inboard

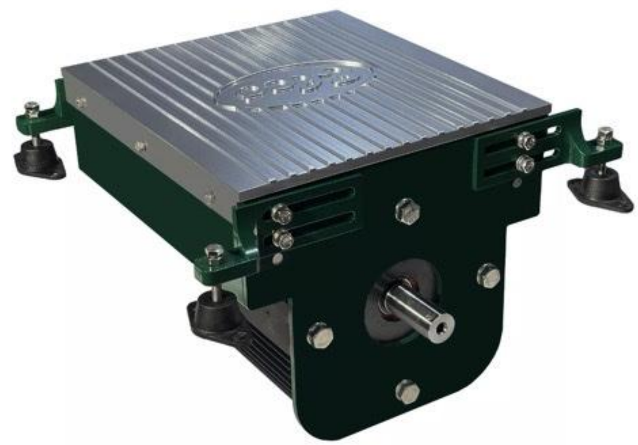


Figure 2.3 Elco EP-6

Key Features:

- Comparable HP: 6 HP
- Voltage: 24V
- Maximum RPM: 900
- Dimensions: 13.9” x 12.7” x 11”
- Weight: 68lbs
- 1-4 hours of boating is typical with suggested battery Amp Hours (Ah)

The Elco EP-6 electric inboard motor is contained in a water-resistant cast aluminum finned housing containing all the electronics, PMAC motor, and safety devices. The system can be mounted directly in place of a typical marine diesel or gas engine. The Elco EP-6 is an efficient and durable alternative to fossil fuel options. All Elco products are built in the USA. Both Lithium and AGM batteries can be utilized with the EP-6.

Table 2.3 Pros and Cons of Elco EP-6

Pros	Cons
• Easily swapped with diesel or gas inboard • Have options when choosing a battery. • Built in the USA • Elco DASH App wirelessly turns any mobile device into a full-function dashboard	• Limited to 4 hours of boating • Batteries are expensive and have a limited life span. • Saltwater can cause problems over time. • Less options for mechanics/technicians compared to popular internal combustion motors

2.4.4 Torqeedo Deep Blue 50i 1800

Figure 2.4 TorqeedoDeep Blue 50i 1800

Key Features:

- 2000 rpm for planing
- Comparable petrol outboard: 80 HP
- Weight: 562 kg
- Dimensions: 1800 x 853 x 236 mm
- Battery aging can be tracked by the user in the on-board computer at any time.

The Torqeedo Deep Blue 50i 1800 is not only powerful and safe, but also a genuine commercial alternative for heavy users. According to Torqeedo, all components of the system are perfectly engineered to match each other and are completely waterproof. The same high-performance lithium batteries used to power cars also power Deep Blue, after Torqeedo further developed them for use in boats. State of the art monitoring technology safeguard the high-voltage system against the risk of short circuits.

Table 2.4 Pros and Cons of Deep Blue 50i 1800

Pros	Cons
● Waterproof ● Ground-breaking safety concept ● Up to a 9-year warranty on the Deep Blue's battery capacity ● Far less maintenance than comparable drive systems using fossil fuel	● Limited to 50 minutes running time at full throttle ● Battery will not last forever ● Cost more than a comparable internal combustion outboard ● Weighs far more than an internal combustion engine when batteries are included

2.5 Existing Models Summary Chart

Our project differs from others as it is specific to the SOLAR SPLASH competition. We will do our best to draw comparisons with our project and commercially available products. It is also important to note our project design criteria is evolving as we work with the solar team and form new ideas. An important project requirement is that the source voltage may not exceed 36 VDC nominal value. The Newport NT300 is the only existing model mentioned above that is designed for 36 VDC. The other existing models either use an integrated battery or 24 VDC. We are leaning towards an outboard propulsion system similar to the Torqeedo and Newport models, the Elco and Torqeedo Deep Blue are both inboard. All of the existing models have shielded components to protect the skipper, an important project requirement. It is difficult to say whether these existing models have improved efficiency or speed over the existing system without testing, but the motor we are using has considerably more power than the 1103 CS, NT 300, and EP-6. The existing models have more features than defined in the project requirements. Some of these features include waterproofing, LCD screens, apps, and digital throttles.

Table 2.5 Comparison Chart for Existing Models

Specifications	Torqeedo Travel	Newport NT300	Elco EP-6	Torqeedo Deep Blue
Inboard			✓	✓
Outboard	✓	✓		
Minimal Maintenance	✓	✓	✓	✓
Integrated Battery	✓			✓
Choice of Battery		✓	✓	
Compact Design	✓	✓	✓	✓
Waterproof	✓	✓		✓
Easily swapped with diesel or gas competition	✓	✓	✓	
Tiller steering	✓	✓		
Built in the USA			✓	

2.6 Relevant Patents

2.6.1 Patent #US10464651B2 – Sternboard Drive for Marine Electric Propulsion

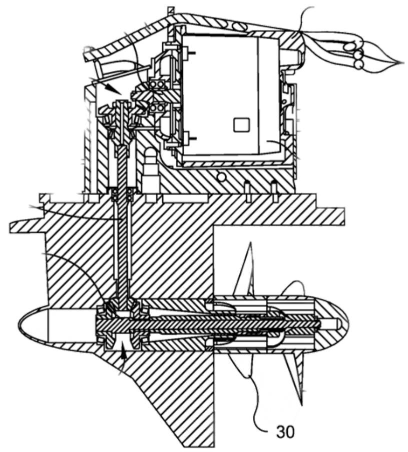


Figure 2.5: Patent # US10464651B2 [Cole]

Key Features:

- Outboard, transom mounted design
- Vertical coupling shaft
- Bevel gears
- Watertight housing

This patent was created to allow for transom mounted electric propulsion. The design is hydrodynamic, sturdy and efficiently transfers the motor shaft output to the propeller. There is an intermediary vertical shaft which couples the motor and propeller shafts. They are meshed through the use of bevel gears. This patent also covers the replacement of the vertical shaft with a belt or chain drive. The housing is watertight, avoiding corrosion that would result from the introduction of brackish or salty water, and allows for the addition of a liquid cooling system. The patent also covers the addition of a mechanical transmission. In this method of propulsion, the entire motor-propeller system is pivoted in order to facilitate steering, therefore 100% of the provided thrust will be used in steering the boat.

Table 2.6 Pros and Cons of Sternboard Drive for Marine Electric Propulsion

Pros	Cons
• Can be added to any transom mounted boat. • Sturdy design minimizes power losses due to bending, as well as mitigates unwanted vibrations. • Fewer moving parts means less opportunity for failures.	• Watertight casing is difficult to construct on a short time schedule. • Gears will likely require coolant/lubricant. • Complex inner workings of gears and shafts would be tricky to build on a tight schedule.

• Highly Streamlined profile; hydrodynamic • Steerable motor; fast, simple and responsive system	• Enclosed unit means increased difficulty of maintenance.

2.6.2 Patent #US5878686A – Pivotal afterplane having a motor positioned thereon.

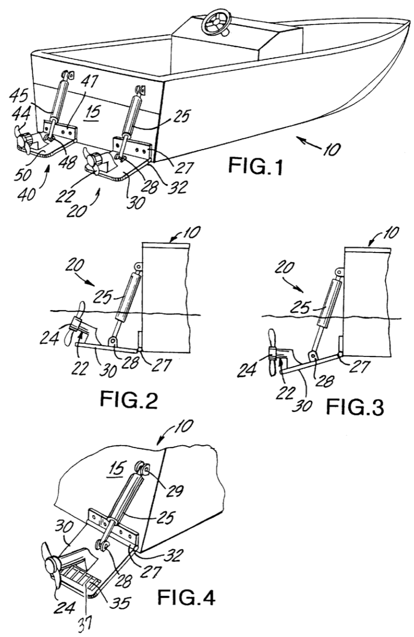


Figure 2.6: Patent #US5878686A [Cole]

Key Features:

- Multiple afterplanes, or "trim tabs" mounted to the boats stern.
- Each afterplane has a motor mounted on top.
- Afterplanes actuated using a linearly adjustable arm.
- Each afterplane has an elongated shape, protecting the motor.

This patent was created to increase the efficiency and stability of a watercraft through the use of afterplanes. Afterplanes, otherwise known as "trim tabs," are mounted to the stern of the boat and actuate up and down in order to assist the boat maintain a plane position. While planing, a boat moves most efficiently. When the boat accelerates from a standstill position, the trim tabs begin in their lowered positions, forcing water underneath, in turn raising the stern and lowering the bow. This allows for the boat to plane at a lower velocity. As the ship approaches cruising speed, the afterplanes raise to the horizontal position, continuing to plane. The tabs can also be adjusted separately to adjust for imbalance in the vessel. This patent has the motors mounted directly atop the afterplanes, adding further protection to the motors while traversing shallow waters.

Table 2.7: Pros and Cons of Pivotal Afterplane having a Motor Positioned Thereon

Pros	Cons
• Added low speed plane capability to the vessel, increasing efficiency. • Tabs can be adjusted separately to account for imbalance in the boat. • Increased marketability • The motors are mounted above the tabs, shielding them from damage. • All actuating parts are external, leading to simpler maintenance	• Improper use of the afterplanes can result in dangerous instability at speed. • Additional actuating parts leads to increased weight and possible unreliability. • Motors mounted on top of the afterplanes causes many packaging restraints. • Submerged parts can increase drag. • Additional rudders are needed as a supplemental steering mechanism

2.6.3 Patent #US20110263165A1 – Electric Marine Surface Drive

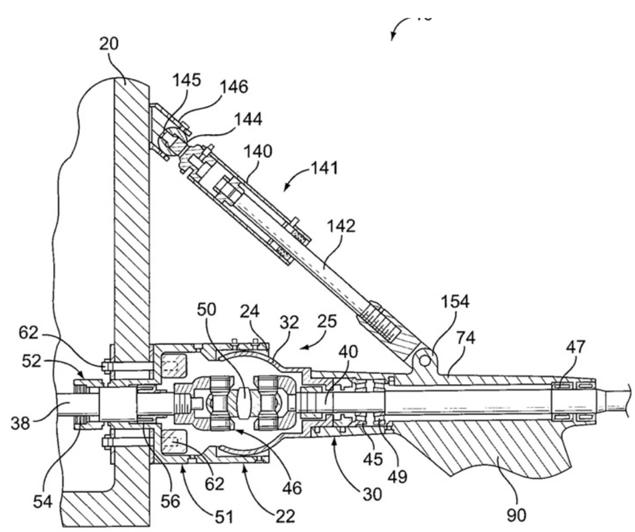


Figure 2.7: Patent #US20110263165A1 [Kai]

Key Features:

- Inboard, output through the transom
- Direct application of motor power

● Surface drive of the propeller
● Universal joints along with linear adjustable arms for trim and steering

This patent was created to allow for direct driven electric propulsion. The design allows for a surface driven propeller, reducing the amount of propeller drag [claim 1]. The shaft exits the back of the boat, and the output shaft can be articulated due to the addition of a universal joint, external of the hull. Trim adjustments are achieved through a linear adjustable arm above the output, while left-right steering is performed in a similar manner with a horizontally mounted adjustable arm on the side(s) of the output [claim 8]. The universal joint is enclosed and protected from corrosion, and the hole in the transom is watertight to prevent water being introduced into the hull.

Table 2.8 Pros and Cons of Electric Marine Surface Drive

Pros	Cons
• Surface mounted for minimal prop drag. • Direct power from the motor allows for high efficiency levels. • Simple construction is conducive for a short design timeframe. • An inboard motor eliminates the need for waterproof drive assembly housing • Exposed parts lead to simple maintenance	• The universal joint leads to inefficiencies while the shaft is at an angle. • Lack of external housing can lead to problems with stability, and therefore vibration issues. • The external linearly adjustable arms may introduce drag from the steering assembly. • A hole in the transom introduces the risk of water seeping into the boat.

2.6.4 Patent #US8337266B2 – Electrically powered watercraft

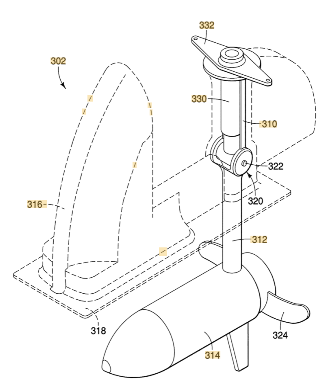


FIG. 3B

Figure 2.8: Patent #US8337266B2

Key Features:

- Motor integrated directly in line with prop.
- Mounting shaft hinges, allowing for the retraction of the motor propeller system into a cavity in the vessel.
- Steering from the rotation of mounting shaft
- Wing mounted below the motor-prop system, aiding the steering system.

This patent was created to be integrated into the bottom of smaller water vessels, allowing for a propulsion system which is quiet, efficient and versatile. This unit has the capability to hinge up and into the hull of the boat, giving way for the use of manual propulsion methods. The motor is fully submerged on the end of the mounting shaft, directly in line with the propeller. Due to the lack of a complex drivetrain system, this design has minimal losses and therefore transmits the maximum power possible between the motor and the propeller. Additionally, the ability to pivot the propeller makes for a more responsive steering system.

Table 2.9 Pros and Cons of Electrically Powered Watercraft

Pros	Cons
• Direct power transfer from motor to propeller • Drive system hinges into hull, reducing drag when not in use. • Pivoting of mounting shaft allows for a variety of precision steering solutions. • Exposed drive system allows for increased simplicity of maintenance	• The motor is completely submerged and therefore must be contained in a watertight package. • Motor packaging restraints due to the necessity of a streamlined package • The hinge in the mounting shaft may decrease rigidity. • The storage cavity underneath the hull will increase drag

2.6.5 Patent #US9926058B2 - Boat Propeller

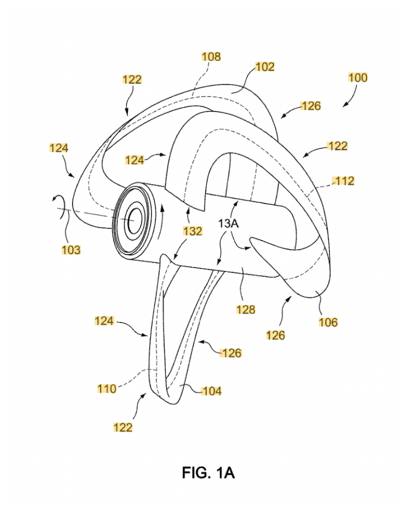


Figure 2.9: Patent # US9926058B2 [Alexander]

Key Features:

- Innovative toroidal design
- Mounts to most current systems
- Reduction in harmful vortices created by the prop

This patent was created to improve the efficiency of boats. The toroidal design has been seen to improve not only the efficiency of the boat but has also seen increases in the top speed achieved during tests. In addition to boats, this design has been used for drones which have experienced similar improvements. This design, while considerably more expensive than conventional designs, will eventually save the user in operational costs due to the vast improvements in efficiency.

Table 2.10 Pros and Cons of Boat Propeller

Pros	Cons
• Claimed 30% increase in range • Mid-range rpm speed increase along with improved efficiency in the mid-range of rpm • Noticeably less noise and reduced vibrations • 50% more reverse thrust • Improved turning at higher speeds	• Much more expensive than conventional props • Tests show varied results in performance gains that may be less than expected • Heavier than a traditional prop • At higher rpm they lose the efficiency benefit

2.6.6 Patent #US7018249B2 - Boat Propulsion System

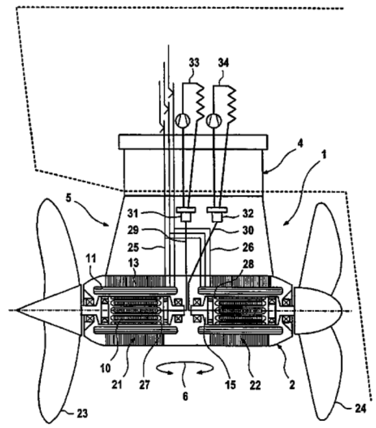


Figure 2.10: Patent # US7018249B2 [Alexander]

Key Features:

- Pod propulsion system
- Powered by one or more electric motors
- Pod design allows for more volume in hull for cargo
- Superconductor wires inside a vacuum cryostat chamber

This patent was created to help improve efficiency, reduce weight and provide more space. This unit is designed to be attached to the underside of the ship. Pod propulsion systems are often seen on large vessels such as cruise ships. This system of propulsion also provides much better handling as the whole system can turn. Additionally, the superconductor wires inside the motor are contained within a vacuum insulated cryostat, cooling the wires to between 15 and 77 degrees Kelvin. This largely contributes to improved efficiency.

Table 2.11 Pros and Cons of Boat Propulsion System

Pros	Cons
• Reduced vibrations due to the minimal weight of the motors • 99% efficiency, in comparison to a 97.5% efficiency in conventional pod propulsions systems • Greater acceleration and speed • Heat loss dissipated by the surrounding water in the environment	• More difficult to maintain this system as it is under water • More expensive than other propulsion methods • Require twin engines • Compared to inboard/outboard this is generally less efficient

2.6.7 Patent #US20220324538A1 - Boat Propulsion System

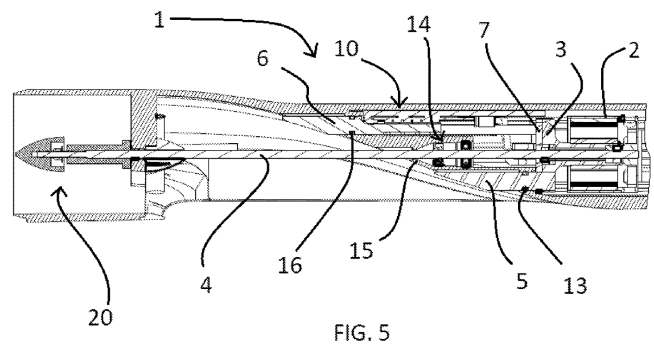


FIG. 5

Figure 2.11: Patent # US20220324538A1 [Soroush]

Key Features:

- Electrically operated propulsion system for small watercraft
- Built in passive cooling system
- Highly compact design
- Easily implemented in surfboards, kayaks, paddleboards, etc.

This patent depicts a propulsion unit designed to be built into smaller recreational watercraft. It functions by pulling water up and into a cavity in the hull, then thrust the water out the backside of the unit. The design remains highly compact since the rotor of the electric motor is mounted directly on the driveshaft, minimizing packaging size and maximizing efficiency. This device also implements a passive cooling system, where long metal fins run along the inside of the device, conducting heat away from the warm motor. The fins are routed in a manner in which they end up in contact with the cool water on the outside, furthering the efficiency of heat transfer.

Table 2.12 Pros and Cons of Boat Propulsion System

Pros	Cons
• Enclosed prop design is safer for the user of the vessel • Provides a safety barrier for the prop from items in water • Reduced cavitation from the prop • Increased stability at lower speeds • Increase in static thrust	• The enclosure adds additional drag • Items can become stuck between the prop and the housing inducing more damage than if not present • The advantage of the duct is lost at higher speeds • More difficult to maneuver these types of systems

2.6.8 Patent #US10266237 - Watercraft Having Retractable Drive Mechanism

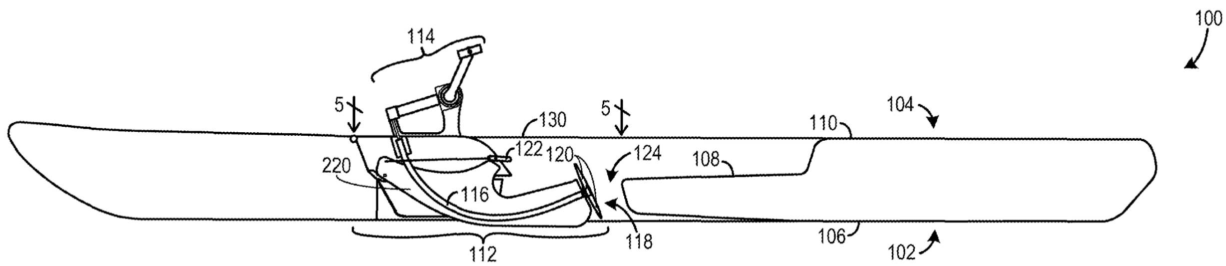


Figure 2.12: Patent #US10266237 [Soroush]

Key Features:

- Flexible drive shaft, connecting power input directly to propeller
- Ability to retract propeller into cavity in hull while not in use
- Adaptable for small motor or pedal power

This patent depicts a propulsion unit designed for lower power applications. The powerplant of the drive system is located inside the hull, and can either be traditional combustion, electric, or human driven. From this power input, the energy is transferred through a flexible drive shaft and to the propeller underneath the boat. One benefit of a flexible driveshaft is the leniency of motor placement during the design process. The propeller and driveshaft can be retracted into a cavity in the hull when not being used, in order to minimize drag. This system is simple, and therefore robust, not needing frequent maintenance.

Table 2.13 Watercraft Having Retractable Drive Mechanism

Pros	Cons
• Flexible drive shaft makes for a simpler design process • Propeller and drive shaft retract into the hull, reducing drag when not in use • No extensive watertight housing required • Lack of complex assemblies makes for comprehensive maintenance and infrequent failures	• Flexible drive shaft may cause vibrations or power loss in higher powered applications • Cavity in hull will increase drag • Drive system takes up a large volume, taking space away from other components • Hard to achieve a desirable center of gravity with the drive system in this location

2.7 Relevant Patents Summary Chart

The two main configurations of boat propulsion units consist of inboard and outboard. Inboard motors have the benefit of being centrally mounted in the craft, often allowing for more flexibility in mounting solutions and less material needed for waterproofing of the drive motor. The tradeoff for an inboard is that the mechanism for steering becomes either increasingly complex or inefficient. Outboard motors are mounted on the transom of the boat, and allow the motor and propeller to pivot in unison. This uses 100% of the motor thrust to turn, while avoiding varying output shaft angles in relation to each other, reducing complexity. The difficulty of designing an outboard generally comes in the form of the motor shaft housing, which often needs to be waterproof and rigid to avoid vibrations. Both inboard and outboard configurations can have difficulties or simplicities associated with maintenance, depending on the setup.

Patent in section 2.6.1 is similar to that of a traditional outboard combustion motor, requiring complex inner workings and housing. Patent 6.2.2 exhibits outboards mounted to trim tabs, an interesting technology to aid in boat maneuverability, however the motor mounting in this patent would be difficult to achieve without proprietary manufacturing techniques. In patent 6.2.3, the motor is kept inboard and does not require complex housing, but there are losses associated with the intricate output shaft. Patent 6.2.4 depicts a common configuration of an outboard electric boat motor, with the added benefit of being able to retract into the boat hull. The difficulty here lying in rigidity and the constraints of the motor housing. Patent 6.2.5 investigates technology in a toroidal propeller, which can be mounted onto any motor output, in an attempt to increase efficiency. Patent 6.2.6 is of an electric motor designed for larger applications, configured as an outboard. The interesting technology is that of the cooling system, which greatly increases the efficiency of the motor under typical use. Patent 6.2.7 shows a low-profile inboard setup, which pulls water into the hull and puts the water out in the form of a concentrated stream. This is effective for getting the most out of a small motor, however packaging and versatility is a challenge with this setup. Patent 6.2.8 is of a boat with a lower power output, utilizing a flexible drive shaft to transfer energy. This is good for packaging constraints however can run into problems with vibrations or instability under higher loads. We will use the information collected in these patents to aid in the design a novel propulsion system for our solar boat.

Table 2.13 Comparison Chart for Patents 1-4

Specification	Patent #US10464651B2	Patent #US5878686A	Patent #US20110263165A1	Patent #US8337266B2
Inboard	X	X	✔	X

Outboard	✓	✓	X	✓
Ease of Maintenance	X	✓	✓	✓
Simple Packaging	X			X
Doesn't Require Watertight Packaging	X	✓	✓	X
Pivotable Propeller	✓	X	✓	✓
Rudder Steering	X	✓	X	X
Low Drag	✓	X	X	X
Highly Efficient		✓	X	✓
Rigid	✓	✓	X	X
Lightweight	X		✓	✓

Table 2.14 Comparison Chart for Patents 5-8

Specification	Patent # US9926058B2	Patent # US7018249B2	Patent # US20220324538A1	Patent # US10266237
Inboard		X	✓	✓
Outboard		✓	X	X

Ease of Maintenance		X	X	✓
Simple Packaging		X	X	✓
Doesn't Require Watertight Packaging		X	X	✓
Pivotable Propeller		✓	X	X
Rudder Steering		X	✓	✓
Low Drag	✓	✓	X	X
Highly Efficient	✓	✓	✓	
Rigid		✓	✓	X
Lightweight		X	✓	✓

+

Chapter 3. Product Design Specifications

3.1 User Characteristics

The user profiles of our potential consumers are described as:

- Intermediate boat users with general knowledge of boating and how to operate an outboard motor.
- Advanced boat users with prior experience with outboard motors and some knowledge of electric motors.

3.2 User Principles

- It provides increased propulsion for a boat in competition
- The user defines the speed of the motors
- The propulsion system is simple to operate, equipped with basic controls

3.3 Constraints

- Wind resistance: The high winds from the large bodies of water will counteract the propulsion and reduce top speed.
- Dependence on sunlight: Given the electric motors rely on sunlight to generate power, an overcast day may affect the boat's energy output.
- Limited load capacity: The weight of the solar panels affects the boat's top speed and forces the group to compromise on, for example, the weight of the driver.
- Cost: Certain parts in our design including a hydraulic steering system and housing for the transmission are essential and force the group to reduce budget for other aspects as deemed necessary by the solar racing team.

3.4 Design Requirements

Table 3.1 Functional Requirements

Req. #	Requirement	Description	Comments	Priority	Date Added or Changed
FR_01	Power	Source voltage to the motor may not exceed 36VDC	Anything more than 36VDC is a violation of the SOLAR SPLASH rules	1	09/25/2023
FR_02	Speed	The goal of the new propulsion system is to push the boat more than 30 mph. Power is controlled using a throttle in the form of a lever.	We want to improve on last year's sprint performance and get a top 3 place.	2	09/24/2023
FR_03	Steering	The propulsion system must be able to rotate/move so steering team can attach their mechanism using a shaft that is rotated with hydraulics to 30 degrees each direction.	Without a working steering system, the boat cannot finish the courses. The steering must also be responsive for the slalom race.	1	09/28/2023

Table 3.2 Service Requirements

Req. #	Requirement	Description	Comments	Priority	Date Added or Changed
SE_01	Vibration	The system must be able to withstand vibrations caused by waves, wind, and speed.	The races are in protected water, but we must be prepared for all weather conditions.	1	09/27/2023
SE_02	Waterproof	All submerged areas of the propulsion system must be waterproof to ensure no damage to components and keep all occupants in the boat safe.	Saltwater can corrode and destroy propulsion components in the first event. Second event is not an issue as it takes place in freshwater.	1	09/28/2023

Table 3.3 Packaging Requirements

Req. #	Requirement	Description	Comments	Priority	Date Added or Changed
PA_01	Saltwater	All materials used below the waterline must be able to withstand saltwater corrosion or be resistant for at least 12 hours before getting cleaned.	The propulsion system may survive this year's races but if this criteria is not met the following years team could suffer unless proper precaution and cleaning is done.	2	09/28/2023
PA_02	Maintenance	All moving parts must be able to be fixed/maintained upon failure with relative ease of access.	This is essential for the future team's success as there will be issues that will need rapid repair and cannot require complete disassembly.	2	09/28/2023
PA_03	Assembly	All parts must be easy to assemble and disassemble as well as not be too complicated to put together.	The system must be able to be fixed in the event of a failure in a fast pace during events where time may be limited for changes to be made.	3	11/01/2023

3.5 Deleted or Changed Requirements

Table 3.4 Deleted or Changed Functional Requirements

Req. #	Requirement	Description	Comments	Priority	Original Date

Table 3.5 Deleted or Changed Service Requirements

Req. #	Requirement	Description	Comments	Priority	Original Date

Table 3.6 Deleted or Changed Packaging Requirements

Req. #	Requirement	Description	Comments	Priority	Original Date

Chapter 4. Conceptual Design

4.1 Concept Overview

The team came up with the following list of the most important complex mechanisms and overall system architecture following the Product Design Criteria of chapter 2 and the design requirements of chapter 3. It is important to note as of the Report 2 due date we do not know what motor will be used and therefore do not know expected power, torque, rpm, etc. Without this data it is impossible to have exact geometries of models, so all geometries are estimated.

Complex mechanisms: Bevel gears, Interchangeable propeller, Shaft/motor coupling
Overall system architecture: Submerged motor, Inboard direct drive, Outboard with bevel gears, Outboard with chain drive

4.2 System Concept Designs

4.2.1 Pod Propulsion System (Soroush)

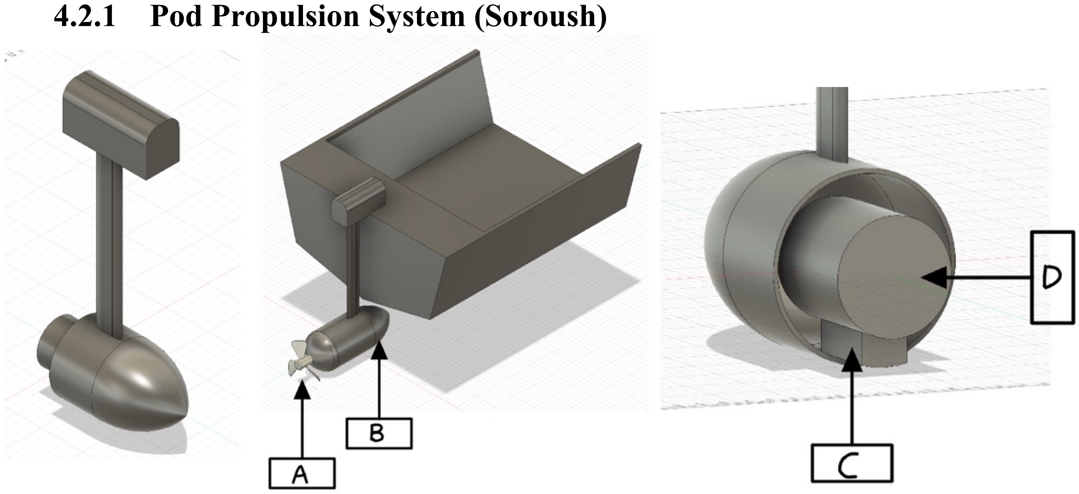


Figure O CAD of the 1st Design of Pod Propulsion System

Table 0.1 Label Letter and its Description for *Pod Propulsion System*

Label	Description
A	Propeller
B	Waterproof housing
C	Motor
D	Motor mount

<u>Key Features:</u>

1. An aerodynamic watertight enclosure.
2. Prop directly mounted to the motor and shaft, without the use of a 90-degree transmission or chain drive.
3. Easy mounting to the boat with a shaft that connects directly to the transom.
4. Reliable design that does not have failure points like gears or chains.

The pod motor design is designed to be the simplest possible method of providing propulsion to the boat as it does not require a 90-degree transmission found in a traditional outboard system or a chain/belt drive as proposed in alternative designs. This design uses a pod that encloses the motor, which is directly connected to the prop via a shaft. The casing around the motor is made of aluminum and is a watertight enclosure. The prop is connected through a shaft seal that keeps the connection between the prop and the motor watertight. The motor is connected to the inside of the pod via a large, yet flexible mounting system that will reduce vibration and keep the motor in place. The connection to the boat is via a shaft that runs through the plate at the top of the boat, and the steering is attached at that point (need to still clarify with the steering team what type of steering will be used and where the mounting will be done).

<u>Pros:</u>

- Simple design with no need for a mechanism to translate output from shaft to prop 90 degrees.
- Easier to design and assemble as the shaft directly connects to the prop.
- Exhibits an efficient hydrodynamic shape whilst keeping the center of gravity for the vessel low.

<u>Cons:</u>

- Maintenance of the motor may be difficult as the motor is inside of a watertight enclosure, and it may compromise that aspect if it is opened.
- Difficult to create a waterproof enclosure for the motor.
- Slower than a traditional outboard propulsion system due to packaging constraints.

4.2.2 Chain Drive Propulsion Design (Soroush)

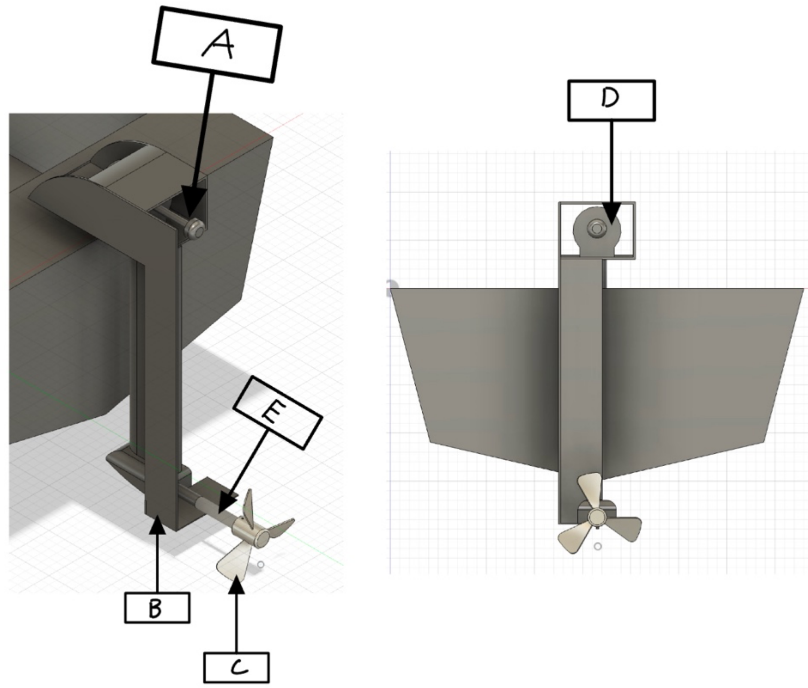


Figure 0.2 CAD of the 1st Design of Chain Drive Propulsion Design

Table 0.2 Label Letter and its Description for Chain Drive Propulsion Design

Label	Description
A	Chain mounts to motor shaft here
B	Waterproof housing
C	Propeller
D	Motor
E	Chain mounts to prop shaft at this point

Key Features:

1. Chain driven design reduces need for a 90-degree gearbox.
2. Use of chain allows for different gear ratios and a possible transmission.
3. Easy access for maintenance as the motor is above the surface of the water and does not need to be in a watertight housing.
4. Lubrication of chain occurs in the prop shaft housing.

The chain driven drive allows for the output shaft from the motor to transmit power to the prop without the need for a 90-degree turn. This is done via a chain that connects between the motor and prop shaft. Using the gear system will allow us to vary the gear ratio for different events such as sprint and endurance races where the efficiency of the battery and motor are imperative to the performance. The Waterproof housing will enclose everything below the motor. The motor enclosure does not need to be waterproof and has easy access as stated above. The chain will have a lubrication system either in the form of a drip mechanism or an oil bath at the bottom of the enclosure. Chain driven systems are generally speaking very reliable, given that proper maintenance is conducted regularly.

<u>Pros:</u>

- Easy to design and assemble as not many complex parts are involved.
- Motor is easy to access and remove if necessary for maintenance.
- Allows for customizable gear ratios for different events such as endurance or sprint.

<u>Cons:</u>

- More variables necessary for design such as bearings and chain/sprocket.
- Need lubrication for the chain in the base of the outboard casing.
- Not a conventional propulsion system and chain could slip or come undone during long events.

4.2.3 Transmission (Kai)

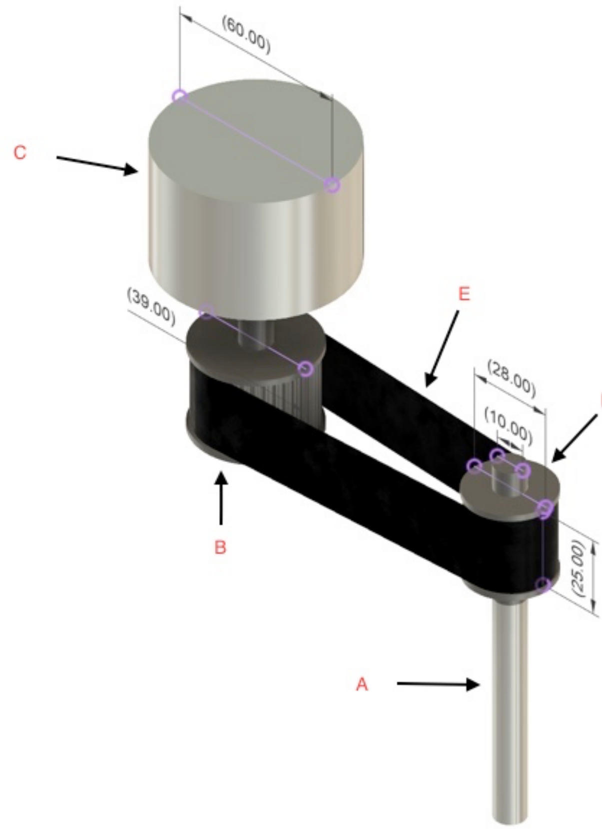


Figure 4.3 3D Model of the Transmission

Table 0.3 Label Letter and its Description for Transmission

Label	Description
A	Drive shaft
B	Sheave A
C	Motor
D	Sheave B
E	Belt

The Transmission was designed to transmit power between the motor and drive shaft. The configuration of the transmission will depend on the motor output data. In most belt drives the input sheave is rotating at a faster speed than the output sheave, this is called a speed reducer. For a speed reducer application, the smaller sheave is mounted on the motor and the larger sheave is mounted on the driven machine (drive shaft). The other belt drive configuration is when the output sheave is rotating faster than the input sheave, this is called a speed increaser. To increase the drive shaft speed, the larger sheave would be mounted on the motor and the smaller sheave on the drive shaft. Desired torque will also play a factor in sheave size selection. The torque is increased in proportion to the amount that rotational speed is reduced and vice versa.

The motor will be coupled to Sheave A. Sheave A transmits power to Sheave B with the selected belt. Sheave B is connected to the drive shaft that delivers power to the propeller through a set of bevel gears. Speed and Torque of the drive shaft can be controlled through sheave size selection, allowing us to meet design requirements and maximize efficiency.

The concept will help us meet our design requirement that the system must have improved efficiency compared to the existing system. It will also bring the boat one step closer towards our speed requirement of 30 mph. The concept meets all packaging and service requirements.

Pros:

- Allows us to control speed and torque of the drive shaft.
- Low vibration.
- No lubrication required.
- Corrosion resistance.

Cons:

- Failure of the belt during a race would be catastrophic.
- The housing for the belt drive would add weight.
- Complex to assemble and design mounting system for

4.2.4 Coupling (Kai)

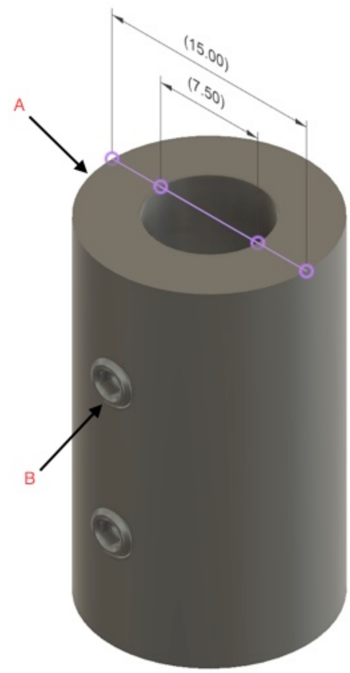


Figure 0.4 3D Model Coupling

Table 0.4 Label Letter and its Description for Coupling

Label	Description
A	Coupling
B	92015A102 18-8 Stainless Cup-Point Set Screw

The coupling is a device for connecting parts of machinery. For our application the coupling will connect the motor shaft to the drive shaft for the direct drive bevel gear system. The inside diameter of the coupling must match the outside diameter of the motor and drive shaft. The motor shaft diameter will be provided in a data sheet once the motor is selected, the drive shaft diameter will be calculated based on motor performance. The material and screws chosen must be able to withstand expected torque and speed. The coupling function is very simple, you slide the motor and drive shafts into their respective sides and tighten the screws to a torque spec based on force, screws, and material.

The concept is important to hit our speed requirement of 30 mph, it will be transferring power from the motor to the driveshaft. The coupling will meet the vibration and waterproof service requirements as well as the corrosion resistance requirement due to material selection.

Pros:

- Direct transfer of power from motor to drive shaft.
- No lubrication required.
- Corrosion resistance.

Cons:

- Failure of the coupling during a race would put us dead in the water.
- The motor and drive shaft must be aligned perfectly.
- Slippage could occur.

4.2.5 Watertight Bearing for Inboard System (Alexander)

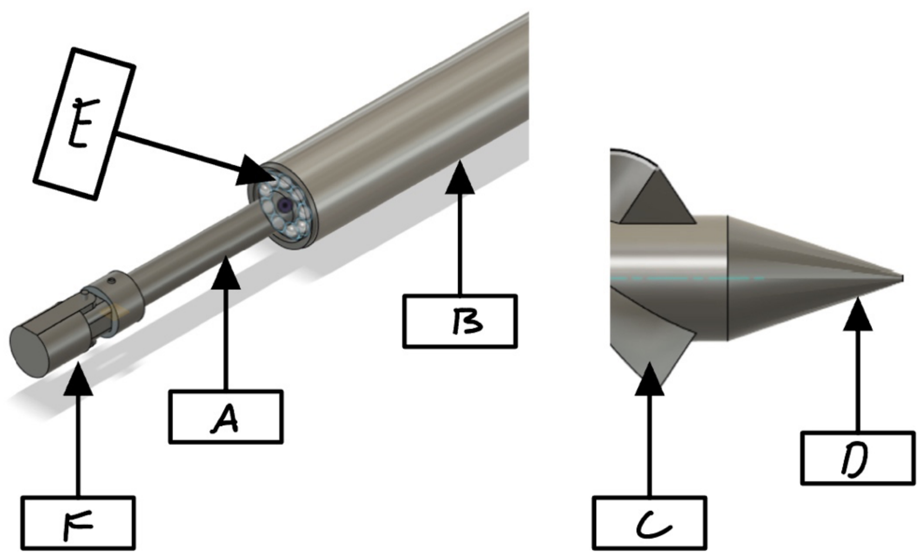


Figure 0.5: 3D Model of the Watertight Bearing for Inboard System

Table 0.5: Part Letter and Description for Watertight Bearing for Inboard System

Label	Description
A	Drive Shaft
B	Shaft Casing
C	Propeller
D	Prop Nut
E	Ball Bearing

F	Coupling with Pin

The watertight bearing is essential for connecting the output shaft of the motor beneath the hull of the boat to the propeller shaft. A ball bearing is used to reduce the friction between the connecting shafts and is enclosed by a shaft cover to prevent water infiltration. This cover is also used as a protection layer against rocks and other debris. The propeller is equipped with a prop nut to ensure that the propeller stays seated along the shaft taper. A coupling is mounted onto the drive shaft to allow three degrees of freedom while fastening both shafts to each other. A coupling pin is used to lock both shafts into place and becomes fixed withing the two locking holes.

This design satisfies three of our main project requirements: It ensures that the transmission of power to the propeller is safeguarded against water, the anti-corrosive materials will not corrode when exposed to saltwater, and since this shaft design exposed there is an ease of maintenance in case of part failure.

Pros:
- Allows shaft to pivot with two degrees of freedom.
- Drive shaft and bearing are watertight.
- Simple, lightweight mechanism.
- Reduced friction and vibrations

Cons:
- Maintenance and accessibility are limited compared to outboard systems.
- Drive shaft casing exposed to rocks/debris.
- Transfer of power from shafts can lead to slipping.

4.2.6 Direct Drive Inboard System (Alexander)

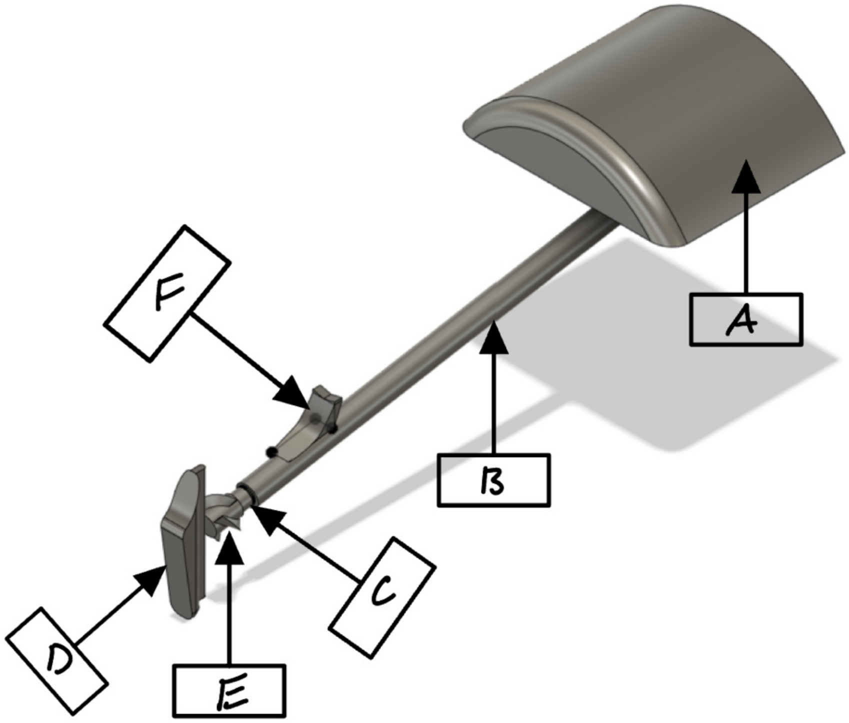


Figure 0.6: 3D Model of the Direct Drive Inboard System

Table 0.6: Part Letter and Description for Direct Drive Inboard System

Label	Description
A	Motor Housing
B	Drive Shaft Casing
C	Drive Shaft
D	Rutter
E	Propeller
F	Frame Support

The Direct-Drive System can be used to have a direct transmission of power from the motor to the propeller while limiting the possibility of slippage. In the figure above, the propeller is attached to the drive shaft by mating gears. This shaft is protected by a shaft casing made from anti-corrosive materials (aluminum) to combat the deteriorating effects of saltwater. This casing is firmly attached to the hull of the boat by the frame support. Behind the propeller sits the rutter, which will be controlled manually by the driver. The drive shaft extends through the hull of the boat to the motor which is encased by the motor housing.

This concept meets the project requirements as it coordinates with the steering team. Using the proposed rutter, the steering team can set up a cable system to manually turn the boat. Additionally, the casing and motor housing satisfies the waterproof requirement.

Pros:

- The Direct Drive system reduces the possibility of slippage.
- Ease of maintenance and accessibility.
- Motor is protected compared to outboard systems.

Cons:

- Housing reduces available space within the hull.
- Shaft casing exposed to rocks/debris.
- Frame support prevents pivoting of shaft.

4.2.7 Coupling (Alexander)

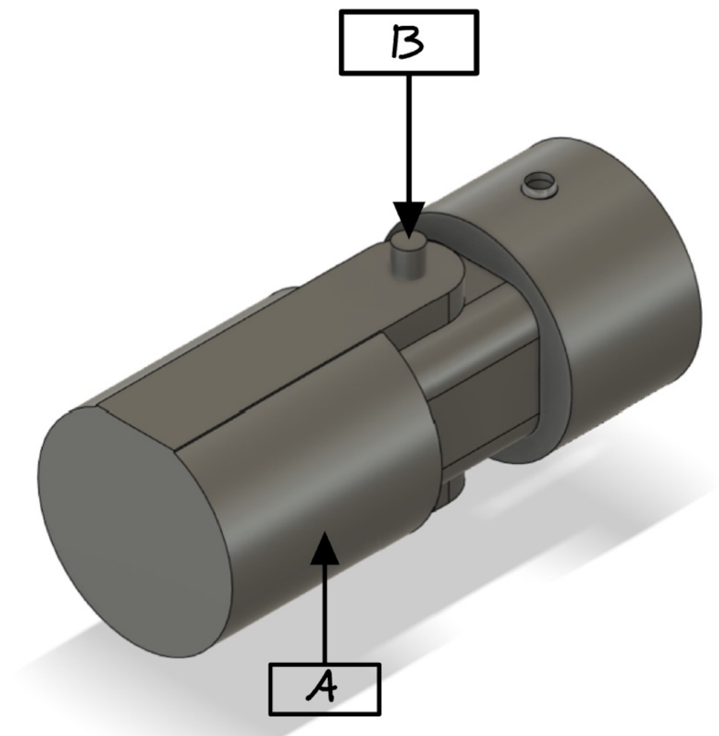


Figure 0.7: 3D Model of the Coupling

Table 0.7: Part Letter and Description for Coupling

Label	Description
A	Coupling
B	Coupling Pin

The coupling device will be used to connect the output shaft of the motor to the ball bearing shaft connected to the propeller. Each shaft will be slid into their respective sides given the inside diameter of the coupling is equivalent to the outside diameter of both shafts. The ball bearing shaft is equipped with two notches that lock into the coupling. As for the motor shaft, a coupling pin is used to connect both components. Once connected, there will be a direct transmission of torque from the motor to the propeller. The ball bearing shaft will be able to pivot vertically allowing users to raise or lower the propeller when needed. This will also help reduce vibration and friction.

This design satisfies our project requirements as it is waterproof and reduces vibration within the drive shaft. The coupling will help our boat reach our goal of 30 miles per hour and is suitable for our project given the material is anti-corrosive and will be able to withstand saltwater for prolonged periods of time.

Pros:

- Direct transfer of torque from motor shaft to propeller shaft.
- Pivotable, allows for two degrees of freedom.
- Lightweight, compact

Cons:

- Increased possibility of slippage compared to direct drive systems.
- Put under high load, fracture will result in total power loss.
- If fails during event, replacement will be difficult.

4.2.8 Chain Drive Sub-Assembly (Cole)

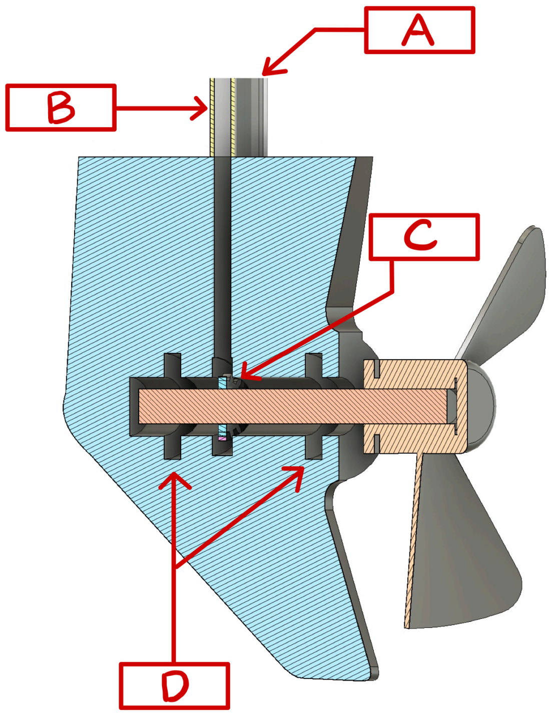


Figure 0.8 3D Model Chain Drive Sub-Assembly

Table 4.8 Part Letter and Description for Chain Drive Sub-Assembly

Label	Description
A	Drive Chain
B	Submergible Chain Housing
C	Sprocket Mounted to Propeller Shaft
D	Propeller Shaft Bearings

The chain drive sub-assembly depicts the lower unit portion of the chain drive propulsion system. The horizontal axis of rotation from the drive motor rotates the chain and sprocket to rotate the propeller. The submergible chain housing bridges the lower unit to the motor, connecting the assembly to the rest of the boat. The housing is made of non-corrosive aluminum and protects the chain from the harsh submerged environment. A sprocket is fixed to the propeller shaft which spins on two bearings placed on either side of the chain's plane. The use of sprockets allows for the rotational speed of the propeller shaft to be easily modified by the tooth ratio between the motor and output shaft. The true motor specifications are still unknown, therefore chain, sprocket and shaft dimensions are still variables.

The design meets the project speed requirement by allowing for customization of the sprocket ratios. The waterproofing and anti-corrosiveness of the design is satisfied through the selection of materials, such as aluminum. The design is relatively simple when compared to traditional outboard lower unit systems, leading to comparatively simple construction and maintenance.

Pros:

- Ease of manufacturing when compared to a bevel gear system.
- Sprockets are cheaper and more readily available, compared to bevel gears.
- Sprocket and chain sizes can be designed to withstand the applied horsepower.

Cons:

- Added possibility of dropping the chain, meaning decreased reliability.
- Rigidity of the chain housing is less than that of a traditional outboard, which could lead to harmful vibrations.
- The un-optimized chain housing causes an increase of hydrodynamic drag.
- An addition of a chain increases frequency of maintenance due to chain stretch and sprocket wear.

4.2.9 Bevel Gear Driven Sub-Assembly (Cole)

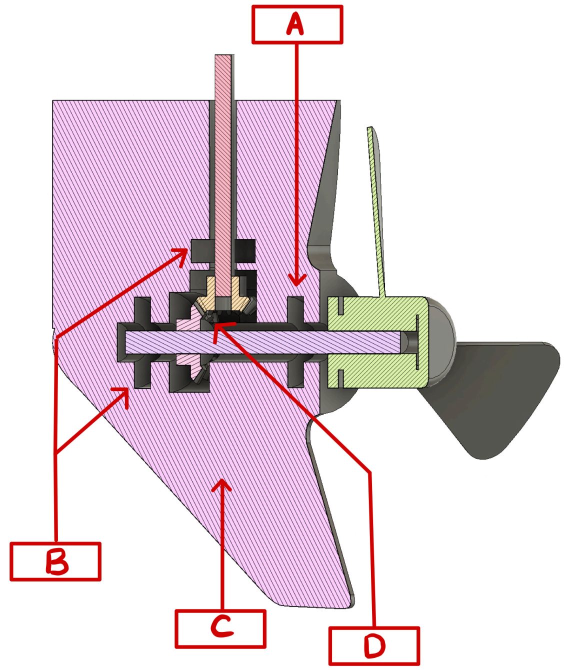


Figure 0.9 3D Model Bevel Gear Driven Sub-Assembly

Table 4.9 Part Letter and Description for Bevel Drive Sub-Assembly

Label	Description
A	Output Shaft Bearing
B	Input and Output Thrust Bearings
C	Hydrodynamic Shell with Fin
D	Right Angle Bevel Gears

The bevel drive sub-assembly depicts the lower unit portion of either a direct drive or transmission driven propulsion system. The vertical axis of rotation from the drive motor rotates the input shaft, which drives a bevel gear set, converting vertical rotation into horizontal revolutions in the propeller shaft. Bevel gears are contained using thrust bearings to combat the radial/tangential contact forces. A traditional bearing is placed on the output shaft to ensure a straight rotation and minimize vibrations. The true motor specifications are still unknown, therefore the bevel gear sizes and ratios, as well as shaft dimensions are still variables.

The design meets the project speed requirement by allowing for customization of the bevel gear ratios. The design is similar to that of a traditional outboard lower unit, a tried-and-true platform. This means we can expect a high level of reliability. The shell will also be constructed of materials which can withstand the corrosive environment, while the more delicate internals are sealed and lubricated.

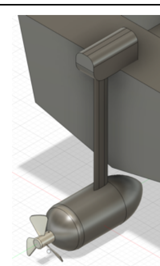
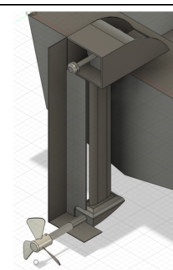
Pros:

- Bevel gears have been proven to provided efficient power transfer.
- The reliability of this system has been well tested for decades.
- Cylindrical shafts and respective cylindrical housing lead to a rigid system.
- Hydrodynamic design for reduced drag effects.

Cons:

- Difficulty of manufacturing due to tight tolerances.
- Difficult to maintain in case of a problem.
- Complex calculations for bearing and bevel gear specifications.

4.3 Concept Evaluation

		Datum	**Soroush**	**Soroush**	**Alex**
Req. #	Requirement Name	Picture of Datum			
					
PA_03	The propulsion system will be easy to maintain and disassemble	N/A	-	+	S
PA_02	The propulsion system will be reliable and will not require frequent maintenance	N/A	+	-	+
SE_02	The propulsion system will provide a waterproof housing for all	N/A	+	+	+

	enclosed components				
FR_02	The propulsion system will be aerodynamic and be faster than previous systems	N/A	S	+	-
	Total of better than rating	N/A	2	3	2
	Total of worse than rating	N/A	1	1	1
	Total of same rating	N/A	1	0	1

Table 4.9 Pugh matrix 1

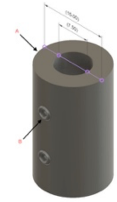
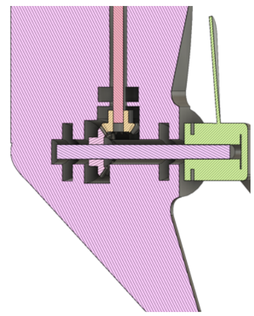
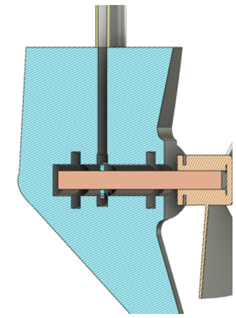
		Datum	**Alex**	**Kai**
Req. #	Requirement Name			
			Coupling 1	Coupling 2
SE-01	Vibration	N/A	S	S
SE-02	Waterproof	N/A	S	S
PA-01	Saltwater	N/A	S	S
PA-02	Maintenance	N/A	S	S
1	For keyed shafts	N/A	-	-
2	Maximum speed greater than 3000 rpm	N/A	-	+
3	Maximum torque greater than 500 in-lbs	N/A	+	-
4	Does not mar the surface of the shaft	N/A	S	-
	Total of better than rating	**Σ+**	1	1
	Total of worse than rating	**Σ-**	2	3
	Total of same rating	**ΣS**	5	4

Table 4.10 Pugh matrix 2

		Datum	**Cole**	**Also Cole**
Req. #	Requirement Name			
SE-01	The system must be able to withstand vibrations caused by waves, wind, and speed.	N/A	S	-
SE_02	The propulsion system will provide a waterproof housing for all enclosed components	N/A	S	S
PA-01	All materials used below the waterline must be able to withstand saltwater corrosion or be resistant for at least 12 hours before getting cleaned.	N/A	S	S
PA_02	The propulsion system will be reliable and will not require frequent maintenance	N/A	S	-
PA_03	The propulsion system will be easy to maintain and disassemble	N/A	S	+
FR_02	The propulsion system will be aerodynamic and be	N/A	S	-

	faster than previous systems			
1	Reliability	N/A	S	-
2	Efficiency	N/A	S	S
3	Manufacturing	N/A	-	+
	Total of better than rating	**Σ+**	0	2
	Total of worse than rating	**Σ-**	1	4
	Total of Same Rating	**ΣS**	8	3

Table 4.11 Pugh matrix 3

Chapter 5. Design Iteration

5.1 Concept Redesign Overview

In this section you decide how to optimize your original design concepts based on your evaluation from chapter 4. Each person takes his/her own design concepts, reviews the reasons for the negative evaluations versus the DATUM, and redesigns the concepts accordingly. Each concept redesign is accompanied by new design sketches, as well as an explanation of what aspects of the design changed and why. You should discuss the weaknesses of each design concept with your class professor, then explain at a high level your approach to improving the concepts in this section.

5.2 Concept Redesigns

5.2.1 Redesign of Coupling (Kai)

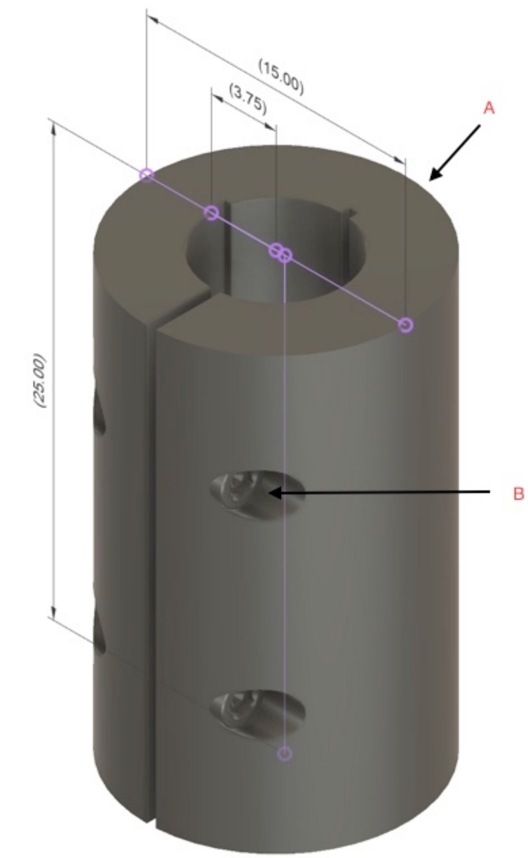


Figure 5.1 Coupling Redesign

Table 5.1 Coupling Redesign Labels

Label	Description
A	Coupling
B	91290A018 Alloy Steel Socket Head Screw

The redesign of the coupling was done to improve upon maximum speed, maximum torque, marring of the shaft surface, and the ability to use a keyed shaft. It is standard practice for couplings to meet vibration, waterproof, saltwater, and maintenance requirements so those aspects were considered. To prevent marring of the shaft a clamping coupling was designed to grip evenly around the shafts, rather than the set screws used in the previous design. To increase speed and torque ratings of the coupling a keyhole was implemented in the redesign so keyed shafts could be used. The clamping and keyhole improvements increased the maximum torque and speed ratings significantly.

5.2.2 Redesign of Coupling (Alexander)

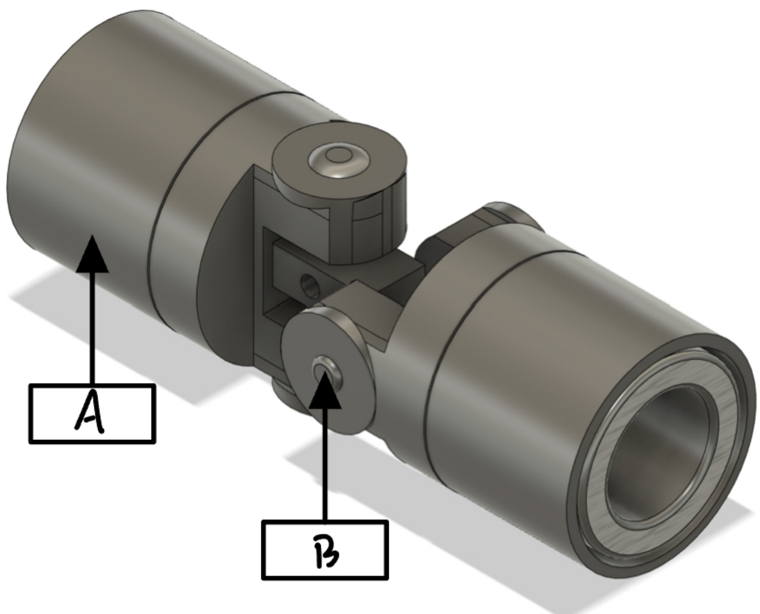


Figure 5.2 Coupling Redesign

Table 5.2 Coupling Redesign Labels

Label	Description
A	Precision Single U-Joint (Detached)
B	Coupling Pin (2)

The purpose for revision of the original coupling was to improve maneuverability of the shaft and exceed expectations for the maximum torque and speed ratings while limiting the vibration of the drive shaft. Thus, the figure above shows an enhanced coupling that increases the degrees of freedom to three and is equipped with bearings to reduce friction and vibration. Compared to the previous design, this concept provides additional protection to the drive shaft as the intended product to be purchased is ½ inch thicker. Additionally, it does not require perfect alignment between the motor shaft and the shaft connected to the propeller. Although this is true for the first design, the new coupling system has two axes of rotation as opposed to one.

5.2.3 Redesign of Pod motor

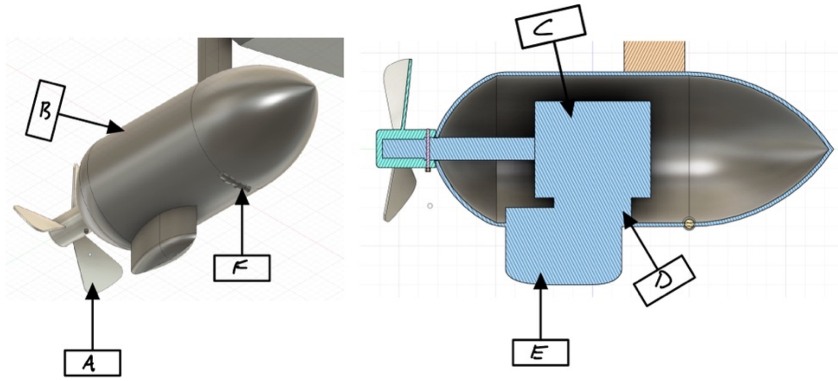


Figure 5.3 Pod Motor Redesign

Table 5.3 Label Letter and its Description for Pod Motor Redesign

Label	Description
A	Propeller
B	Waterproof housing
C	Motor
D	Motor mount
E	Aero Fin
F	Hinge to open casing

The revised pod motor takes the current design and provides improvements in two main aspects where it was lacking before. The first is the addition of an aero fin which provides better stability and better maneuverability of the boat. The second and arguably most important improvement is the addition of a hinge that allows for easy access to the motor for maintenance. This does however mean that more extensive work must be done to ensure that there is a watertight seal between the two sides of the casing. This seal will be achieved with the use of a watertight gasket that will be between the two mating surfaces.

5.2.4 Redesign of Direct-Drive Inboard System (Alexander)

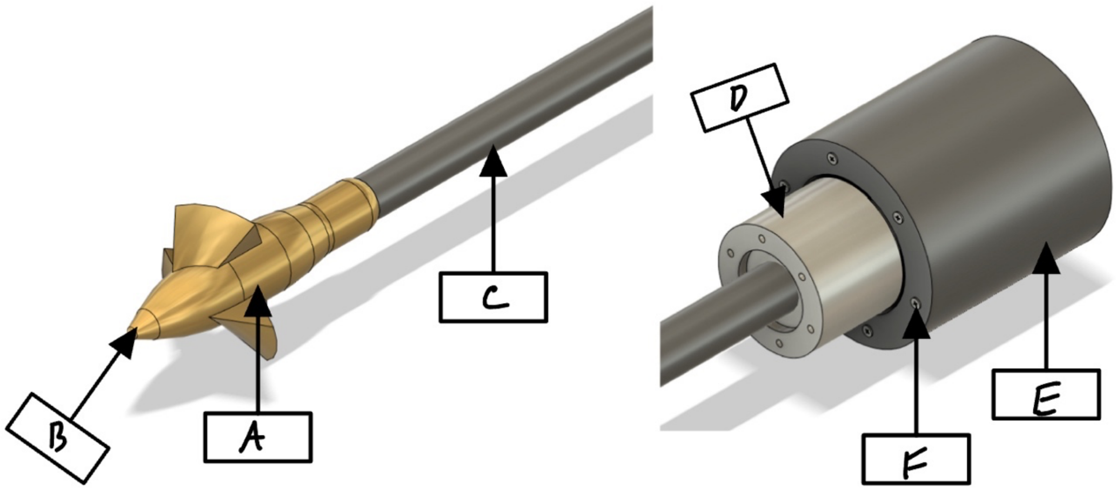


Figure 5.4 3D Model of Direct-Drive Redesign

Table 5.4 Part Letter and Description for direct-drive redesign

Label	Description
A	Propeller
B	Prop Nut
C	Propeller Shaft
D	Intermediate Shaft Bearing
E	Stern Tube
F	Watertight Screw (6)

The revised design for the Direct-Drive Inboard System satisfies all of the project requirements making it significantly more efficient compared to the previous model. While the initial concept was solely designed to prevent water infiltration and to proivde additional protection to the propeller shaft, the new model has reduced overall weight by removing the frame support and shaft sleeve and will result in an increase in top speed as well as acceleration, meeting our 30 miles per hour and maximum torque requirements. It is equipped with a stern tube to accommodate the bearing and propeller shaft. This tube is lubricated with oil to create a watertight barrier preventing any leakage of outside water into the motor compartment. Thus, it has an advantage over the previous concept in terms of waterproofing.

5.2.5 Redesign of Chain Driven Propulsion System

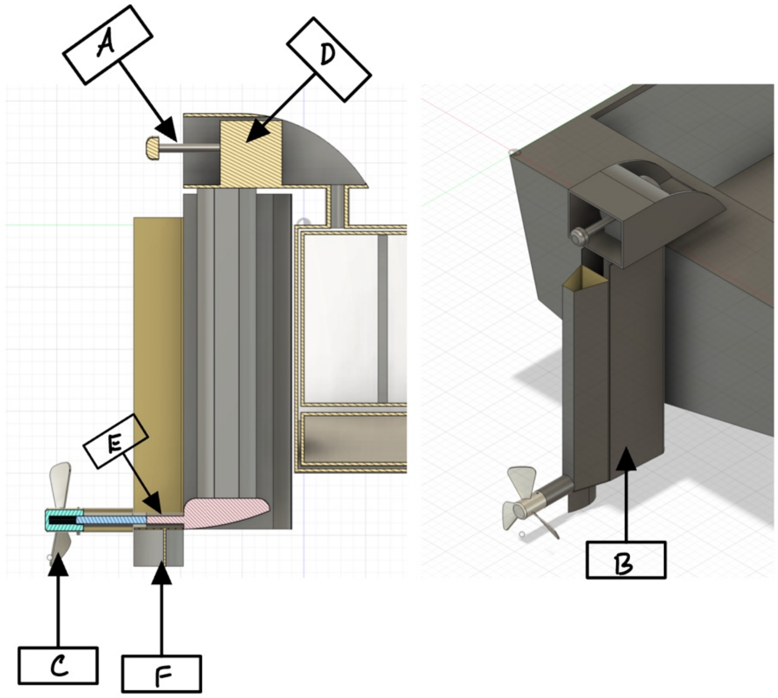


Figure 5.5 Redesign of Chain Propulsion System

Table 5.5 Label Letters for Redesign of Chain Propulsion System

Label	Description
A	Chain mounts to motor shaft here
B	Waterproof housing
C	Propeller
D	Motor
E	Chain mounts to prop shaft at this point
F	Aero fin

The revised chain driven propulsion system has improvements mainly in the hydrodynamic aspect of the system. This system now has a fin that provides better stability and maneuverability of the boat during turns. The outer casing is also now fully surrounding the prop shaft and has an aerodynamic shape to better improve efficiency and speed of the boat, as that is a main requirement of the design for the competition.

5.2.6 Redesign of Bevel Propulsion Sub-Assembly (Cole)

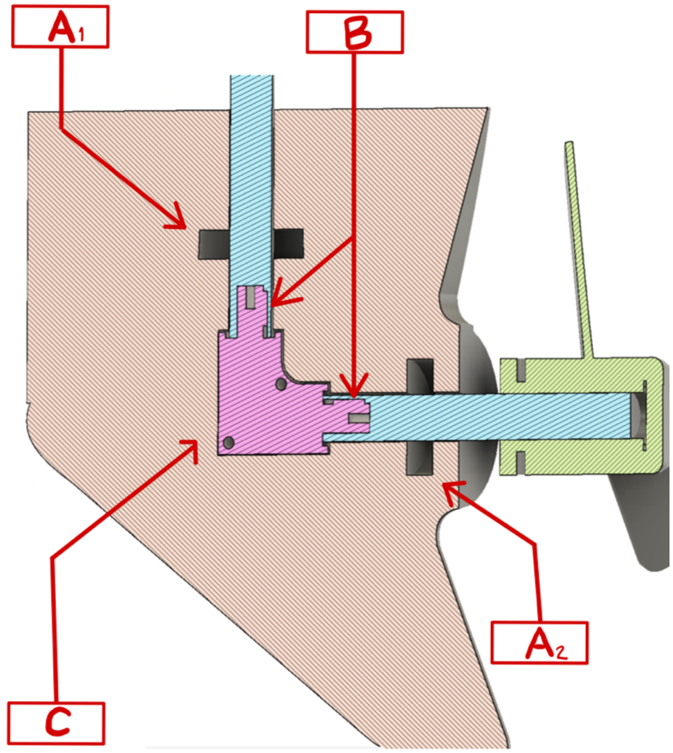


Figure 5.6 Redesign of Bevel Propulsion Sub-Assembly

Table 5.6 Label Letters for Redesign of Bevel Propulsion Sub-Assembly

Label	Description
$A_{1,2}$	Standard Input and Output Shaft Bearings
B	Keyways to Mate Gearbox to Rotating Shafts
C	Commercially Available Bevel Gearbox

The revised bevel driven propulsion system focused on increasing the ease of manufacturing. The predominant feature is the addition of a commercially available 90-degree gear box. This redesign vastly improves the ease of machining and constructing the product, as the task of holding tight tolerances required with meshing bevel teeth is outsourced to specialists. The need for thrust bearings is also alleviated. This design maintains the packaging constraints of a typical lower unit shell, allowing for a low drag profile.

5.2.7 Redesign of Chain Propulsion Sub-Assembly (Cole)

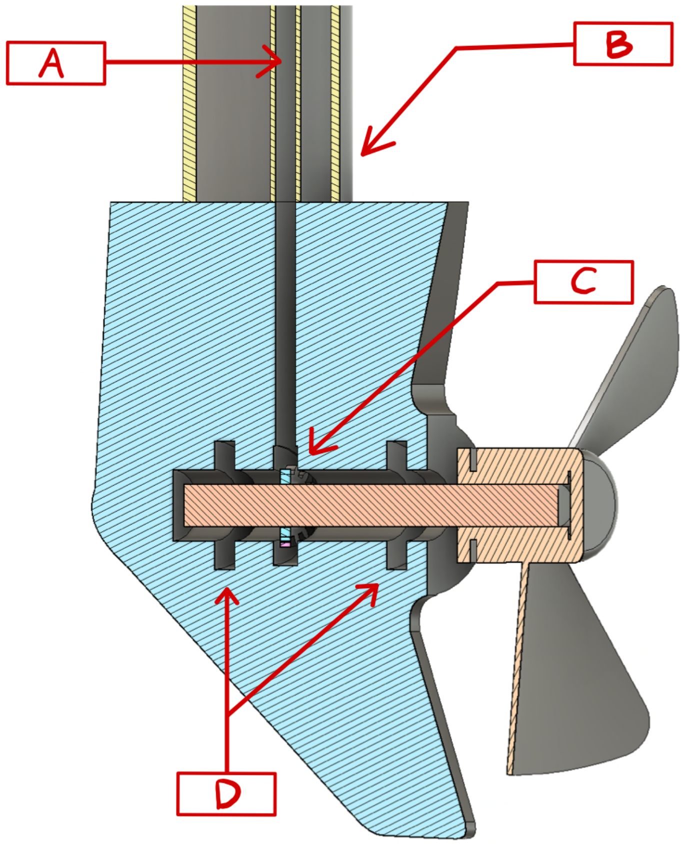


Figure 5.7 Redesign of Chain Propulsion Sub-Assembly

Table 5.7 Label Letters for Redesign of Chain Propulsion Sub-Assembly

Label	Description
A	Drive Chain
B	Hydrodynamic Chain Housing Shroud
C	Sprocket Mounted to Propeller Shaft
D	Propeller Shaft Bearings

The redesign of the chain propulsion sub system addresses two major problems associated with the initial design, lack of rigidity and hydrodynamic efficiency. This task is achieved through the implementation of a foil-shaped shroud surrounding the input chain housing. The cover not only promotes laminar flow of the midsection of the outboard motor, but also increases the rigidity of the unit, therefore reducing the risk of damaging vibrations.

5.3 Concept Re-Evaluation

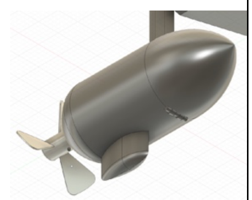
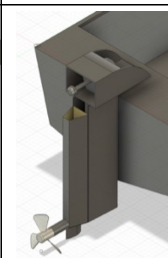
		Datum	**Soroush**	**Soroush**	**Alex**
Req. #	Requirement Name	Picture of Datum			
					
PA_03	The propulsion system will be easy to maintain and disassemble	N/A	+	S	+
PA_02	The propulsion system will be reliable and will not require frequent maintenance	N/A	S	S	S
SE_02	The propulsion system will provide a waterproof housing for all enclosed components	N/A	S	+	S
FR_02	The propulsion system will be aerodynamic and be faster than previous systems	N/A	+	+	+
	Total of better than rating	N/A	2	2	2
	Total of worse than rating	N/A	0	0	0
	Total of same rating	N/A	2	2	2

Table 5.8 Pugh Redesign 1

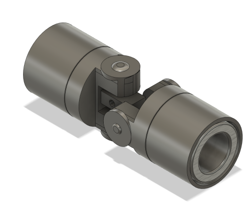
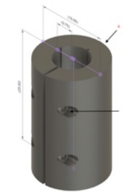
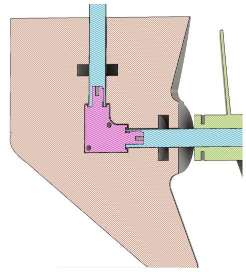
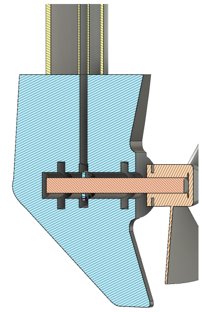
		Datum	**Alex**	**Kai**
Req. #	Requirement Name			
			Coupling 1	Coupling 2
SE-01	Vibration	N/A	S	S
SE-02	Waterproof	N/A	S	S
PA-01	Saltwater	N/A	S	S
PA-02	Maintenance	N/A	S	S
1	For keyed shafts	N/A	-	S
2	Maximum speed greater than 3000 rpm	N/A	+	+
3	Maximum torque greater than 500 in-lbs	N/A	+	-
4	Does not mar the surface of the shaft	N/A	-	S
	Total of better than rating	**Σ+**	2	1
	Total of worse than rating	**Σ-**	1	1
	Total of same rating	**ΣS**	4	6

Table 5.9 Pugh Redesign 2

		Datum	**Cole**	**Also Cole**
Req. #	Requirement Name			
SE-01	The system must be able to withstand vibrations caused by waves, wind, and speed.	N/A	S	S
SE_02	The propulsion system will provide a waterproof housing for all enclosed components	N/A	S	S
PA-01	All materials used below the waterline must be able to withstand saltwater corrosion or be resistant for at least 12 hours before getting cleaned.	N/A	S	S
PA_02	The propulsion system will be reliable and will not require frequent maintenance	N/A	S	-
PA_03	The propulsion system will be easy to maintain and disassemble	N/A	S	+
FR_02	The propulsion system will be aerodynamic and be faster than previous systems	N/A	S	S
1	Reliability	N/A	S	-

2	Efficiency	N/A	S	S
3	Manufacturing	N/A	+	+
	Total of better than rating	**Σ+**	1	2
	Total of worse than rating	**Σ-**	0	2
	Total of Same Rating	**ΣS**	8	5

Table 5.10 Pugh Redesign 3

5.4 Revised Timetable

Deliverable	Deadline
Project Proposal	9/12/2023
Determine type of propulsion (Inboard or Outboard)	9/19/2023
Progress Report 1	9/29/2023
Coordinate preliminary designs with steering team	10/09/2023
Complete the product design specification (PDS)	10/19/2023
Finalize general requirements for steering and propulsion joint functionality	10/25/2023
Progress Report 2	11/03/2023
Determine the motor to be used for the propulsion	11/10/2023
Finalize a design and constraints	11/18/2023
Complete the final CAD file for the propulsion system	12/15/2023
Progress Report 3	12/23/2023
Determine the forces and required bearings/gears necessary	01/29/2024
Purchase all necessary items	02/05/2024
Have first prototype assembled	03/02/2024
Progress Report 4	03/08/2024
Final prototype finished	03/25/2024
Fully mounted and operational in conjunction with steering and solar teams	04/10/2024
Final testing of prototype before competition	04/28/2024
Progress report 5	05/10/2024

Table 5.11 Revised timetable

5.5 Standards Compliance

5.5.1 Codes and standards applied to an electric outboard.

The project is subject to the following codes:

- ASTM G52-20 Standard practice for exposing and evaluating metals and alloys in surface seawater. This standard is relevant to our project because we will be operating in seawater. The outboard must be able to withstand exposure to seawater with minimal corrosion.
- ASTM 1470-19 Standard Practice for Fastener Sampling for Specified Mechanical Properties and Performance Inspection. This standard is relevant as the fasteners that are being used to mount the bevel gear and motor must be able to tolerate 4 hours of run time minimum without failure. This is also relevant for the fasteners that mount the propulsion system to the boat due to the forces faced during operational use.

Chapter 6. Final Concept Design

6.1 Final Subassembly Design

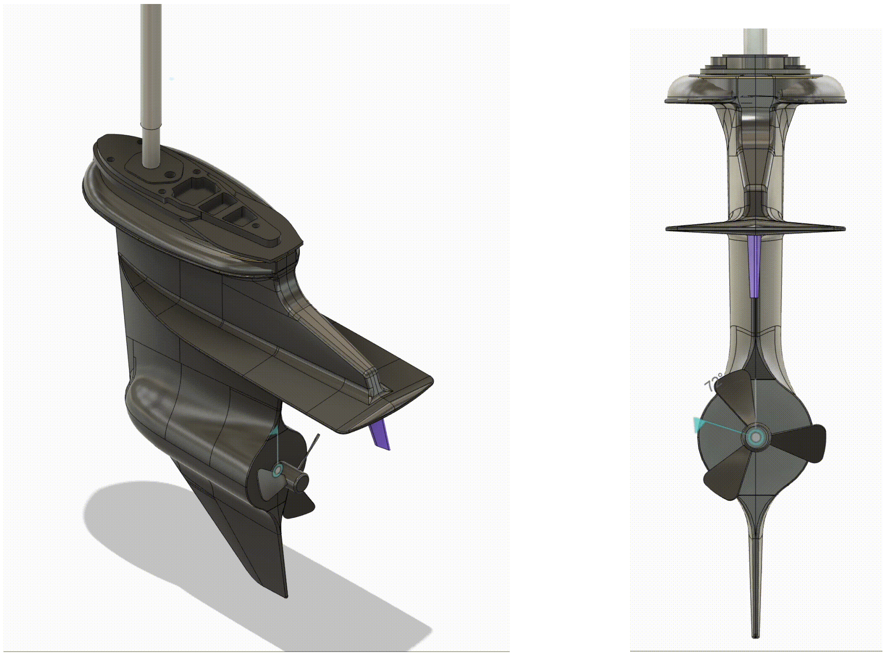


Figure 6.1: GIF of Prop In Motion On Selected Mercury Lower Unit

Figure 6.2: Mounting Plate and Mounting Plate Assembly

The subassembly shown above has been finalized after consulting with each group member and collectively determining that this design will be most beneficial. After scrutinizing design iterations discussed in previous chapters, our group selected the components that we saw as potential candidates for a final design. This selection was based on a series of factors including which parts had anti-corrosive properties, which parts are most-cost-affordable, and which components were the lightest. We've concluded that aluminum and stainless-steel parts served as the most efficient yet affordable.

Specific changes that were made from previous designs include the following: switching from a coupling to thrust bearings responsible for a smooth transmission of power from the motor shaft to the lower unit shaft, removing wall supports for the motor to reduce overall weight and mounting the motor on a flange, and purchasing a low-pressure aluminum shaft casing to enclose the drive shaft. These substitutions were greatly impactful towards our final design as total weight has been reduced, shafts, bearings, and other components are watertight, and our budget goals have been attained.

6.2 3D CAD Assembly

6.2.1 3D Propulsion System Assembly

The objective reasons for this design are to ensure a smooth transmission of power from the shaft of the motor to the shaft connecting the lower unit, to attach a protective casing around the drive shaft with thrust bearings to reduce friction between shafts, and to establish a watertight connection between the casing and lower unit with the use of an aluminum connecting plate. Not only must this design carry out these functions for a prolonged period, but it must also do so while meeting our budget requirements.

With the use of aluminum and stainless-steel parts indicated in the drawing below, the group was successful in developing a lightweight, affordable propulsion system able to withstand the effects of saltwater. First, to provide stable support for the P40 motor, a low-pressure flange is utilized along with stainless-steel head screws. Next, to transfer the rotational motion of the motor while keeping the casing stationary, two stainless-steel ball bearings are placed in between the casing and drive shaft. Internal retaining rings are used for proper connection between the bearing and shaft. The table below indicates the name of each component along with their respective quantities.

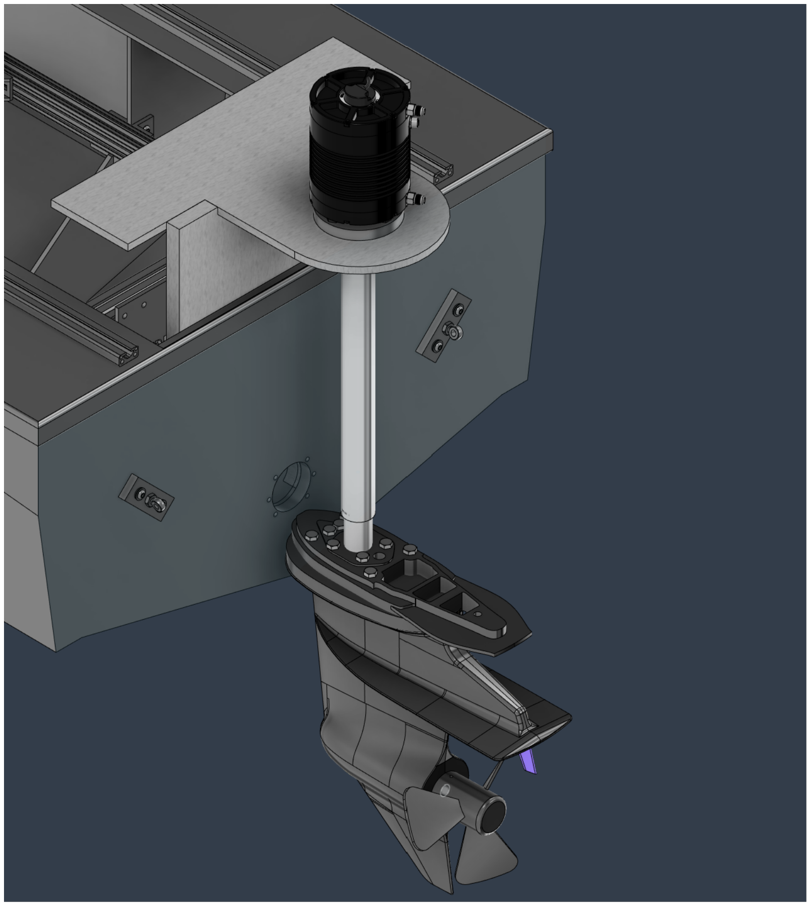


Figure 6.2.1: CAD Rendering of Propulsion System Assembly

The required components for the Propulsion System Assembly are represented below in drawing MEC-440-01. This drawing includes the quantity for each part number with a number identifier connected to each component. Most of the parts were able to be purchased stock apart from a few items that were salvaged. Certain components, for example, stainless-steel head bolts were ordered in surplus as those needed to meet our design requirements and are sold in high quantity packages.

The model includes a 3-foot aluminum casing shaft with an inner diameter of 1.61”. Ball bearings that are 1.625” in diameter can fit perfectly inside this casing and attach to the driveshaft without machining. Additionally, the two snap rings 1.658” in diameter can attach to the outside of these bearings creating a tight connection between themselves and the drive shaft. The dimensions of these parts were strategically chosen based on the diameter of the shaft protruding from the lower unit. Thus, we can develop a rigid propulsion system with minimal vibration.

The subassembly drawing with said part numbers and quantities is included below. Multiple views of the design are used to help visualize the placement of each component and reveal any part that may be hidden:

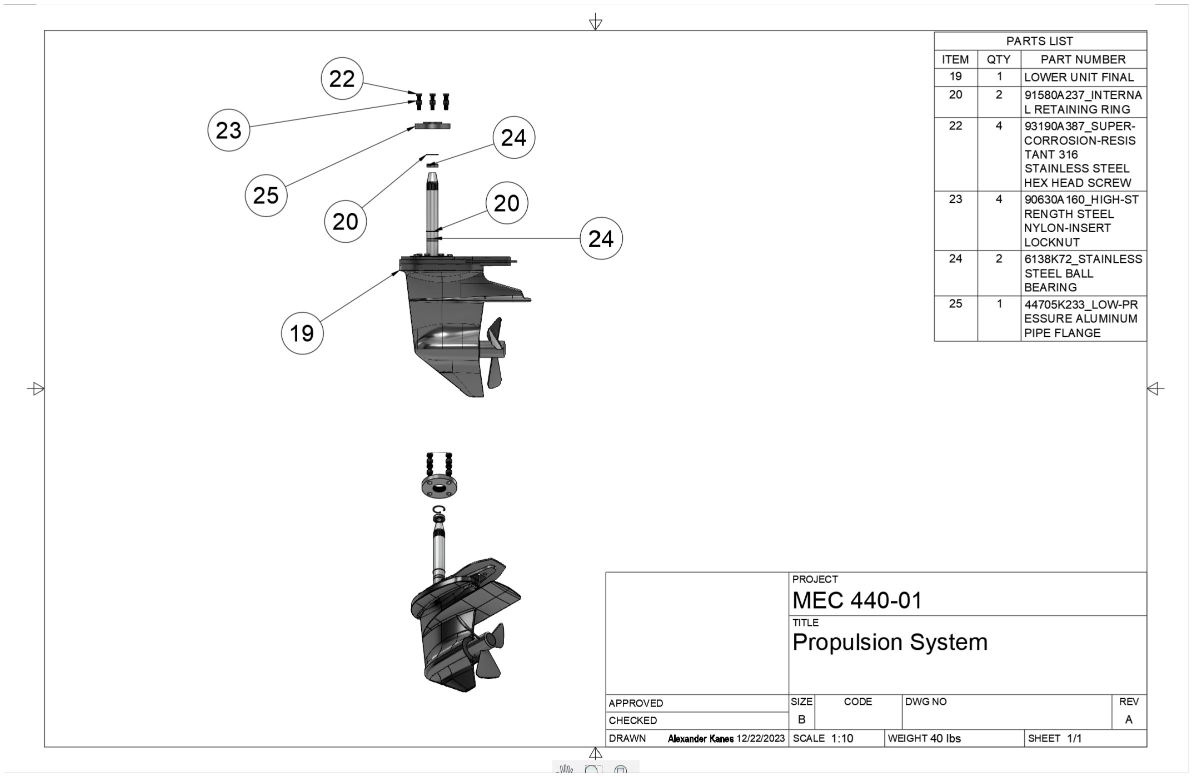


Figure 6.3: MEC 440-01 Propulsion System Subassembly

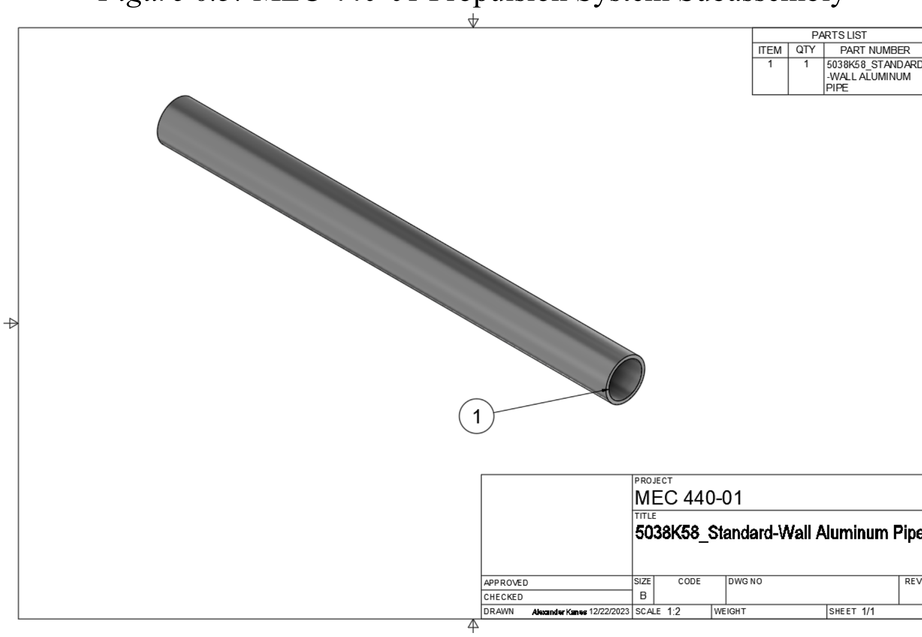


Figure 6.4: MEC 440-01 Standard-Wall Aluminum Pipe

For the lower unit assembly, the manufacturer's components drawing has been included which exposes all components required for the unit and provides a brief description for each part number. Additionally, the manufacturer's version for each of the components listed in the drawings above has been included that indicate dimensions. These subassembly drawings can be found in Chapter 7.

Chapter 7. Detail Design

7.1 Overview

7.1.1 Detail Design of Outboard Propulsion System

In this chapter, the final conceptual design will be further designed and detailed. First, the engineering analysis and calculations that drive the dimensions chosen for detail drawings and component choice will be presented. We calculated the expected torque from the motor when batteries are in parallel or series, bending stress experienced by the housing due to thrust from the propeller, drive shaft torsional shear, bearing loads, dynamic and static thrust of the system, hull drag at various speeds, stresses on all bolts, weld stresses, stress experienced by the threads between the flange and housing, and ideal propeller specifications. Then 2D CAD drawings for each custom designed part and purchased components will be shown. A wiring diagram of the selected motor will be included. Then, a Bill of Materials will be presented to ensure that our design will fall within the projects budget of $1000. Lastly, a self-assessment of each group member's contributions will be presented.

7.2 Engineering Analysis and Calculations

7.2.1 Batteries and Motor Torque

The following computations were conducted in order to confirm that the subsystems will function reliably separately, along with perform within our described factors of safety when combined to form a system. This also helps to ensure that our purchases are accurate, saving the team both time and money.

We first focused on calculating the output capacity from our battery system. The team was able to secure a battery sponsorship from the UPS Battery Center. The company agreed to support the team by supplying three 12V, 50Ah lead acid batteries, which keep the team in compliance with the Solar Splash regulations.

The battery manufacturer posted values of nominal capacity, giving the amp hour rating for different amounts of run time. With this information, we can calculate the available current for different given run times, using the equation:

$$I = \frac{Ah}{t}$$

Knowing the available current is crucial for understanding the operating characteristics of the electric motor. The output torque vs supplied current graph is liner, giving a slope of k_T, the motor torque constant. The motor torque constant is assigned a value of 0.18Nm/A_{rms}, according to the motor manufacturers data sheet. Using this information, the motor torque per given current input can be found using the simple equation:

$$T = k_T * I$$

The motor speed is found in a similar fashion, using the provided voltage constant, k_E, given as 12.50mV/RPM. Motor speed per given voltage is calculated with the equation:

$$RPM = \frac{V}{k_E} * 1000$$

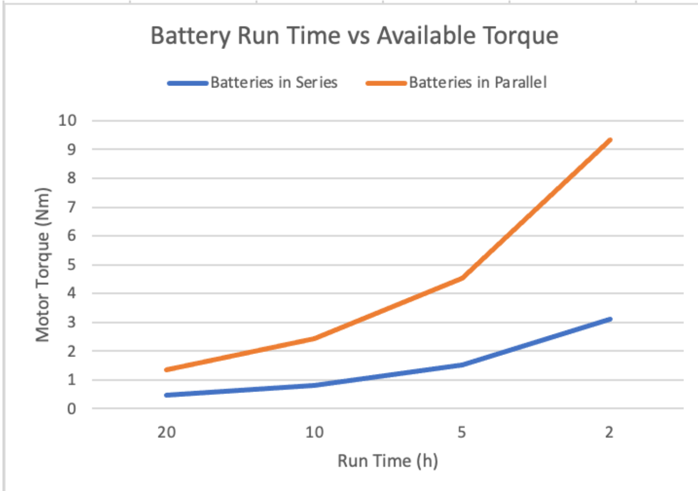
With these values, we calculate the current, motor torques and voltages corresponding to the given values for amp hour and runtime. The excel calculations and resulting plots can be seen below.

3 Battery Series					
Run Time (h)	Ah Rating (A*h) (Series)	Continuous Current (A) I = Ah/time	Motor Torque (Nm) $T = I*k_T$	Continuous Voltage (V) (Series)	Motor RPM $RPM = V/k_E$
20	50	2.5	0.45	36	2880
10	45	4.5	0.81		
5	42	8.4	1.512		
2	34.6	17.3	3.114		
0.083333333		190	34.2		

3 Battery Parallel					
Run Time (h)	Ah Rating (A*h) (Parallel)	Continuous Current (A) I = Ah/time	Motor Torque (Nm)	Continuous Voltage (V) (Parallel)	Motor RPM $RPM = V/k_E$
20	150	7.5	1.35	12	960
10	135	13.5	2.43		
5	126	25.2	4.536		
2	103.8	51.9	9.342		
0.083333333		450	81		

Max Value on Final Value Vs Time Table			
Series	(A)	(min)	(Nm)
	190	5	34.2
Parallel (Peak Rated)	(A)	(min)	(Nm)
	450	5	81

Figure 7.1: Parallel vs. Series Battery Comparison



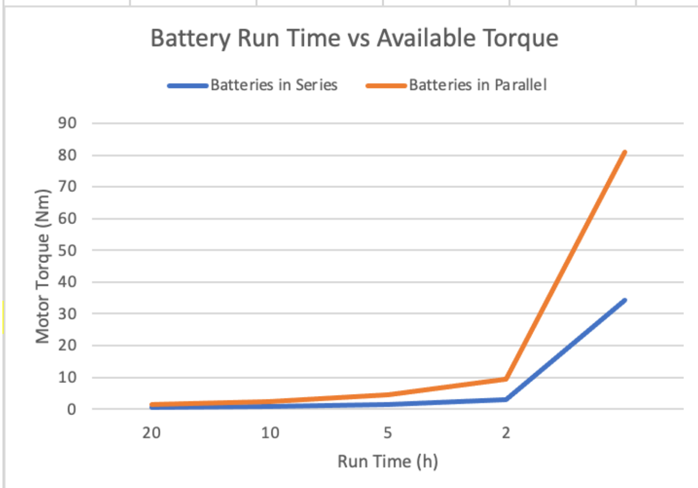


Figure 7.2: Battery Run Time vs. Available Torque

Two graphs were plotted, one excluding the max power and one including, to better visualize the data of an endurance vs sprint application. Knowing these values will help us better understand the requirements and applied stresses for the rest of the system.

7.2.2 Hull Drag Calculations

Drag is the force opposing the boats motion, due to the interaction between our solid hull and the fluid water. In order to better understand the drag forces which must be overcame in order to advance in our boat, we performed calculations for hydrodynamic drag on the hull. The formula for drag according to a NASA article is as follows:

$$D = C_d * \frac{\rho V^2}{2} * A$$

Previous experimental values conducted on our hull have been performed. The values yielded were $C_d = 4.46$ and $A_{submerged} = 0.9m^2$. Upon receiving these values we were informed to take them with an uncertainty, as the team is unsure of the validity of these experimental values. When drag is plotted per meter per second velocity, the proceeding graph is created.

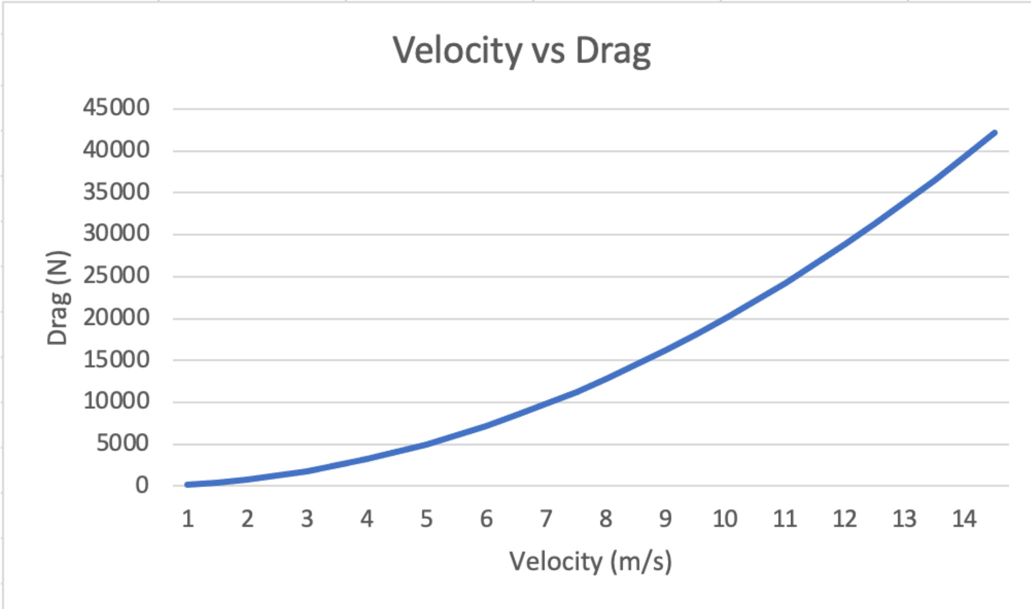


Figure 7.3: Plot of Velocity vs Drag

The solar boat team has provided us with target speeds of 3.6m/s for the endurance race, along with 14m/s for the sprint. The corresponding values of drag for the two targets are listed below.

Velocity (m/s)	Drag (N)
3.6	2598.4709
14	39297.863

To maintain a constant velocity, the dynamic thrust must be equivalent to the hull drag. Intuitively, our value corresponding to 3.6m/s seems to be obtainable. However, when referencing the dynamic thrust calculations for our selected propeller, they fall below these target values. There is uncertainty on whether this error is due to the provided experimental values, or if there is a missing complexity in the imperially derived dynamic thrust equations.

7.2.3 Housing Bending and Applied Stresses

The thrust from the propeller will inevitably cause internal stresses in the housing between our electric motor and lower unit. Failing to consider internal stresses in the housing can lead to catastrophic failure if the material reaches its yield stress. After the yield point, the deflection transitions from elastic to plastic deformation, permanently damaging the system. Proper engineering analysis can prevent these types of failures.

While the boat is in motion, there will be drag forces present on the housing, helping to negate the thrust forces in the opposing direction. For this reason, the scenario where the boat has no velocity and propeller is producing maximum static thrust will be the highest load which the housing will see.

The shaft housing needs to be designed as a hollow tube to contain and protect the drive shaft, along with support hanging weight and thrust forces from the lower unit. The orientation of forces on this structure allows us to treat this system as a cantilever fixed on one end. Where the motor shaft housing is pinned rigidly at the top, at this point the deflection angle will be zero. The thrust force is applied at the bottom of the shaft, causing bending and shear forces along the length of the shaft, which must be considered before finalizing our bill of materials.

The independent variables driving these calculations include the maximum static thrust force, shaft housing length, and the pipe outer and inner diameter. The moment about the fixed point of the shaft housing is found using the static thrust F applied at a length L away from the top:

$$M = FL$$

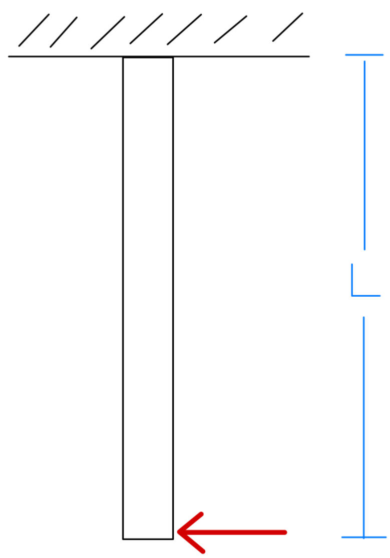


Figure 7.5: Moment Diagram

As a result of the long lever arm from the shaft housing, the bending stress in the drive shaft housing is a crucial calculation. The equation for bending stress is dependent on bending moment, distance from the shapes centroid, and the polar moment of inertia of the cross-sectional geometry. Polar moment of inertia represents an object's ability to resistance torsional deformation. To calculate the polar moment of inertia for a hollow shaft, the equation is as follows:

$$I = \frac{1}{4}\pi({r_o}^4 - {r_i}^4)$$

This yields a result in units of m^4. From here, we have enough information to find the maximum bending stress of our housing, which came out to be 101.07MPa. The excel computations which led to these results can be seen below.

Bending Stress Calculation				
Description	Value	Unit	Variable	Equation
Max Static Trust Force	1185.96	N	F	
Shaft Housing Length	0.508	m	L_s	20 in
Pipe Outer Diameter	1.90625	in	d_o	
Pipe Inner Diameter	1.61	in	d_i	
Pipe Outer Diameter	0.0484188	m	d_o	in*2.54/100
Pipe Inner Diameter	0.040894	m	d_i	in*2.54/100
Pipe Outer Radius	0.0242094	m	r_o	
Pipe Inner Radius	0.020447	m	r_i	
Distance to Neutral Axis	0.0242094		c	
Polar Moment of Inertia	1.325E-07	m^4	I_c	$I_c = \frac{1}{4}\pi({r_o}^4 - {r_i}^4)$
Bending Moment	602.46772	Nm	M	$M = F*L_s$
Bending Stress	110071050	Pa	σ	σ = c*M/I
Bending Stress	110.07105	MPa	σ	Pa*10^-6

Figure 7.6: Bending Stress Calculations

This is by far the most substantial value of stress we have in the housing, and therefore will indicate the material strength and thickness of the housing required. Given the yield strength of 240MPa for 6061 aluminum, we will have a safety factor greater than two.

Continuing with bending calculations, we can determine the maximum deflection of our housing. This evaluation can ensure that the driveshaft will remain sufficiently straight between the motor and the bevel gears, along with that our lower unit will have sufficient clearance from the boat's transom. Using the lever length, applied force, the young's modules of the prescribed material and the polar moment of inertia, we apply the formula for max deflection of a beam fixed on one end:

$$\delta = \frac{F * L^3}{3 * E * I}$$

When computed for our given system, the magnitude of the deflection is determined to be 0.00567m, a reasonable value.

In order to uphold a through engineering analysis of our system, the analysis of shear stress was included in our evaluations. Shear stresses are the result of forces parallel to the surface, making the material want to slide along itself. It is a function of the applied force, maximum first moment, the polar moment of inertia and the cross-sectional width. The calculations can be followed below, which produced a value of 4.47MPa, well under the maximum design stress of the aluminum housing.

Shear Stress Calculations				
Description	Value	Unit	Variable	Equation
Cross Sectional Area	0.0005278	m^2	A	$A = \pi(r_o\text{^}2 - r_i\text{^}2)$
Width of Cross Section (b)	0.0075247	m	b	$2*(r_o - r_i)$
Max First Moment	3.76E-06	m^3	Q_{max}	$(2/3)*(r_o\text{^}3 - r_i\text{^}3)$
Max Shear Stress	4472590.5	Pa	τ_{max}	$V*Q_{max}/(I_c*b)$
Max Shear Stress	4.4725905	MPa	τ_{max}	

7.2.4 Static and Dynamic Thrust Calculations

The propeller is how the motor's electric power will be converted into fluid movement, referred to as thrust. Thrust is the force, in pounds, generated by the propeller at a given speed. We calculated dynamic and static thrust. Dynamic thrust refers to thrust generated at speed while static thrust is the value at maximum power with the boat tied to a dock. Static thrust is considered maximum thrust so to prevent failure the static thrust value was used in housing bending, bolt stress, and the housing bearing calculations. Formulas for the thrust analysis were taken from the Propeller Handbook by Dave Gerr, a highly regarded book in the marine industry.

Static Thrust				
Variable	Value	Unit	Description	Equation
Propeller Speed	4000	rev/min	RPM	From propeller calculations
Shaft Horsepower at propeller	14.05	hp	SHP	From propeller calculations
Propeller Diameter	7.40	inches	D	$D = (632.7*SHP^{0.2})/RPM^{0.6}$
Static Thrust	266.63	pounds	T_s	$T_s = 62.72*(SHP*D/12)^{0.67}$
Static Thrust	1185.96	Newtons	T_s	lbf*4.448

Dynamic Thrust				
Variable	Value	Unit	Description	Equation
T	110.45	pounds	Dynamic Thrust	T = (326*SHP*e)/Va
SHP	14.05	hp	Shaft horsepower at propeller	From propeller calculations
e	0.75	%	Propeller efficiency	From Chart 5-6 Gerr
Va	31.11	knots	Speed of water at the prop.	Va = V*Wf
V	31.85	knots	Speed in knots	From propeller calculations
Wf	0.98		Wake factor	$Wf = 0.83*Kts^{0.047}$
Wt	0.02		Taylor wake fraction	Wt = 1 - Wf

Figure 7.7: Thrust Calculations

7.2.5 Bearing Load Analysis

Bearings are an essential component to our Propulsion system. They are responsible for the freedom of motion of the drive shaft and the entire system. We have two types of bearings in the system. Bearings within the housing that allow for smoother rotation of the drive shaft and a single bearing that allows the entire system to rotate which is essential for our steering system. For the bearings within the housing a radial force had to be calculated. Radial load from the bevel gears were calculated and estimated has the maximum radial force experienced by the bearings to prevent failure. Radial load formulas were taken from Chapter 10 of Machine Elements in Mechanical Design. With the calculated radial load bearing selection from Chapter 14 was performed. Then for the single bearing outside the housing the thrust load was found from the weight of the system and the radial load was estimated at a maximum using the static thrust previously calculated. Bearing selection from Chapter 14 was again performed for the single bearing. It is important to note that the drive shaft diameter was already known so the bearing selection process was merely used to be sure the bearing that fit the known dimensions could withstand the calculated load.

Selecting adequate interfaces is an important process of bearing analysis. SKF, a reputable bearing manufacturer, has an intuitive user interface to simplify this process. Conditions of rotation was used to select interfaces. Conditions of rotation refers to the relative motion between a bearing ring and the load acting upon it. There are three different conditions: rotating load, stationary load, and direction of load indeterminate. Rotating loads occur where either the bearing ring or the applied load is stationary while the other rotates. A bearing ring mounted with a loose fit will creep on its seat when subjected to a rotating load, and this can lead to fretting corrosion and eventually wear. To prevent this from happening, an adequate interference fit, between the ring subjected to rotating load and its seat, is required. This type of condition of rotation occurs in both our bearing types. A table is included below with the exact tolerance values.

Once the bearings are selected and interferences accounted for steps must be taken to perform proper mounting. According to NSK, bearings with cylindrical bores are usually mounted by pressing them on shaft or heating them to expand their diameter. Exact mounting techniques will be determined as we get closer to production.

Radial Load Calculations Bevel Gear				
Variable	Value	Unit	Description	Equation
P	14.05178979	hp	Power	P = n*T/5252
n	2000	rpm	rev/min	Given
r	1	in	mean radius of pinion	Estimate
T_p	442.6313785	lb in	Torque on pinion	T_p = 63000*P/n
W_t	442.6313785	lb	Tangential Force	W_t = T/r
Ø	20	degrees	pressure angle	Estimate
Y	18.43	degrees	pinion pitch cone angle	Estimate
W_r	904.3542514	lb	Radial Force	W_r = W_t·tanØ*cosY

Bearing Selection for Shaft				
Variable	Value	Unit	Description	Equation
k	3		for ball bearings	Given
R	904.3542514	lb	Radial load	Maximum load seen
V	1		rotation factor	Inner race rotates
P	904.3542514	lb	Equivalent Load	P = VR
D	0.75 "	in	From shaft OD	Given
Bearing Type	Single-row, deep-groove ball		Type of Bearing	
Design Life	1000-2000		Expected life	Table 14-4
C	103.5227192	lb	Basic Dynamic Load Rating	
Bearing Selection	6138K72	Meets Load Rating and Dimensions		

Bearing Selection Outside Casing				
Variable	Value	Unit	Description	Equation
Y	1.5		Thrust Factor	Table 14-5
V	1.2		Rotation Factor	Outer race rotates
R	266.63	lb	Radial Applied Load	From Thrust Calculations
T	30	lb	Applied Thrust Load	Weight of System
X			Radial Factor	
P	319.9532571		Equivalent Load	P = VR
T/R	0.112516435		Because T/R < e use P = VR	Table 14-5
D	1.90625	in	Casing Diameter	Given
L	1500	h	Expected life	Table 14-4
C	36.62550503		Basic Dynamic Load Rating	
Bearing Selection	8828T321	Meets Load Rating and Dimensions		

Figure 7.8: Bearing Load Analysis

table 1 - Tolerances for solid steel shafts - seats for radial ball bearings[1]

Conditions	Shaft diameter	Dimensional tolerance[2]	Total radial run-out tolerance[3]	Total axial run-out tolerance[3]	Ra
	mm	–	–	–	µm
Rotating inner ring load or direction of load indeterminate					
Light loads (P = 0,05 C)	= 17	js5	IT4/2	IT4	0,4
	> 17 to 100	j6	IT5/2	IT5	0,8
	> 100 to 140	k6	IT5/2	IT5	1,6
Normal to heavy loads (0,05 C < P = 0,1 C)	= 10	js5	IT4/2	IT4	0,4
	> 10 to 17	j5	IT4/2	IT4	0,4
	> 17 to 100	k5	IT4/2	IT4	0,8
	> 100 to 140	m5	IT4/2	IT4	0,8
	> 140 to 200	m6	IT5/2	IT5	1,6
	> 200 to 500	n6	IT5/2	IT5	1,6
	> 500	p7	IT6/2	IT6	3,2
Stationary inner ring load					
Easy axial displacement of inner ring on shaft desirable		g6[4]	IT5/2	IT5	1,6
Easy axial displacement of inner ring on shaft unnecessary		h6	IT5/2	IT5	1,6
Axial loads only		j6	IT5/2	IT5	1,6

Figure 7.9: Bearing Tolerance Table

7.2.6 Bolt Stress Calculations

Bolt stress calculations are a simple yet necessary task. A bolt failure could compromise the entire system, causing water to infiltrate the gearbox and misaligning the drive system. The team used Chapter 3 Stress and Deformation Analysis from Machine Elements in Mechanical Design to evaluate normal and shear stress for every bolt. Static Thrust was used as the maximum shear force so there was an added level of safety. Normal stresses on the bolts are limited and only caused by the weight of the system. The bolts selected for the flange and the lower unit are well within the manufacturer load specifications.

Lower Unit Plate Bolts				
Variable	Value	Unit	Description	Equation
P	266.63	lb	Max Shear Force	From Thrust Calc.
N	5		Number of Bolts	
D	0.394	in	Bolt Diameter	
A	0.12	in^2	Cross section area	
τ	2186.869988	lb/in^2	Shear Stress per bolt	$\tau = P/A$
F	30	lb	Normal Force	System Weight
σ	246.0588159	lb/in^2	Tensile Stress	$\sigma = F/A$

Flange and Motor Fasteners				
Variable	Value	Unit	Description	Equation
P	266.63	lb	Static Thrust	From Thrust Calc.
N	4		Number of Bolts	
D	0.5	in	Bolt Diameter	
A	0.20	in^2	Cross section area	
τ	1357.923798	lb/in^2	Shear Stress per bolt	$\tau = P/A$
F	30	lb	Load	System Weight
σ	152.7887454	lb/in^2	Tensile Stress	$\sigma = F/A$

Figure 7.10: Bolt Stress Calculations

7.2.7 Propeller Selection

The goal in propeller selection is to determine what style and size will maximize your boats performance. Propeller choice is based on weight of the boat, propeller shaft speed, and propeller shaft torque. Before the desired diameter and pitch of the propeller could be chosen the team had to determine the expected speed of the boat as well as propeller shaft specifications. These calculations were based on torque and speed calculations provided by the electric motor manufacture and gear ratios provided by the lower unit manufacturer. The Propeller Handbook by Dave Gerr was an amazing tool in this endeavor. Crouch's Planing Speed Formula produced expected speed values and simple power formulas and gear reduction equations from 410 provided us with propeller shaft specifications. These calculations can be seen below. Armed with the proper specifications we were able to calculate desired diameter and pitch of the propeller as seen below. The best commercial propeller was selected that met diameter, pitch, and propeller shaft requirements. The Mercury Black Max 10-3/8x 13P Propeller is within 0.7% of the desired pitch and within 40% of desired diameter.

Crouch's Planing Speed Formula				
Variable	Value	Unit	Description	Equation
C	190		High Speed Runabouts Constant	Chart 2-3
LB	500	lb	Displacement in pounds	Weight of loaded boat
SHP	14.05	hp	Shaft hp	Calculated
Kts	31.85	Kts	Speed	$Kts = C/(LB/SHP)^{0.5}$
MPH	36.66	MPH	Speed	Kts*1.151

Propeller Shaft Specifications				
Variable	Value	Unit	Description	Equation
N	2000	rpm	Nominal Speed	Given
N_p	4000	rpm	Speed at Prop	N*2
T	36.9	ft lb	Cont. Torque	Given
	2		Gear Ratio	Given
T_p	18.45	ft lb	Torque at Prop	$T_p = T/2$
SHP	14.05	hp	Power	$SHP = N*T_p/5252$

Figure 7.11: Boat and Propeller Speed Specifications

Propeller Pitch Calculations				
Variable	Value	Unit	Description	Equation
N	4000	RPM	rev/min	Given
V	36.66	mph	Speed	Crouch's Formula
V	3226.21	ft/min	Speed	Crouch's Formula
P	0.90	feet	Propeller Pitch	P = V/(N*0.9)
P	10.75	inches	Propeller Pitch	P*12
SLIP	20	%	slip	$SLIP = 1.4/Kts^{0.57}$
P_s	12.9	inches	Prop. Pitch with Slip	$P_s = P*s+1$

Propeller Diameter Calculations				
Variable	Value	Unit	Description	Equation
SHP	14.05	hp	Shaft hp at prop	From Prop. Calc
RPM	4000.00	rev/min	Shaft RPM at prop	From Prop. Calc
D	7.40	in	Prop. Diameter	$D = (632.7*SHP^{0.2})/RPM^{0.6}$
P/D	1.45		Pitch Ratio	
Avg. P/D	1.13		Pitch Ratio	$Avg. P/D = 0.46*Kts^{0.26}$

Figure 7.12: Propeller Diameter and Pitch Calculations

Figure x: Mercury Black Max 10-3/8x 13P

7.2.8 Lower Unit Selection

The Team decided it would be best to purchase a commercial lower unit rather than design and produce a waterproof bevel box due to time and budget restrictions. Before a commercial unit could be selected, we had to determine the expected power output of the motor. The motor is a DHX machines Peregrine P40(76V version), the specification sheet is seen below. We will be running the system at 36V so rather than use max speed and peak torque values for power calculations we went with nominal speed and continuous torque, these values still provide us with a large safety net. The calculations seen below show that the expected power of the motor at the given speed and torque is 30.9 hp. Commercial units are manufactured in strange horsepower increments in the order of 15, 20, 25, 30, 40, and 50 hp. We decided a 40 hp rated lower unit would be best to meet power requirements and keep weight as low as possible. With this rating in mind the team started the search for a 40 hp rated lower unit. A team member had a connection and was given a 2017 40 hp lower unit at no cost to the team! Calculations, motor datasheet, and the lower unit can be seen below.

Lower Unit Calculations				
Variable	Value	Unit	Description	Equation
N	4400	rpm	Nominal Speed	Given
T	36.9	ft lb	Torque	Given
P	30.9	hp	Power	P = N*T/5252

Figure 7.13: Lower Unit Calculations

Figure 7.14: Mercury 2017 40 hp Lower Unit

Rev - 2 07/08/21

DHXmachines

PEREGRiNE P40

The PEREGRiNE permanent magnet synchronous motors (SMPM) are designed for low-voltage traction applications at nominal DC bus voltage of 96 VDC.

- Robust performance
- Air cooled rotor
- Lightweight aluminum shaft
- Compact terminal design
- Standard AN coolant fittings
- Compact RTD connection

Tractive Effort Spec.

Nominal speed	4400RPM	
Continuous torque	50Nm	36.9ft.lb
Peak torque (S2- 30s)	80Nm	59ft.lb
Continuous power	23.0kW	30.8hp
Peak power (S2- 30s)	36.8kW	49.3hp
Max. speed	6500RPM	

Electrical Spec.

Motor type	SMPM(TEWC)
DC Bus voltage (Nom.)	96VDC
Rated current	$292A_{rms}$
Peak current (S2- 30s)	$450A_{rms}$
No. of poles	10
Voltage Constant (kE)	$12.50mV_{rms}/RPM$
Torque Constant (kT)	$0.18Nm/A_{rms}$
Max. efficiency	95%

Mechanical Spec.

Rotor inertia	$1.25e\text{-}3kg.m^2$	
Max. coolant inlet temperature	50°C	122°F
Min. coolant flow rate	7.68LPM	2gpm
Total mass	8.6kg	19.0lb
Exterior volume	2.2L	0.6gal
Torque density (gravimetric)	9.3Nm/kg	3.1ft.lb/lb
Torque density (volumetric)	37.0Nm/l	103.4ft.lb/gal

Feedback Sensors

Encoder	Encoder RLS RM58AC0001S10F2F10
Temp. Sensor	RTD Sensors, PTFM Type, 1.2 x 4 mm, -50 °C 600 °C, 1kohm, MEAS PTF Series

Figure 7.15: DHX Machines P40 Peregrine Data Sheet

7.2.9 Plate Weld Calculations

In order to ensure a secure and watertight seal throughout the whole propulsion system, the lower unit is welded to a plate that holds the shaft bearings and allows the motor shaft to connect to the propeller shaft. The lower unit and plate are both constructed of aluminum and therefore TIG welding will be the desired solution for this application. Because of the complex geometry of the surface that is being welded, the plate is approximated as a rectangle to make the calculations manageable. The force on the weld is direct tension from the weight of the lower unit and components within. The value necessary is the minimum leg size (w). The allowable force per inch of leg was not in the MEC 410 lecture notes, but from some internet research a value of 6700 lb/in of leg was found to be a general value for an aluminum TIG weld.

Type of Loading	Direct Tension		
Force (P)	266.61	lb	
Length (d)	8	in	
Weld Area (Aw)	16	in	Aw=2d
Fs	16.6634	lb/in	Fs=P/Aw
FL	6700	lb/in	From Internet Search
minimum leg size (w)	0.002487075	in	w=Fs/FL
thickenss (t)	0.001758362	in	t=0.707w
min leg from table (w')	0.1875	in	

Figure.7.16: Plate Weld Calculations for Minimum Weld Leg

7.2.10 Galvanic Corrosion

The ability of electrons to move freely is the property which makes metals electrically conductive. It is also the driving force behind a destructive occurrence known as cathodic corrosion, or more specifically to our case, galvanic corrosion. Cathodic corrosion occurs when two different types of metals are exposed to each other. If the two metals have different numbers of electrons in their valance shells, there will be a tendency for the electrons on the more negative side to move to the spaces in the less negative side. Galvanic corrosion is the same process, when applied in an electrolyte solution. This can lead to a substantial loss in strength of the part. When selecting our components, we must choose materials that are close on the galvanic series, shown below.

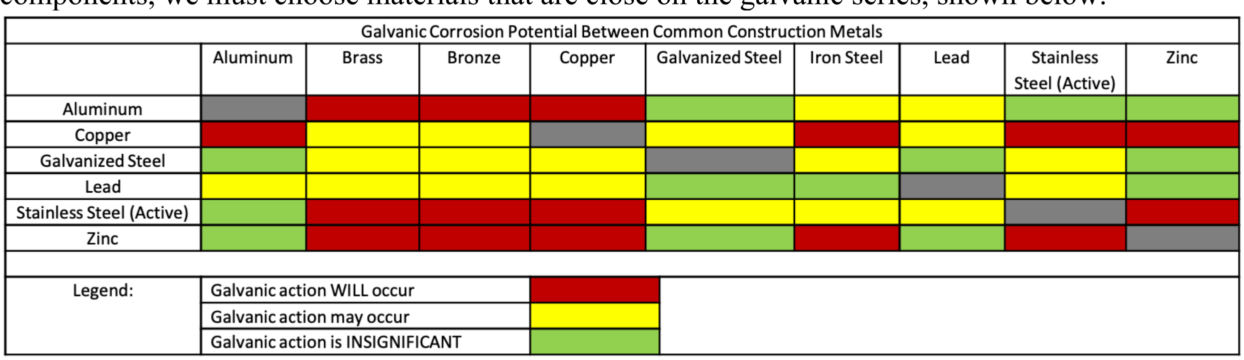


Figure x: Galvanic Series Chart (*Matthew Stuart,* PDH Online)

To avoid this destructive process, we must choose compatible materials. In this project, we have selected aluminum and active stainless steel, due to their reasonable costs and non-corrosive behavior when combined into an electrolyte solution.

7.3 3D CAD Drawings

7.3.1 Component for Propulsion System 2D Drawing

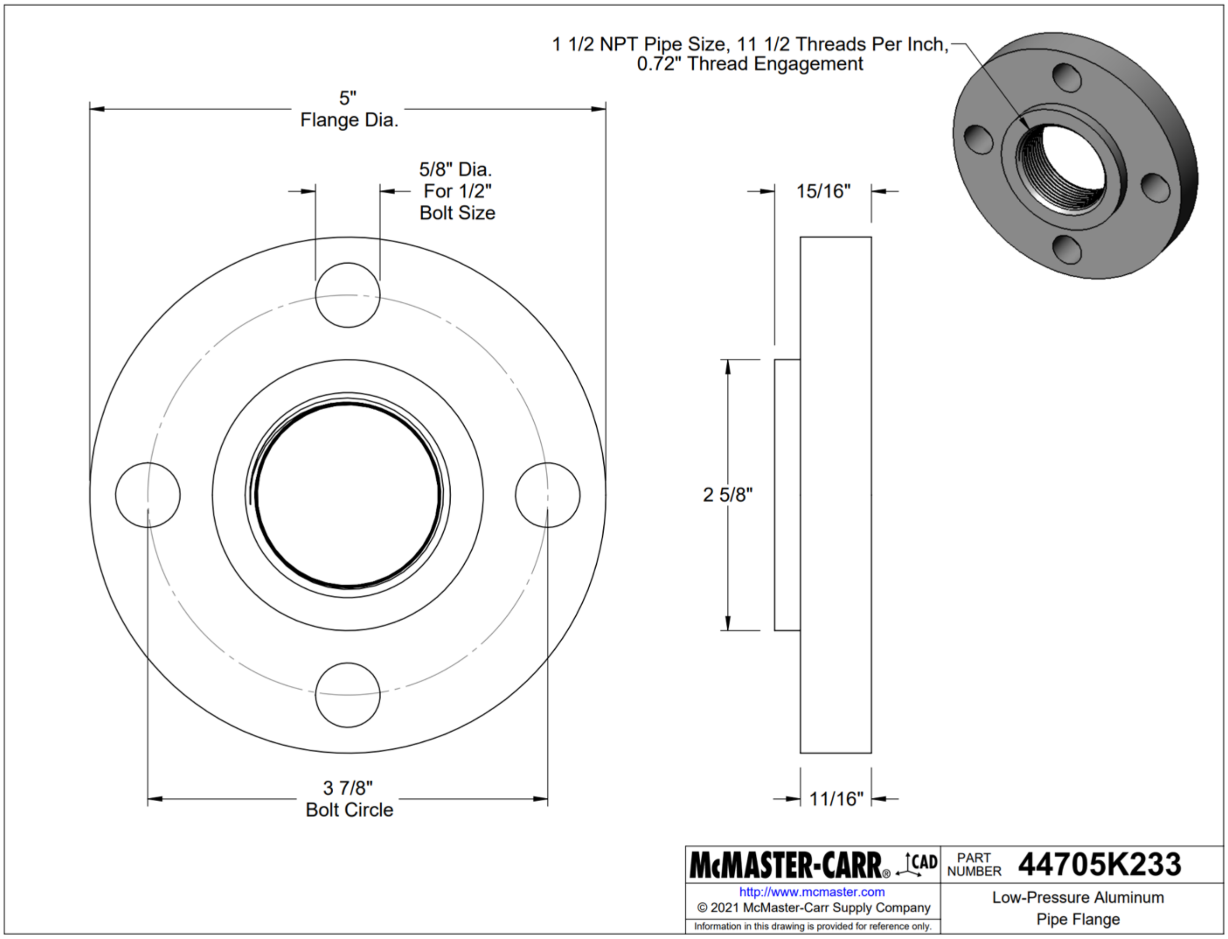


Figure 0.1: 2D CAD drawing of the 44705K233 Flange

7.3.2 Component for Propulsion System 2D Drawing

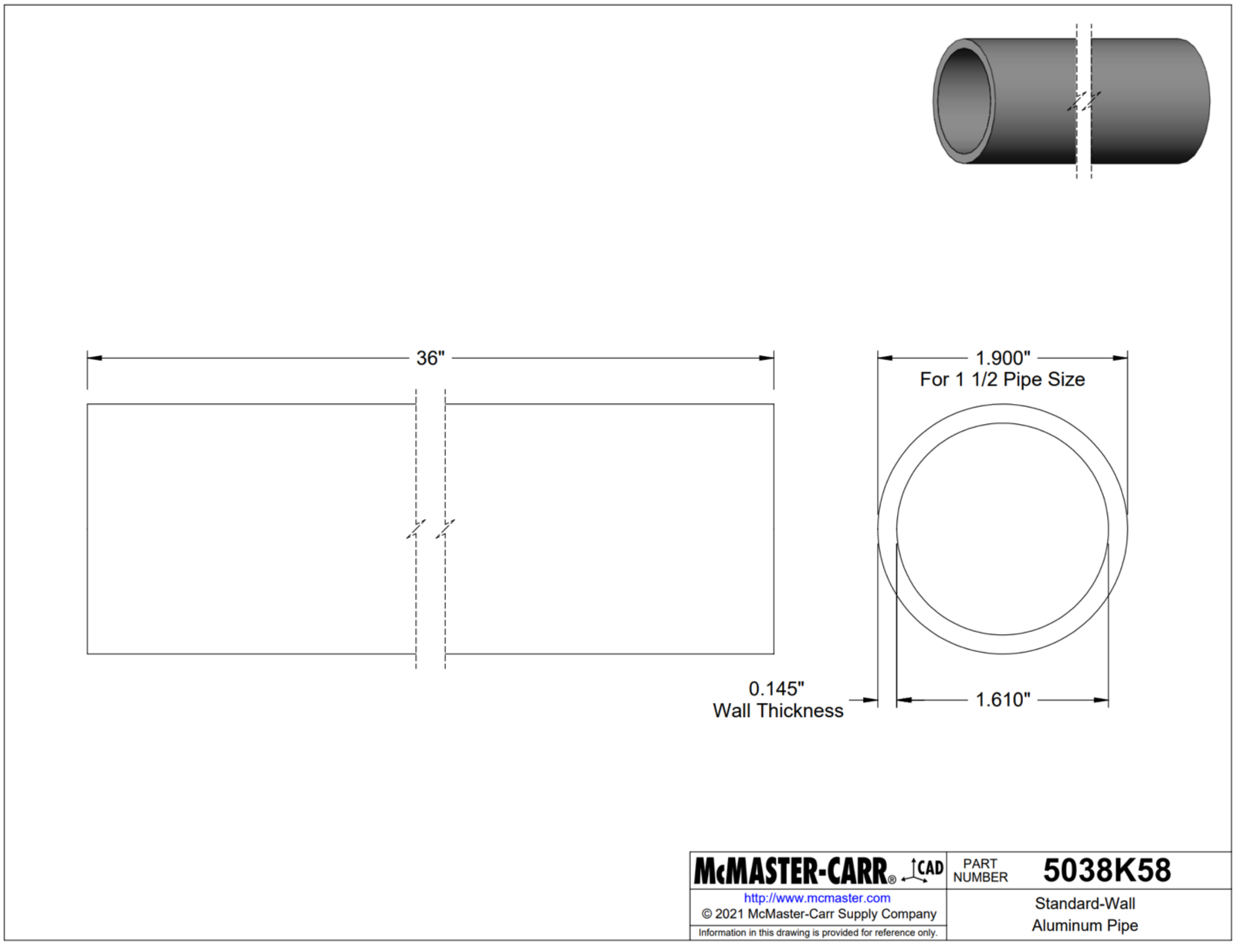


Figure 0.2: 2D CAD drawing of the 5038K58 Pipe

7.3.3 Component for Propulsion System 2D Drawing

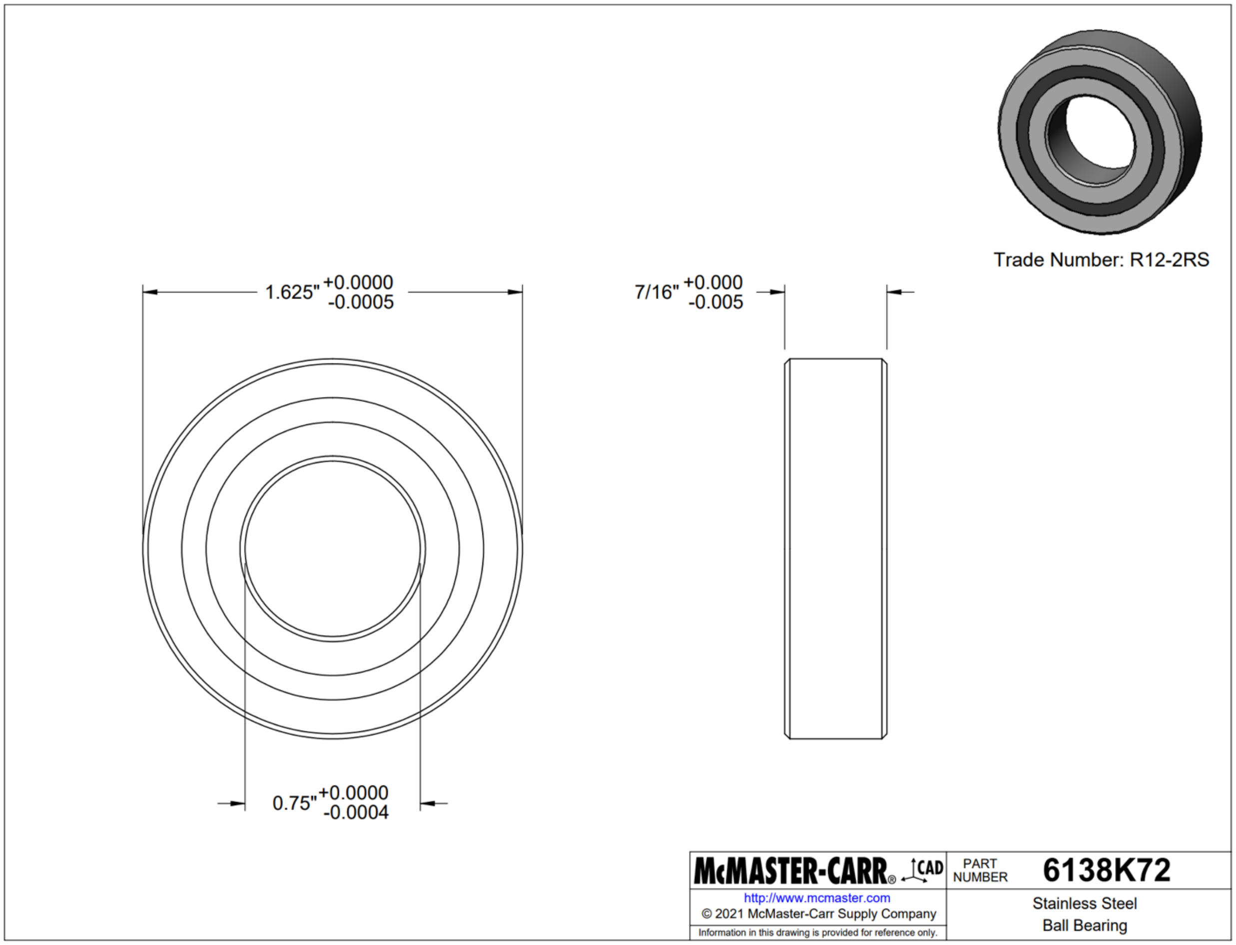


Figure 0.3: 2D CAD drawing of the 6138K72 Ball Bearing

7.3.4 Component for Propulsion System 2D Drawing

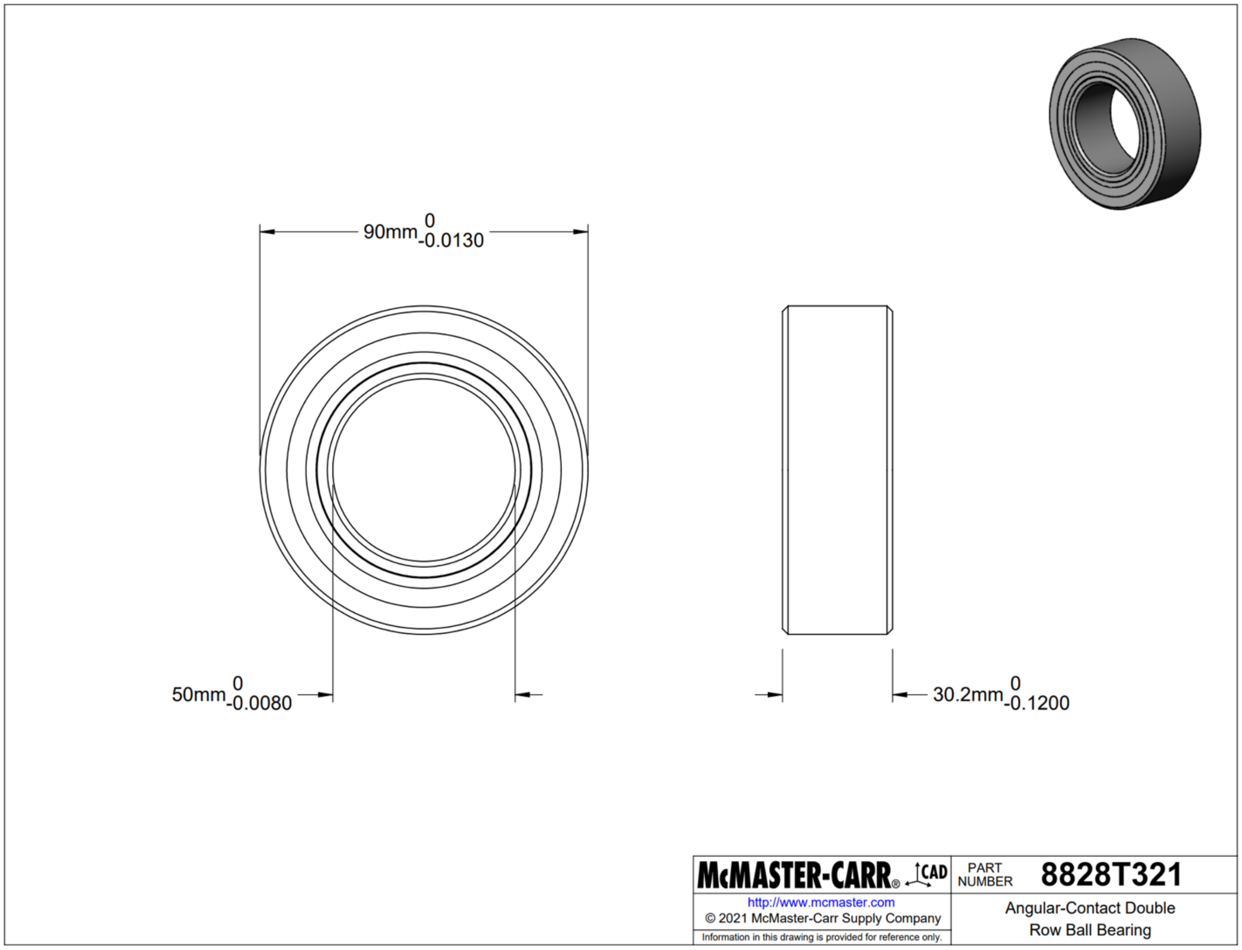


Figure 0.4: 2D CAD drawing of the 8828T321 Ball Bearing

7.3.5 Component for Propulsion System 2D Drawing

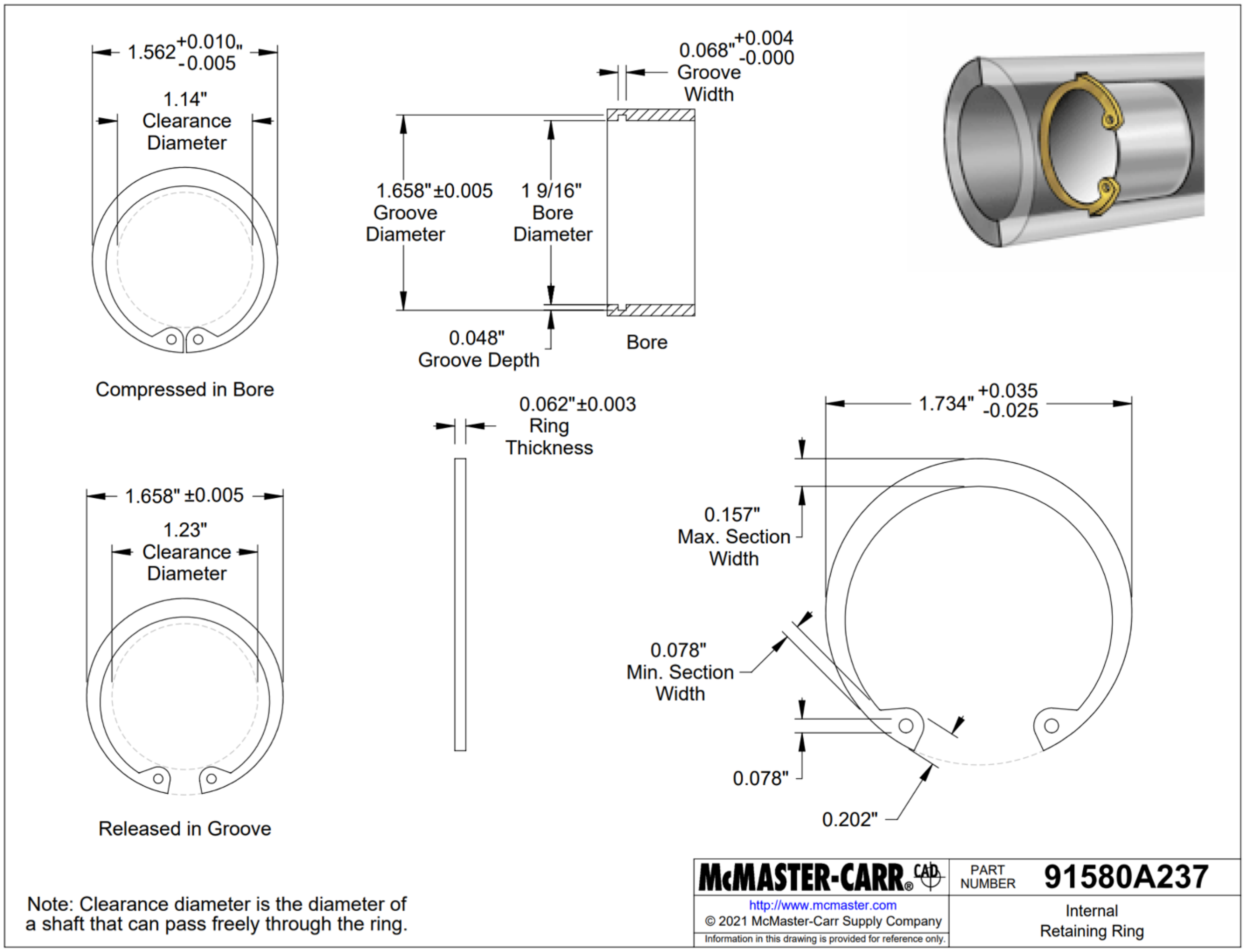


Figure 0.5: 2D CAD drawing of the 91580A237 Retaining Ring

7.3.6 Component for Propulsion System 2D Drawing

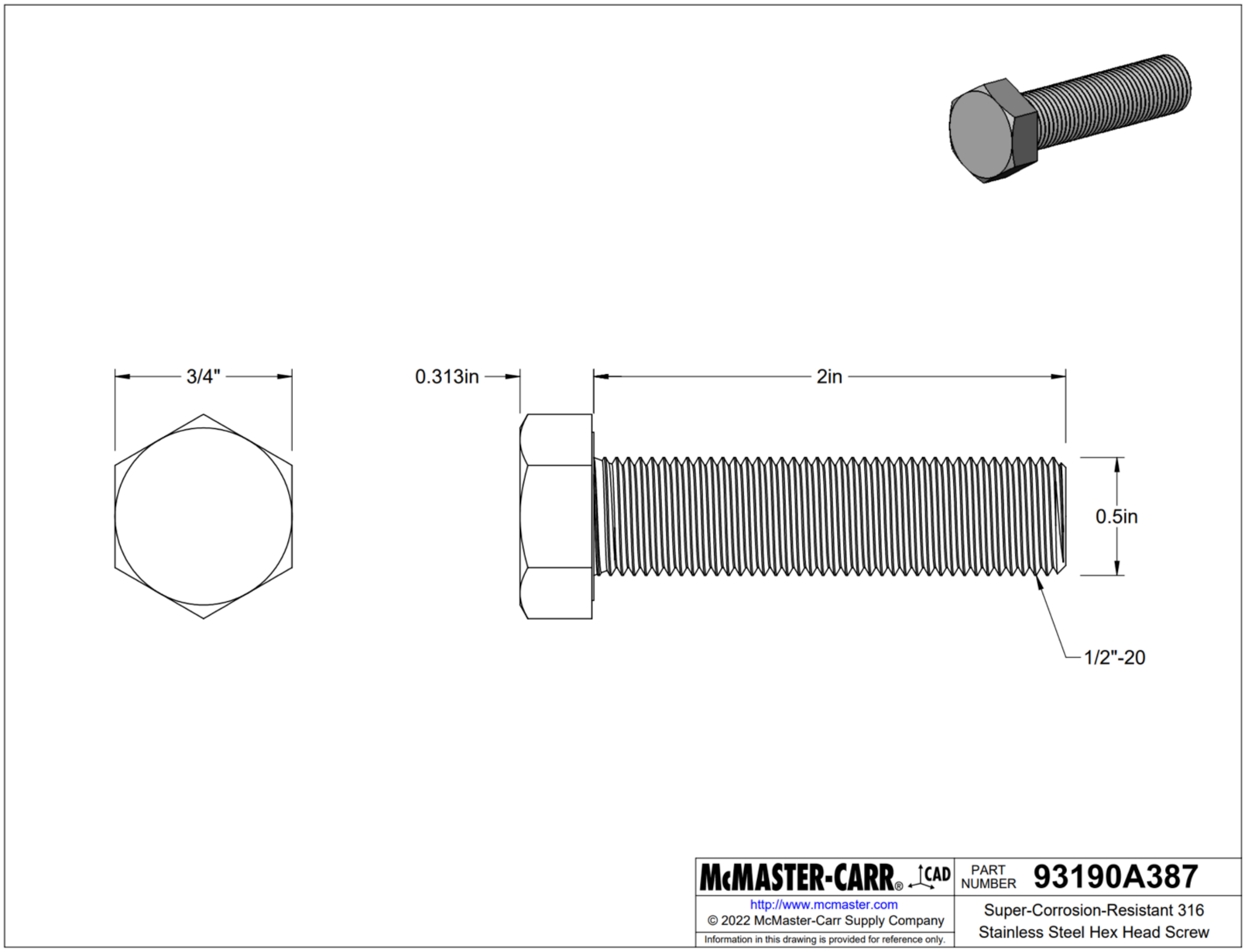


Figure 0.6: 2D CAD drawing of the 93190A387 Screw

7.3.7 Component for Propulsion System 2D Drawing

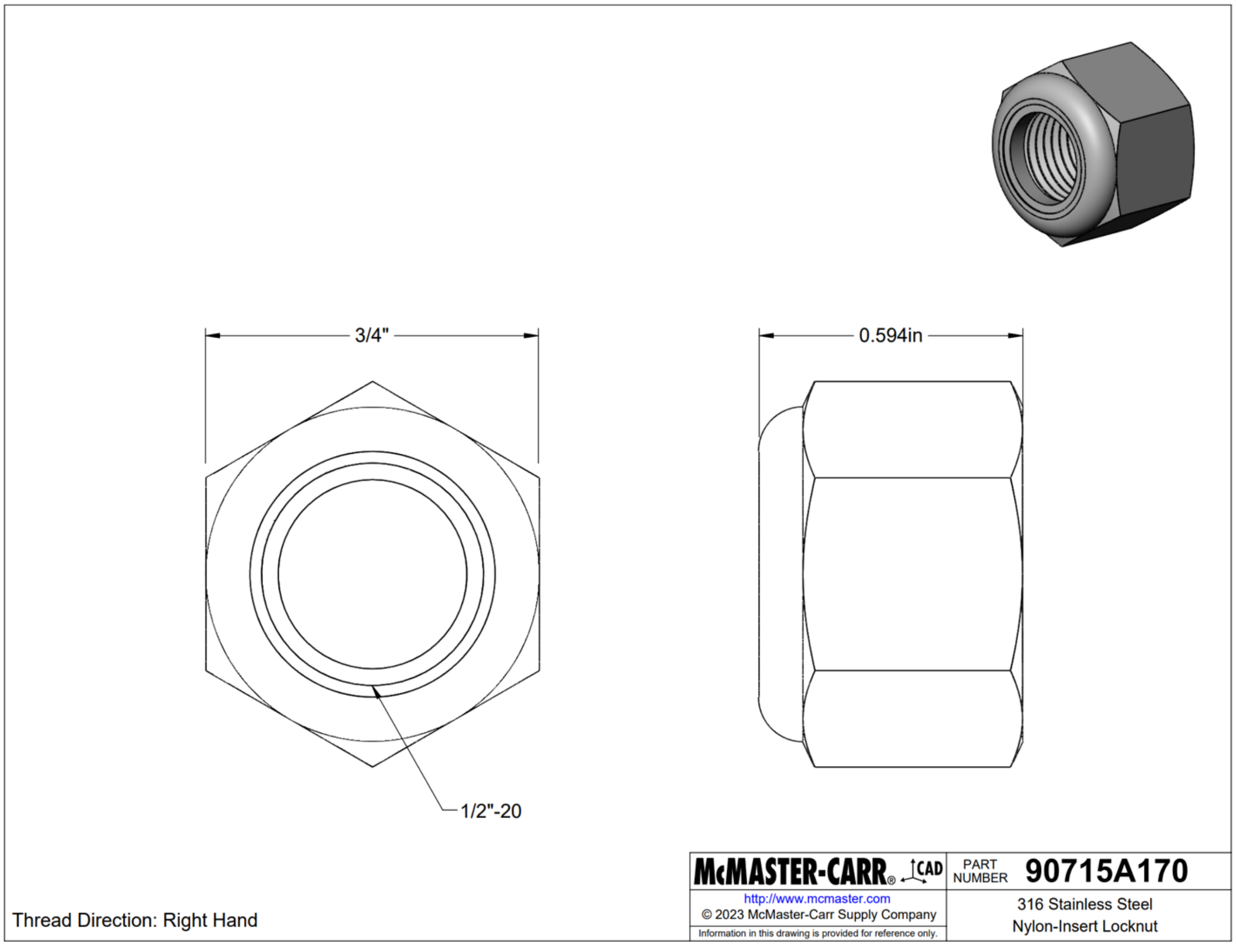


Figure 0.7: 2D CAD drawing of the 90715A170 locknut

7.3.8 Component for Propulsion System 2D Drawing

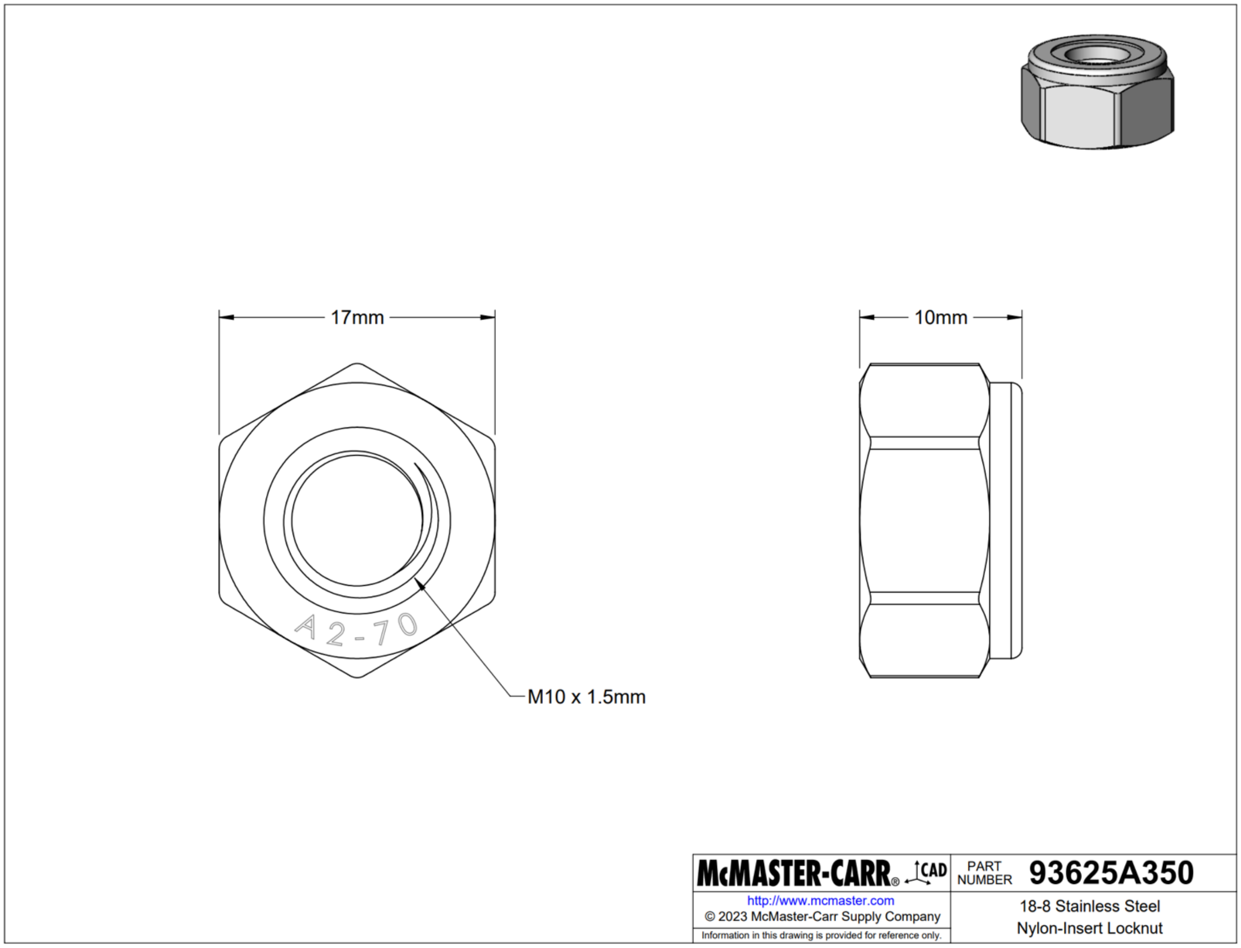


Figure 0.8: 2D CAD drawing of the 93625A350 locknut

7.3.9 Component for Propulsion System 2D Drawing

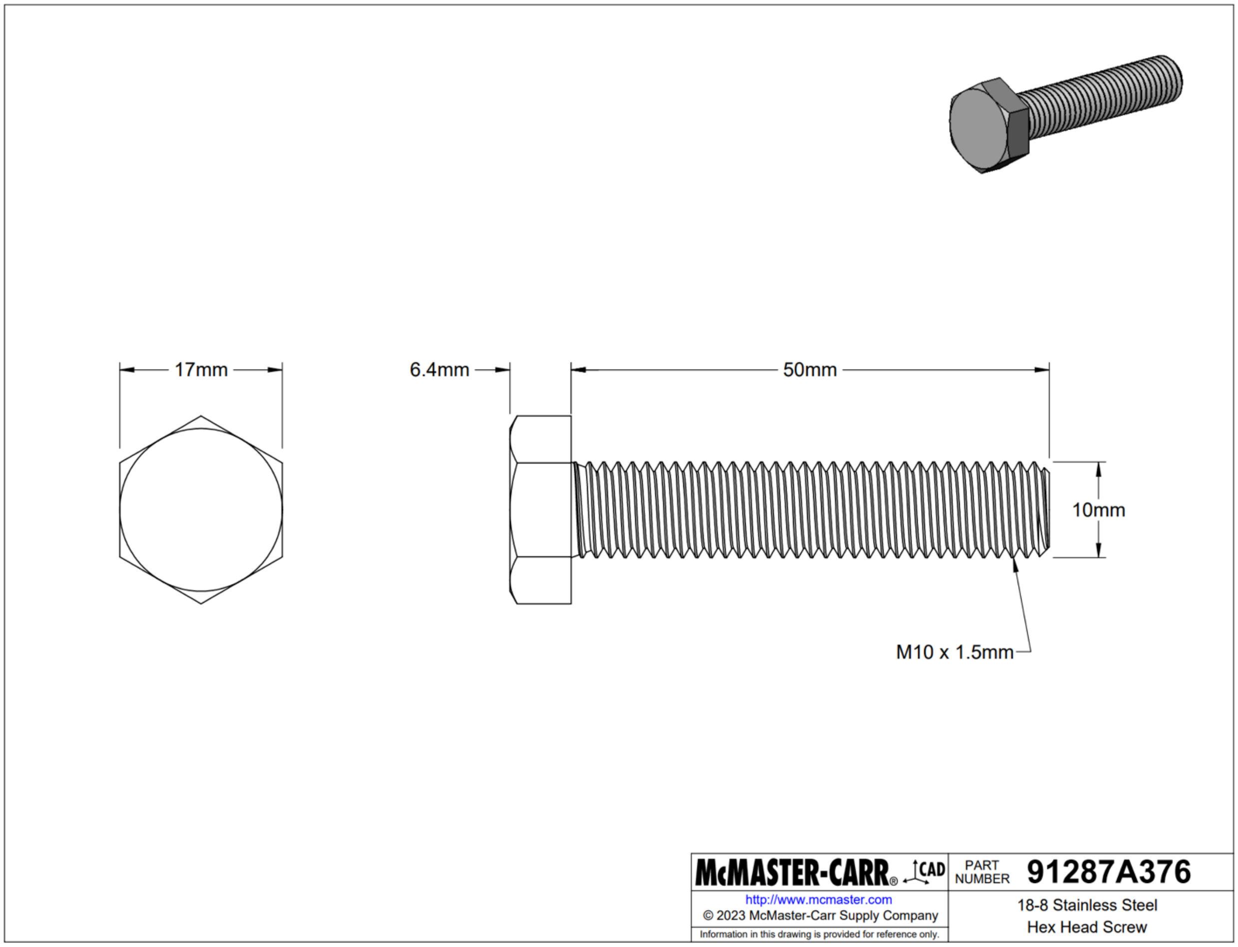


Figure 0.9: 2D CAD drawing of the 91287A376 screw

7.3.10 Component for Propulsion System 2D Drawing

The lower unit and propeller shaft subassembly drawing below has separated components to help visualize how each component interacts with the other and to reveal hidden parts. Each part number listed in the drawing is represented in the table below which assigns both the part number for each component as well as a description for each part. The table provides the required quantity for each component.

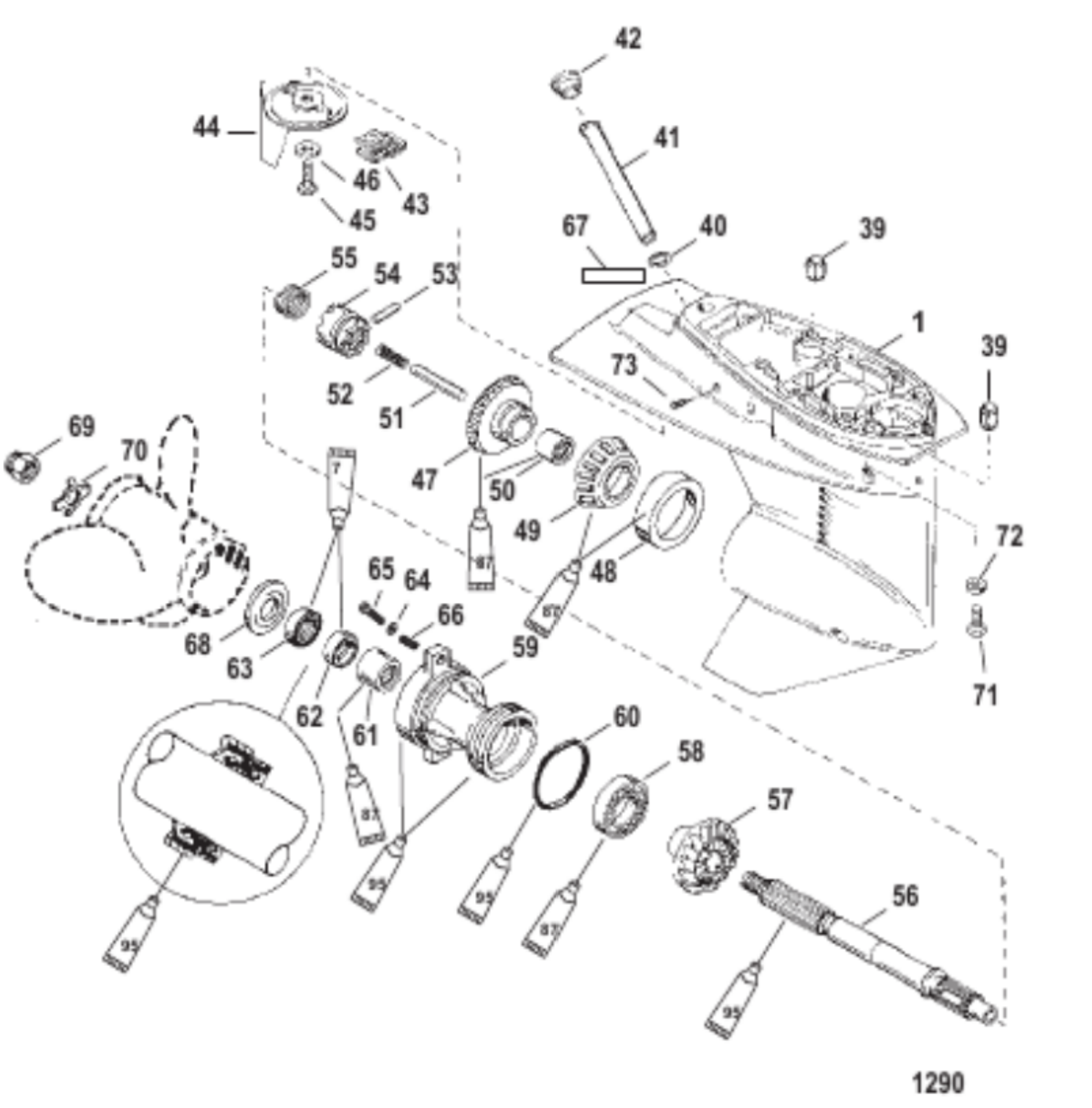


Figure 0.10: 2D CAD drawing of the Mercury Lower Unit

Ref #	Part Class	Part Number	Description	Comments	Qty	Note
-	1682	821306T54	GEAR HOUSING ASSEMBLY (3.44 Inch/87.37 mm Torpedo Diameter) Complete	(SHORT)	1	
-	1682	821306T17	GEAR HOUSING ASSEMBLY Complete	(LONG)	1	
1	1682	821306T12	GEAR HOUSING ASSEMBLY Basic	(BASIC)	1	
39	0017	821327	PIN Dowel		2	
40	0027	823942	GASKET		1	
41	0032	821828	TUBE		1	
42	0019	824928	PLUG Rubber	[USA-0T979999/BEL-0P325499] & Below	1	
42	0019	824928001	PLUG Rubber	[USA-0T980000/BEL-0P325500] & Up	1	
43	0000	821829	SCREEN		1	
44	0000	822157T2	TRIM TAB		1	
45	0010	82497020	SCREW (M8 x 20)		1	
46	0012	72397	WASHER		1	
47	0043	821315T1	GEAR ASSEMBLY Forward - 26 Teeth (26 TEETH)		1	
48	0031	99328A1	BEARING ASSEMBLY Roller		1	
49		NSS	NOT SOLD SEPARATE Cup			
50	0031	41326	BEARING Roller		1	
51	0000	821578	FOLLOWER Cam		1	
52	0024	8261991	SPRING		1	
53	0017	85093	PIN		1	
54	0052	821314T	CLUTCH		1	
55	0024	38114	SPRING		1	
56	0044	8215772	PROPELLER SHAFT		1	
57	0043	821312T1	GEAR Reverse - 26 Teeth (26 TEETH)		1	
58	0030	20839T	BEARING Ball		1	
59	0000	19291A3	CARRIER ASSEMBLY Bearing		1	
60	0025	815460	O-RING		1	
61	0031	21700	BEARING Needle		1	
62	0026	69188	SEAL Oil		1	
63	0026	69189	SEAL Oil		1	
64	0012	855941	WASHER (.323 x .590 x .112) Stainless Steel		2	
65	0010	85594030	SCREW (M8 x 30)		2	
66	0000	8227731	INSERT Threaded		2	
67		NSS	NOT SOLD SEPARATE Decal 2:1		1	
68	0000	73345A1	THRUST WASHER		1	
69	0011	69578Q1	PROP NUT KIT		1	
70	0014	76281	TAB WASHER		1	
71	0010	4000380	SCREW (M10 x 45)		4	
72	0012	856774	WASHER (.406 x .750 x .105) Stainless Steel		4	
73	0019	95925	PLUG		1	

Figure 0.11: Labels for Figure 7.26 lower unit

An additional subassembly drawing for the driveshaft is listed below. This drawing incorporates the lower unit and reveals how the driveshaft is properly mounted to the lower unit. The drawing is followed by a respective part number table.

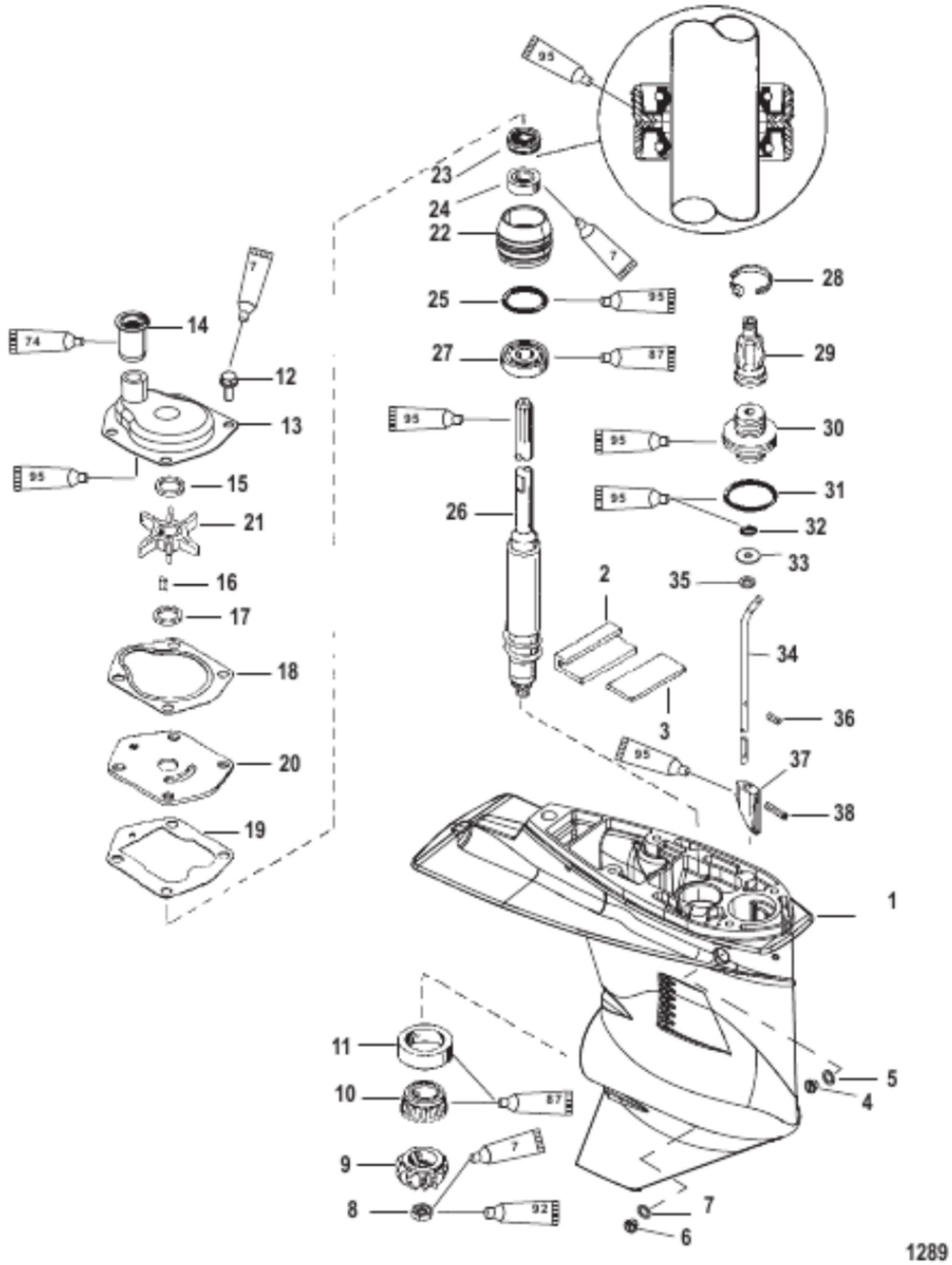


Figure 0.12: 2D CAD drawing of the Mercury Lower Unit Drive Shaft Assembly

Ref #	Part Class	Part Number	Description	Comments	Qty	Note
-	1682	821306T54	GEAR HOUSING ASSEMBLY (3.44 Inch/87.37 mm Torpedo Diameter) Complete	(SHORT)	1	
-	1682	821306T17	GEAR HOUSING ASSEMBLY Complete	(LONG)	1	
1	1682	821306T12	GEAR HOUSING ASSEMBLY Basic	(BASIC)	1	
2	0000	818226A1	SEAL/PLATE KIT		1	
3		NSS	NOT SOLD SEPARATE Plate		1	
4	0010	79953Q2	SCREW KIT (.375-16 x .250) Drain		1	
5	0012	191833	SEAL		1	
6	0010	79953Q2	SCREW KIT (.375-16 x .250) Drain		1	
7	0012	191833	SEAL		1	
8	0011	55910	NUT (.437-20)		1	
9	0043	821326T1	GEAR Pinion - 13 Teeth (13 TEETH)		1	
10	0031	821321A2	BEARING ASSEMBLY		1	
11		NSS	NOT SOLD SEPARATE Cup		1	
12	0010	8248324	SCREW (M6 x 16)		4	
13	0046	821351A3	HOUSING ASSEMBLY Water Pump Upper		1	
14	0000	887774	SEAL Water Tube	(SHORT - 1-3/4)	1	
14	0000	8235471	SEAL	(LONG - 2-1/4)	1	
15	0012	8M0027721	WASHER		1	
16	0028	85119	KEY		1	
17	0012	8M0027721	WASHER		1	
18	0027	822189	GASKET Upper Water Pump		1	
19	0027	822217	GASKET Lower Water Pump (LOWER)		1	
20	0000	8213542	FACE PLATE		1	
21	0047	8508910	IMPELLER		1	
22	0046	821307A2	BASE ASSEMBLY Water Pump		1	
23	0026	821309	SEAL		1	
24	0026	821310	SEAL		1	
25	0025	821308	O-RING (1.421 x .139)		1	
26	0045	826193T2	DRIVESHAFT	(SHORT)	1	
26	0045	826194A1	DRIVESHAFT	(LONG)	1	
27	0030	821311	BEARING Ball		1	
28	0000	823548T	TIE STRAP		1	
29	0000	822158	BOOT		1	
30	0000	821827	RETAINER		1	
31	0025	26855	O-RING (1.609 x .139)		1	
32	0025	85594	O-RING (.239 x .174)		1	
33	0012	814803	WASHER		1	
34	0000	827865A2	SHIFT SHAFT	(SHORT)	1	
34	0000	827865A1	SHIFT SHAFT	(LONG)	1	

Figure 0.13: Labels for Figure 7.28 drive shaft assembly

7.4 Electrical Schematics and Wiring Diagrams

7.4.1 Schematic of the Solar Propulsion Electrical System

This section details the design and structure of the electrical components necessary to control and run the boat propulsion system. Shown below in the figure is a complete schematic of the electrical system.

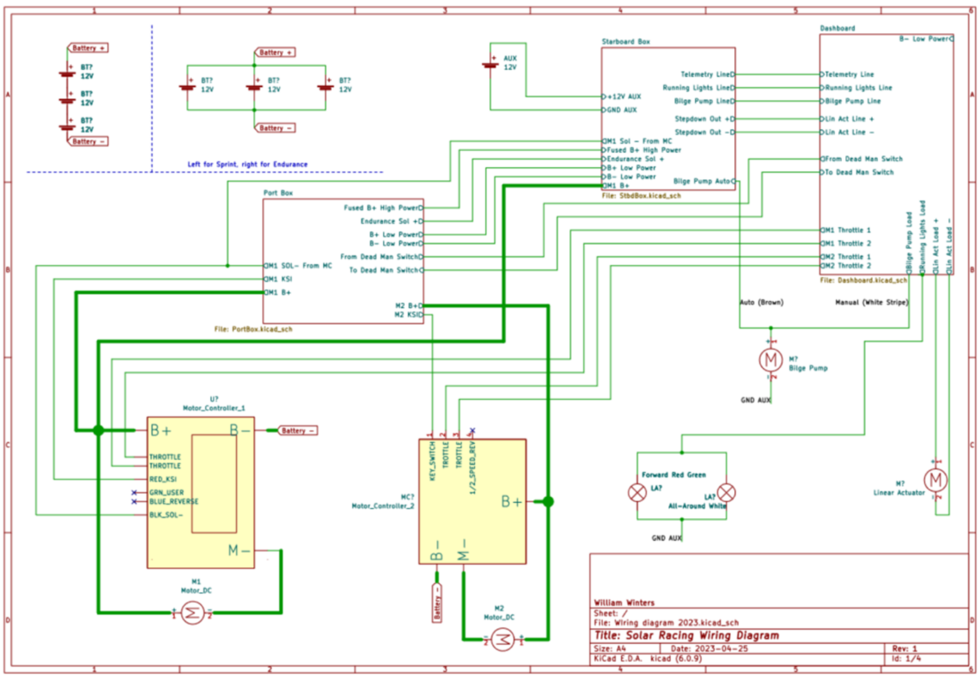


Figure 0.3014: Current Electrical Schematic made by Wesley Ng of Solar Racing Team

There are two circuits in parallel to drive our two motors with two different models of motor controllers. This circuit will be different to the one we eventually design, as we will be using a brushless 3 phase AC DHX P40 vs the brushed DC Agni 95R in this schematic, three leads vs two. The motor controller is still undecided as per the request of the solar racing team but will probably a VESC STR-500 motor controller.

Figure 0.15: VESC STR- 500

7.5 Costed Bill of Materials

7.5.1 BOM for a Propulsion System

Part	Vendor	Price per part	Quantity	Total Cost ($)	Link
Lower Unit	Mercury	0	1	0	N/A one member had a lower unit already
Propeller	Wholesale marine	150	1	150	https://www.wholesalemarine.com/mercury-black-max-10-3-8x-13p-propeller-48-19640a40/?gad_source=1
Motor	DHX	N/A	1	Covered by Solar Racing Team	https://www.dhxelectricmachines.com/motors
6138k72 bearing	McMaster-Carr	39.70	2	79.40	https://www.mcmaster.com/catalog/129/1388/6138K72
8828T321 thrust bearing	McMaster-Carr	156.18	1	156.18	https://www.mcmaster.com/catalog/129/1395/8828T321
5038K58 Casing	McMaster-Carr	129.80	1	129.80	https://www.mcmaster.com/catalog/129/70/5038K58
44705K233 Flange	McMaster-Carr	48.97	1	48.97	https://www.mcmaster.com/catalog/129/66/44705K233
91580A237 Snap Rings	McMaster-Carr	5.40	4	21.60	https://www.mcmaster.com/catalog/129/3702/91580A237
93190A387 Bolts for flange to P40	McMaster-Carr	4.77	4	19.08	https://www.mcmaster.com/catalog/129/3536/93190A387
90715A170 Nuts for flange to P40	McMaster-Carr	1.076	4	10.76	https://www.mcmaster.com/catalog/129/3594/90715A170 (Pack of 10 only)
93625A350 Nuts for lower unit plate	McMaster-Carr	0.62	10	6.20	https://www.mcmaster.com/catalog/129/3595/93625A350
91287A376 Bolts for lower unit plate	McMaster-Carr	1.978	10	19.78	https://www.mcmaster.com/catalog/129/3541/91287A376
Total	-	-	-	$641.77	-

Table 0.1: Costed BOM for a Propulsion System

7.6 Revised Timetable

8 Deliverable	Deadline
Project Proposal	9/12/2023
Determine type of propulsion (Inboard or Outboard)	9/19/2023
Progress Report 1	9/29/2023
Coordinate preliminary designs with steering team	10/09/2023
Complete the product design specification (PDS)	10/19/2023
Finalize general requirements for steering and propulsion joint functionality	10/25/2023
Progress Report 2	11/03/2023
Determine the motor to be used for the propulsion	11/10/2023
Finalize a design and constraints	11/18/2023
Complete the final CAD file for the propulsion system	12/15/2023
Progress Report 3	12/23/2023
Have a completed list of items to buy, and order all	01/29/2024
Determine any items to be manufactured and have them done by this date	02/05/2024
Have first prototype assembled	03/02/2024
Progress Report 4	03/08/2024
Final prototype finished and assembled with steering team	03/25/2024
Initial testing of prototype	04/10/2024
Fix any issues and finish testing	04/28/2024
Progress report 5	05/10/2024

Table 7.15: Revised timetable

7.7 Team Member Evaluations

Kai: In Report 1 I researched two commercially available electric outboards and two electric inboards. These were compared in a chart of existing models. In Report 2 I designed a transmission system and a shaft coupling. Neither of these designs were included in the final design of Report 3. In Report 3 I helped begin the lower unit plate design but mostly focused on calculations. I completed static and dynamic thrust calculations, bearing load analysis, bolt stress calculations, propeller selection, and lower unit selection. I also researched and selected each component and created the costed BOM. I wrote and edited many parts of the report including 7.1, all writing for my designs and market research, 4.1, 2.3, etc.

Alexander: In Report 1, most of my time was spent completing Chapter 1, including a summary of the project, the main objective and how it will be solved, and researched the societal factors that will be involved along with the challenges our group will encounter during production of the propulsion system. For Report 2, I developed three CAD models including a U-Joint Coupling to connect the drive shaft to the propeller shaft, an outboard system design that protrudes through the rear of the boat, and a direct drive system with an aluminum outer casing to protect the drive shaft from corrosion and debris. Benefits as well as downsides were listed for each model. In report 3, I developed the final CAD design that will be used and designed the motor mount collaboratively so that it would be accessible for a steering team. I created 3D CAD drawings to display each component and where they are located.

Cole: In Report 1, spent much of my time performing patent analysis. The patent summary statement and the summary chart are also of my doing, along with some information from Chapter 1 (predominantly the “Problems and Objective” section). Report 2, I focused on my designs of the inner workings for the bevel and chain drive lower unit assemblies. I completed the comparisons for both the preliminary and revised versions of this subassembly. Report 3, I helped considerably with the calculations and analysis. Evaluating the batteries, housing bending, along with the hull drag and galvanic corrosion. Moreover, I was highly active with group meetings, collaborations with steering team, and the overall conceptual design in our system. I consistently proofread and participate in other sections.

Soroush: In report 1 I worked on creating the initial timetable for the project as well as conducting research on two different methods of propulsion and the benefits and downsides of each. In addition to that work in chapter 1 such as the skills table was also done. In report 2 I came up with two CAD designs, a chain drive propulsion system, and a pod motor system, these two designs were refined in chapter 5 of report 2. I also found two ASTM standards that are relevant to our project and worked on multiple Pugh Matrices. In report 3 I worked on the plate weld calculations as well as gathering electrical circuit diagrams from the Solar Racing Team’s existing boat. I also worked on creating the bill of materials and gathering the 2D CAD drawings of components purchased.

Perception	Cole	Alexander	Kai	Soroush
Cole	26%	24%	26%	24%
Alex	26%	24%	26%	24%
Kai	25%	25%	25%	25%
Soroush	31%	23%	23%	23%

Table 0.16 Evaluation Matrix

Chapter 8. Initial Prototype Build and Test

8.1 Overview

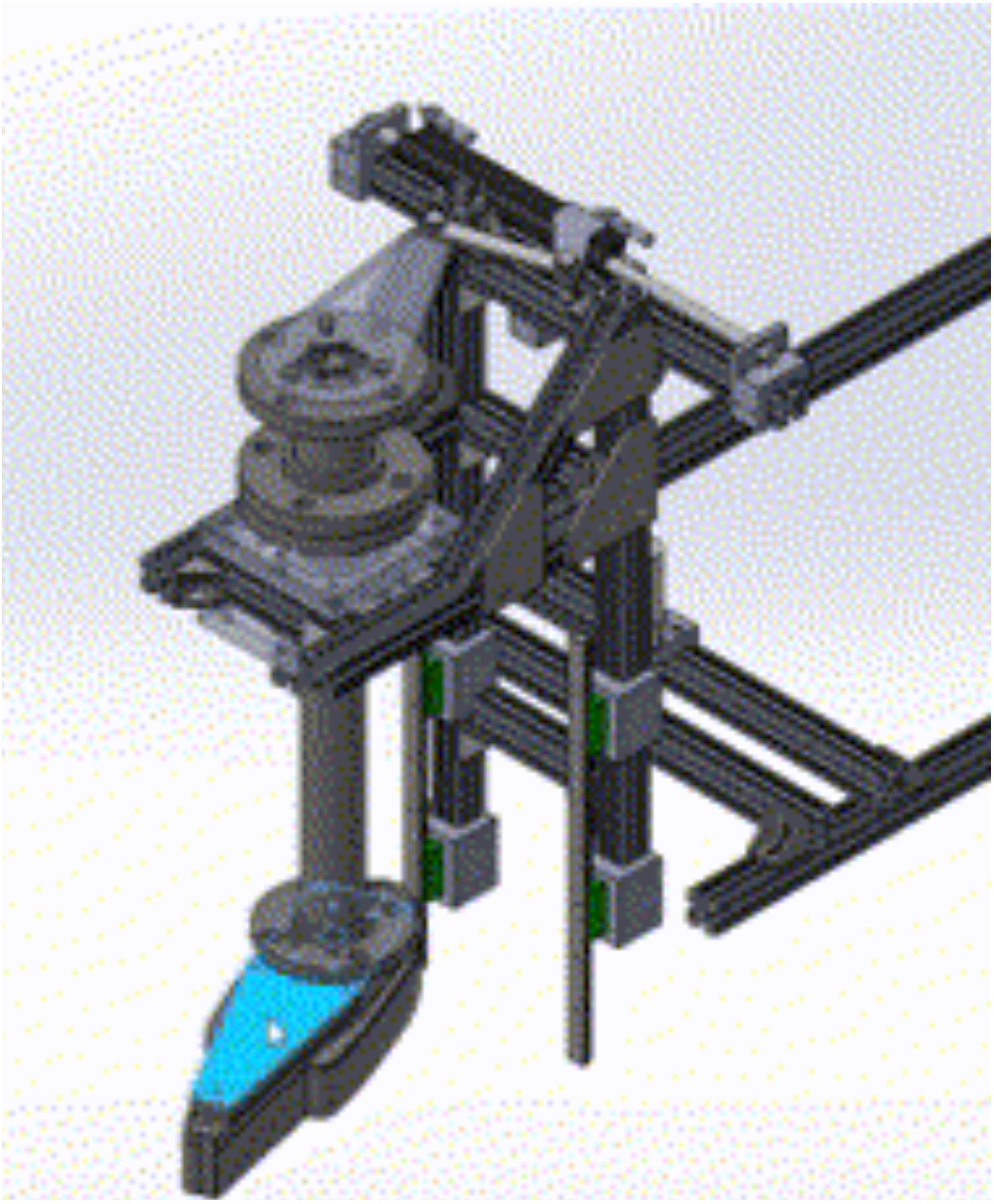
8.1.1 Solar boat Propulsion System

- While developing our coupling design after report three, we found the initially selected 2” aluminum casing would be too restricting. This occurred to us when we realized the motor output was a D-shaft and would need to be coupled to the splined input of the lower unit. The initial design’s 2” nominal pipe did not leave us with enough room to build a coupler that could mate the two geometries and simultaneously withstand the operating torque of the motor.
  - To remedy this, the team selected a 2-inch NPT aluminum pipe for the main section which would be connected by threaded flange to a 2.5-inch NPT aluminum pipe. The larger 2.5” section will start directly below the input splines, containing the coupling and thus giving us ample room for the coupling’s diameter. This can be seen in our CAD views included in the following sections. The selection of a new aluminum casing meant we had to pick different outer bearings for integration with steering, flanges, and hardware.

- At the due date of report three the team did not have the mounting bolt pattern for the motor. Once the team acquired the motor and thus the bolt pattern, we had to develop a plate that would allow us to connect the motor with a 2.5-inch flange with no hardware interference.
  - We decided to use a commercially available aluminum flange as the basis of our motor mounting plate. We also understood that steering teams steering-tiller arm must attach between this piece and the motor. We opted to install the motor mounting hardware into the tiller arm plate facing upwards, press threaded studs downwards into the tiller arm, and use those studs to connect to the top flange of our assembly. The subsystem can be seen in our final design.

- In report three, it was assumed that the lower unit mounting plate would be welded directly to the housing pipe. Realizing that welding will decrease reliability as well as serviceability, we chose instead to connect the lower unit and housing using hardware.
  - Our design utilizes wheel studs, with the bolt head counterbored into the bottom of the mounting plate. This is to maintain flat plane as to not interfere with the lower unit. The studs stick upwards and will line up with holes drilled into the bottom flange. This will allow for us to connect the flange to the mounting plate, and simultaneously the mounting plate to the lower unit.

8.2 Updated Components



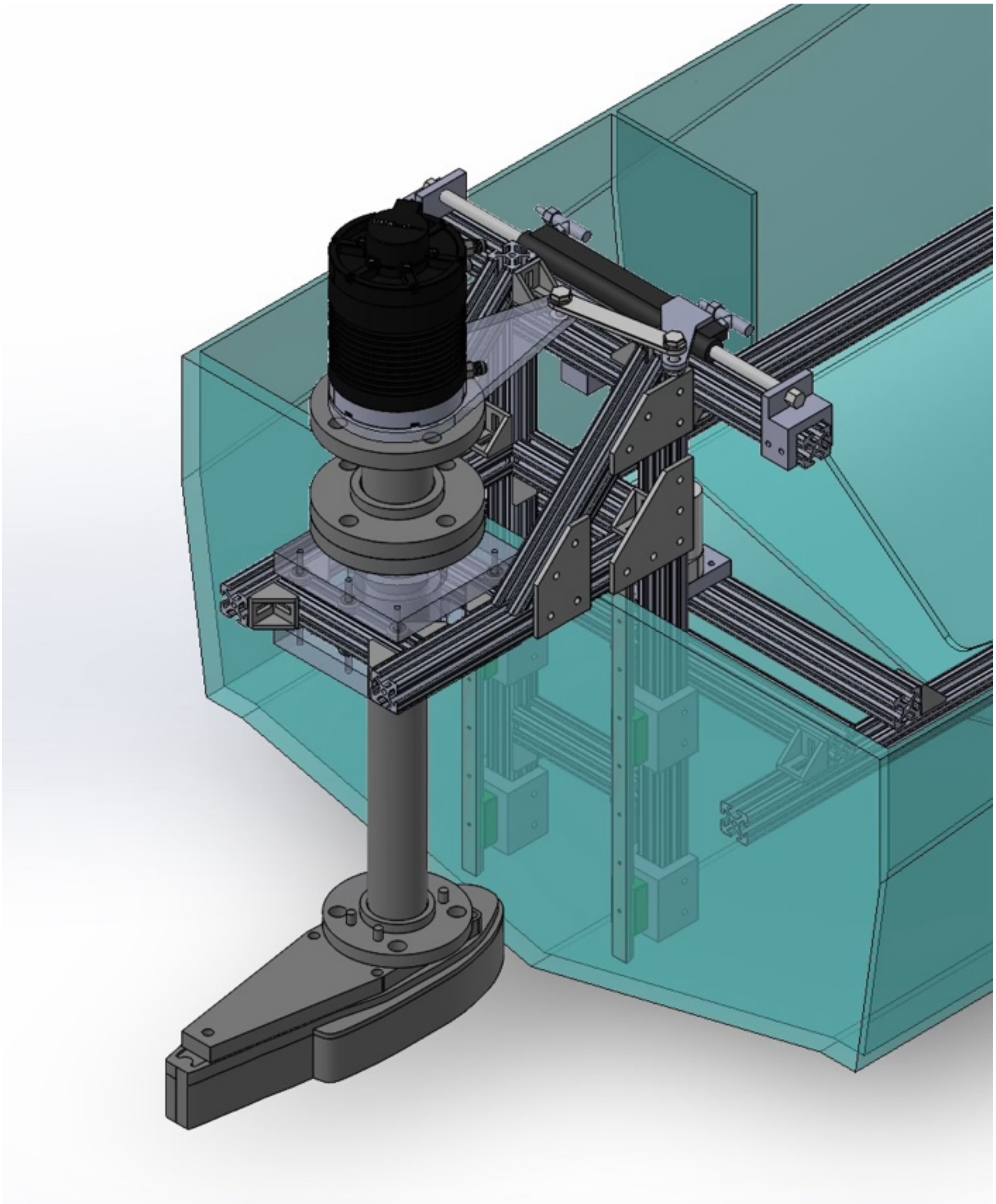


Figure 0.1: Propulsion and steering combined mechanism.

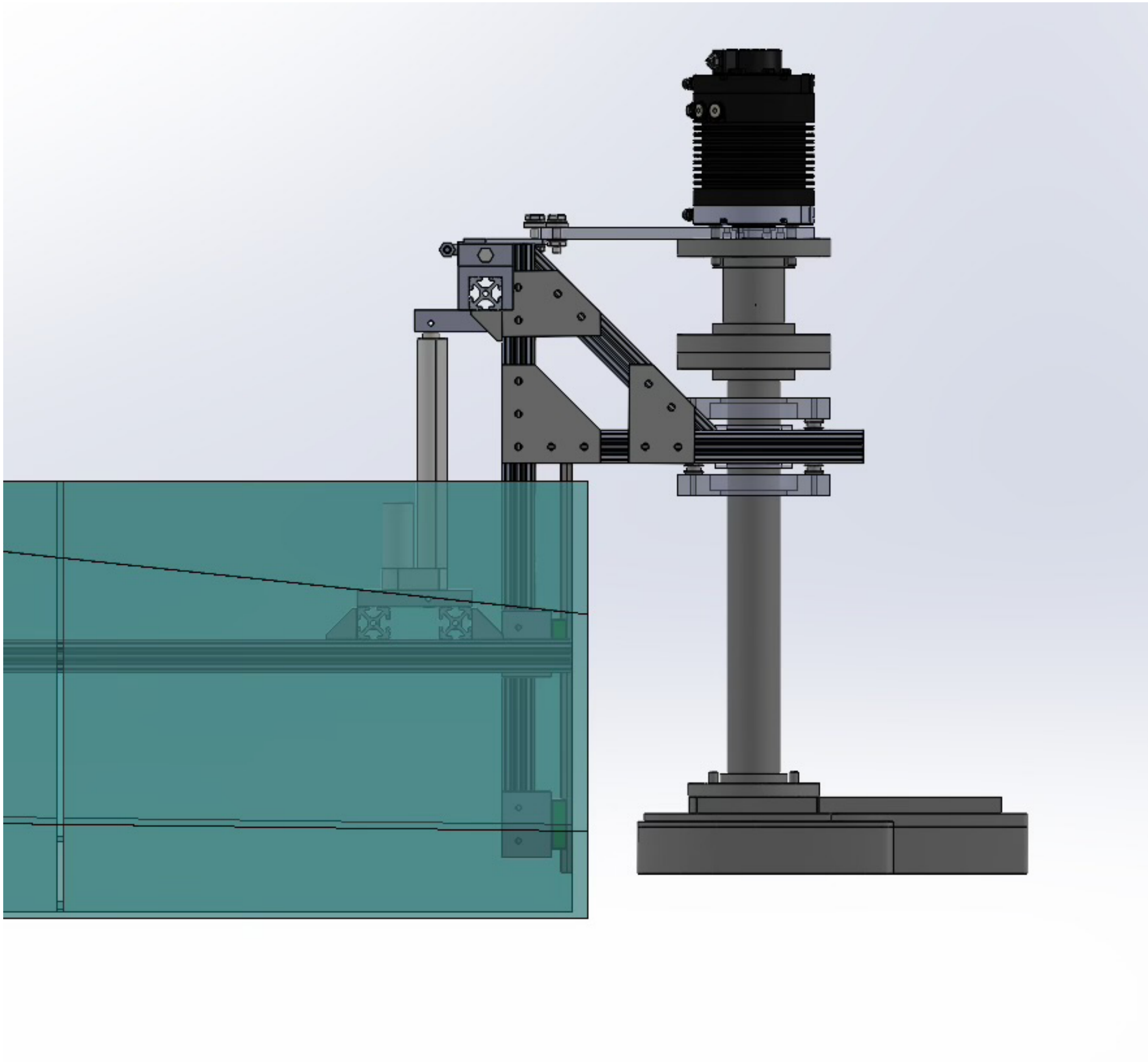


Figure 0.2: Location of lower unit in comparison to bottom of boat.

Figure 0.3: Propulsion only outboard system.

Figure 0.4: Tiller that connects to steering system and the bolts connecting motor to system.

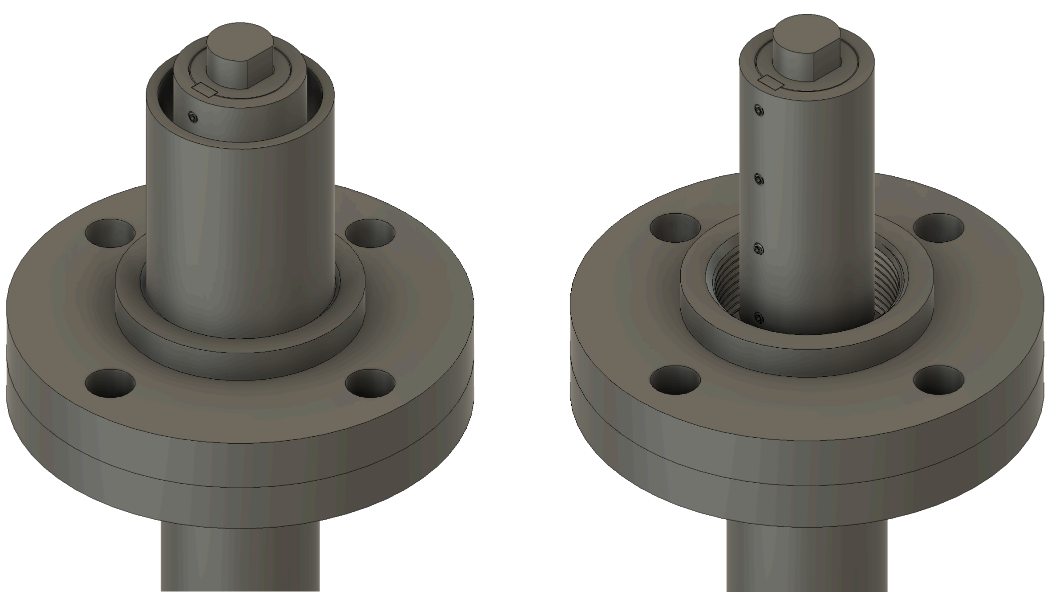


Figure 0.5: Coupling system from motor shaft to lower unit shaft with set screws in place.

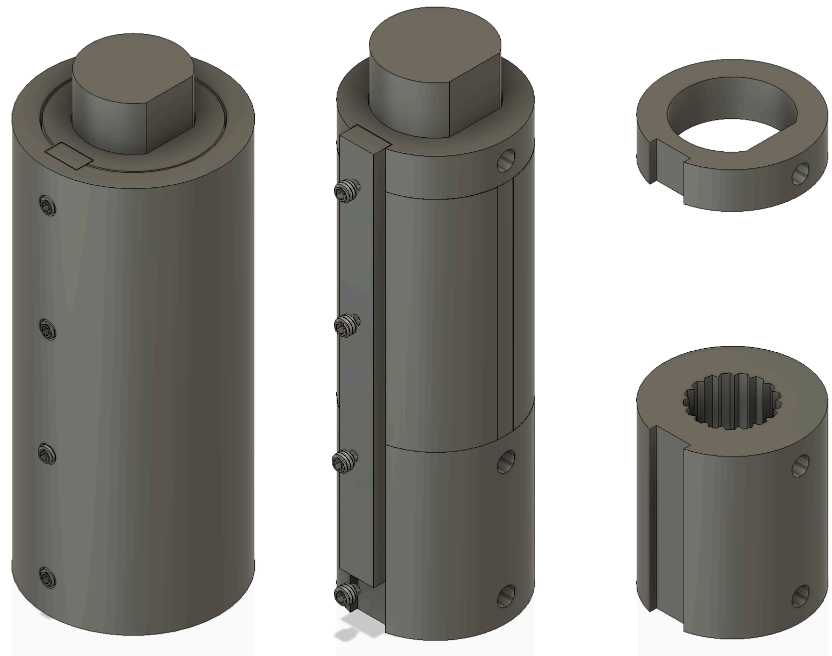


Figure 0.6: Breakdown of the coupler with key and set screws, followed by further cutaways to display spline and D portions of the coupler.

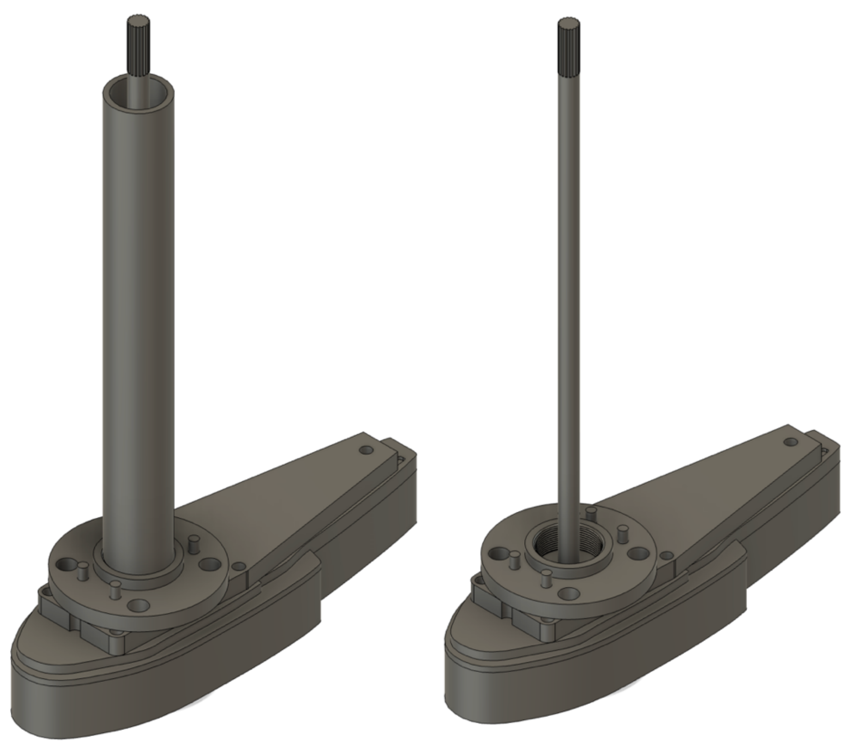


Figure 0.7: Flange from lower unit with outer pipe enclosure for lower unit shaft as well as with shaft removed.

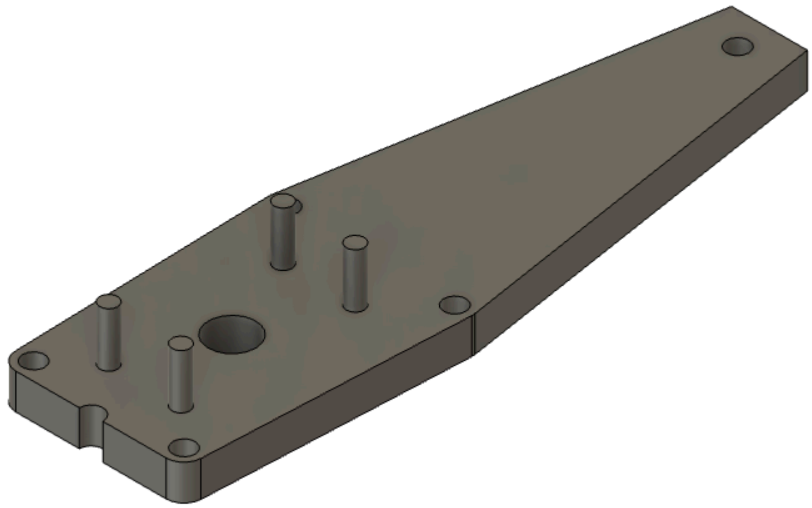


Figure 0.8: Lower unit mounting plate.

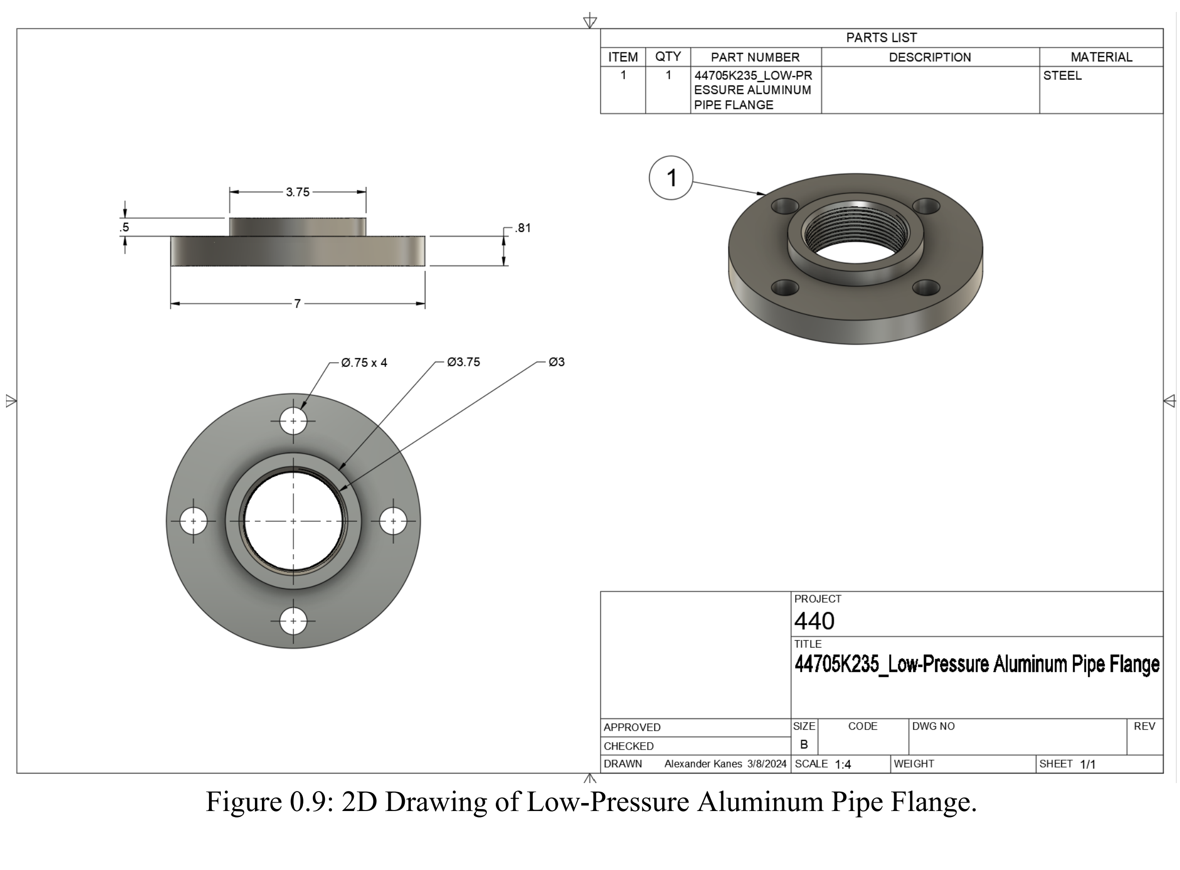


Figure 0.9: 2D Drawing of Low-Pressure Aluminum Pipe Flange.

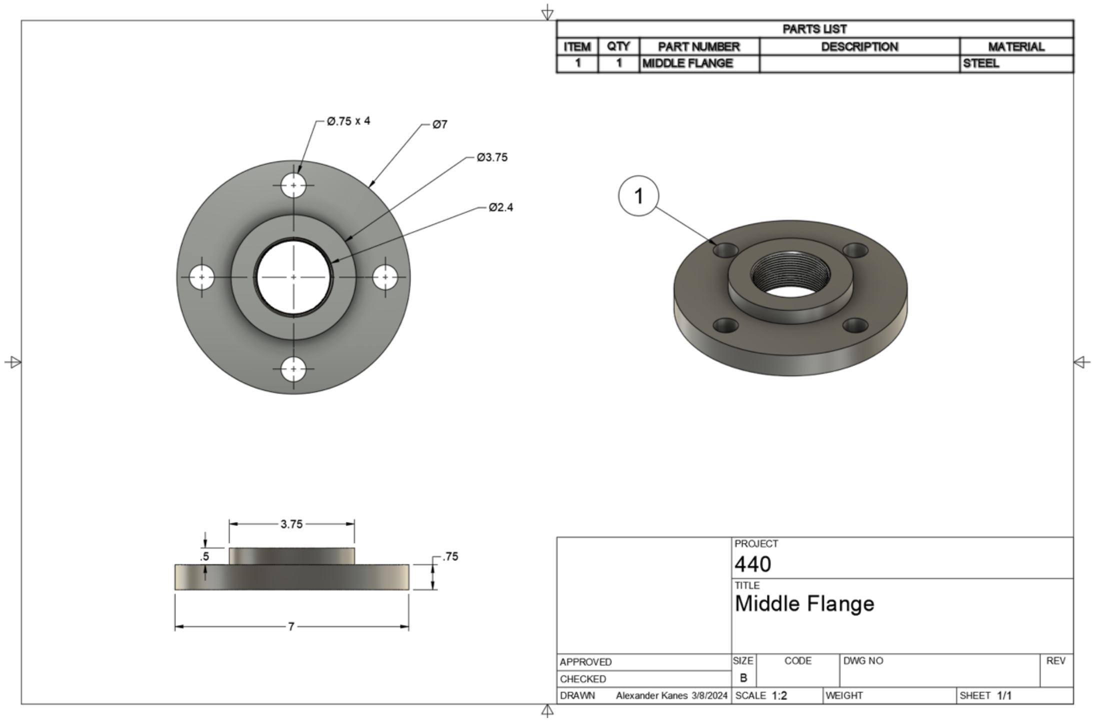


Figure 8.10: 2D Drawing of Middle Flange.

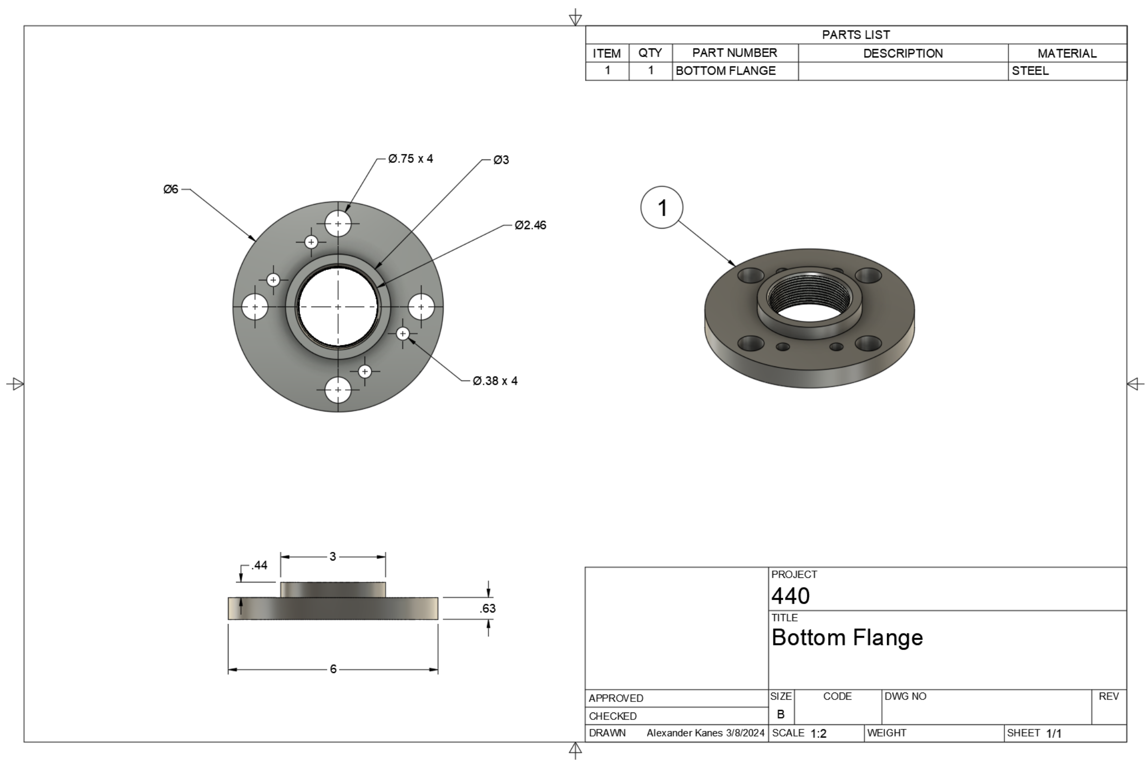


Figure 8.11: 2D Drawing of Bottom Flange.

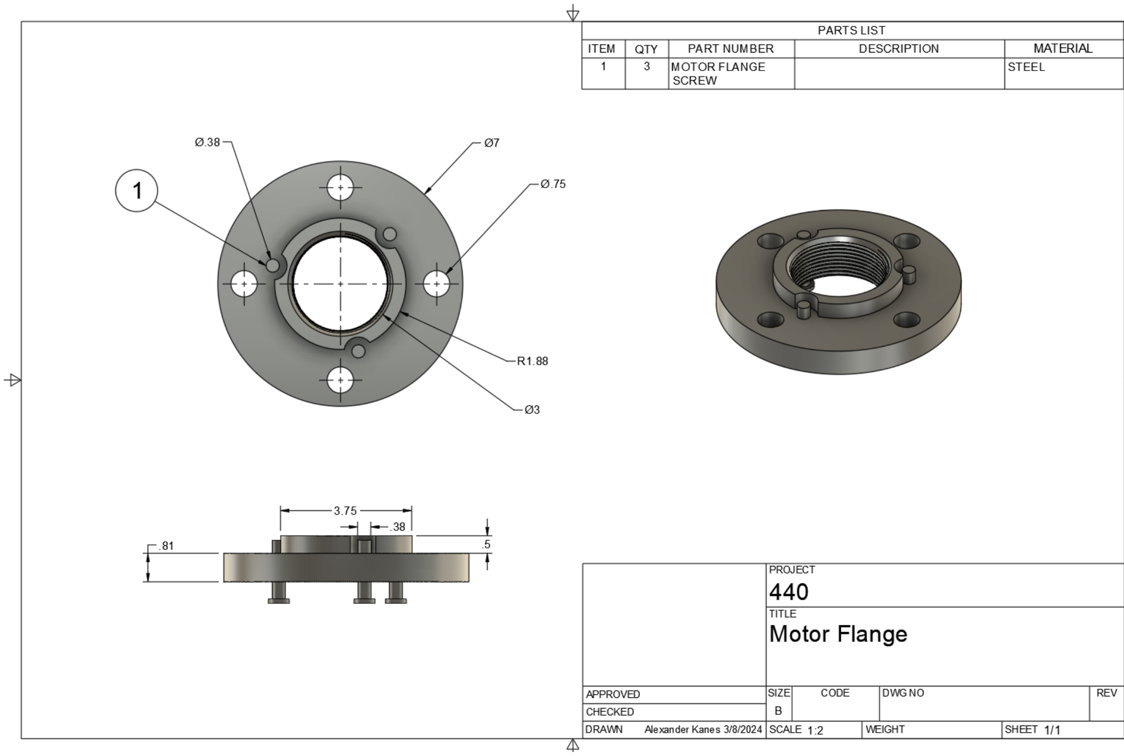


Figure 8.12: 2D Drawing of Motor Flange with Mounting Hardware.

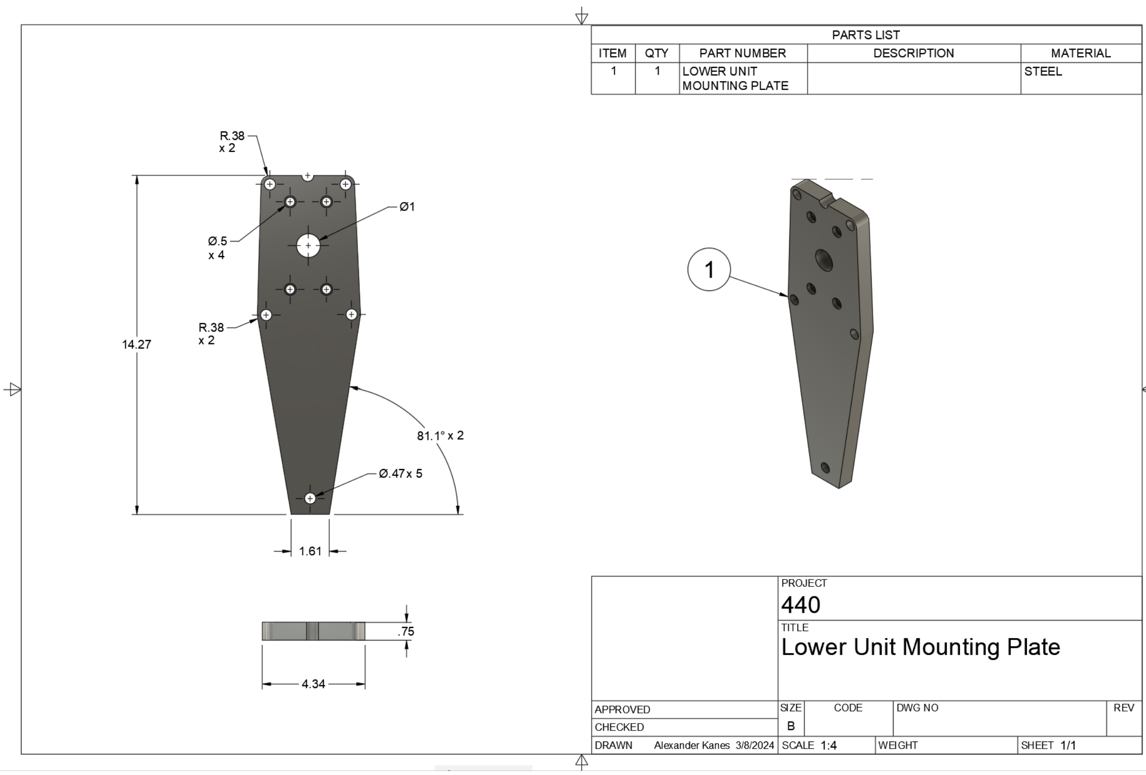


Figure 8.13: 2D Drawing of Lower Unit Mounting Plate.

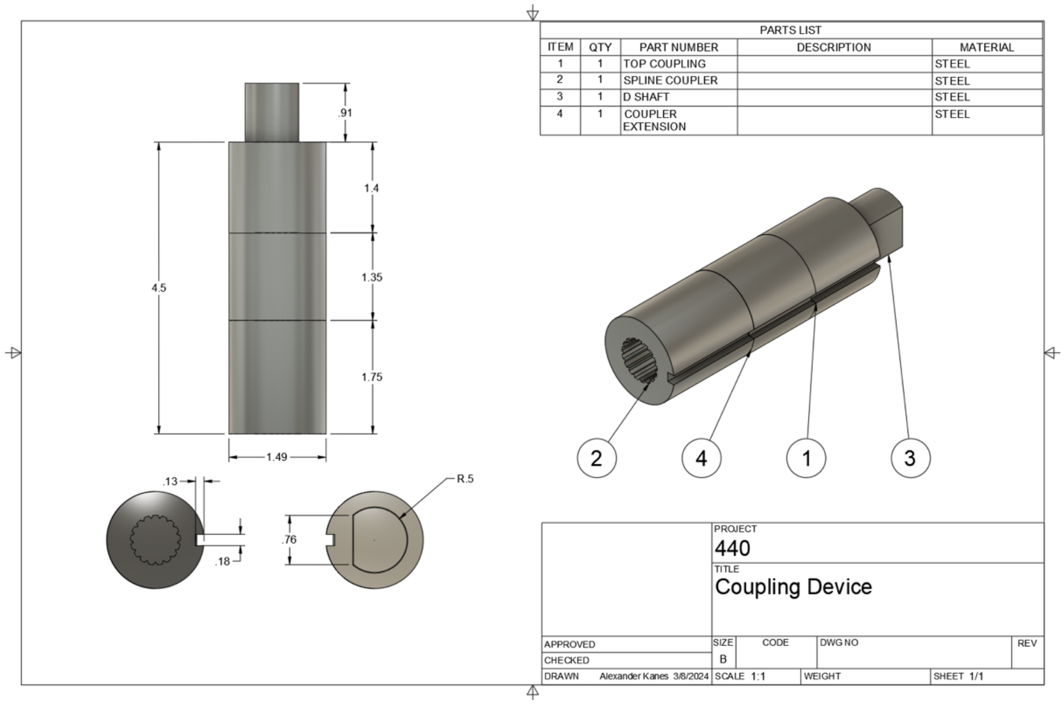


Figure 8.14: 2D Drawing of Coupling Device.

Figure 0.15: Screenshot of VXB 2 3/8” ID Tapered Roller Bearing

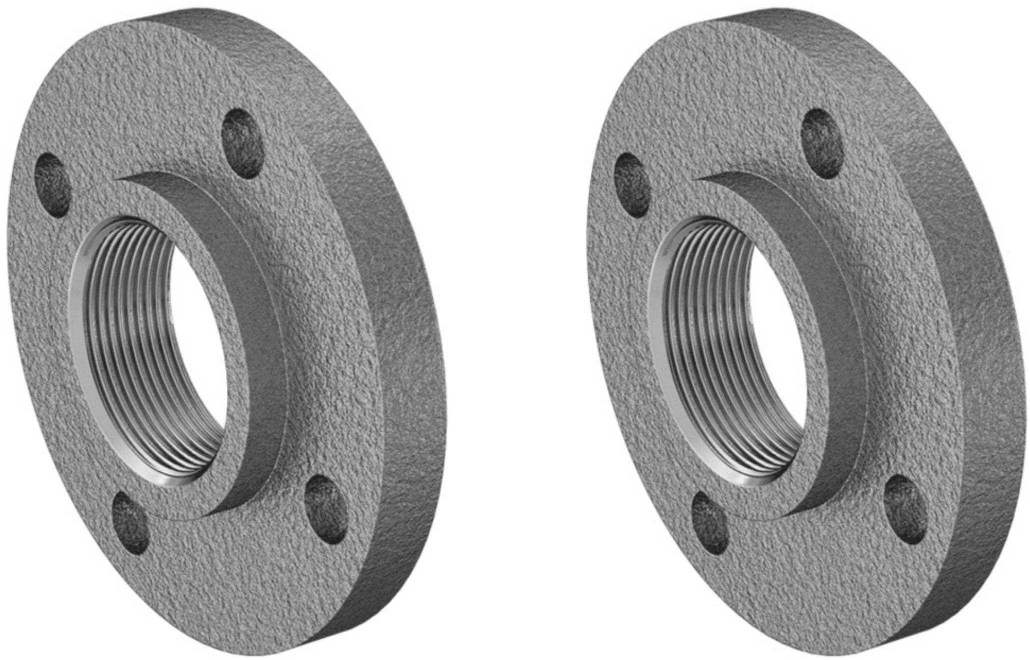


Figure 0.16: Screenshot of 2 and 2-1/2 NPT Aluminum Pipe Flange

Figure 0.17: Screenshot of 2-1/2 x 2 NPT Aluminum Reducing Flange

Figure 0.18: Screenshot of Ball Bearing for ¾” Shaft with 2” OD

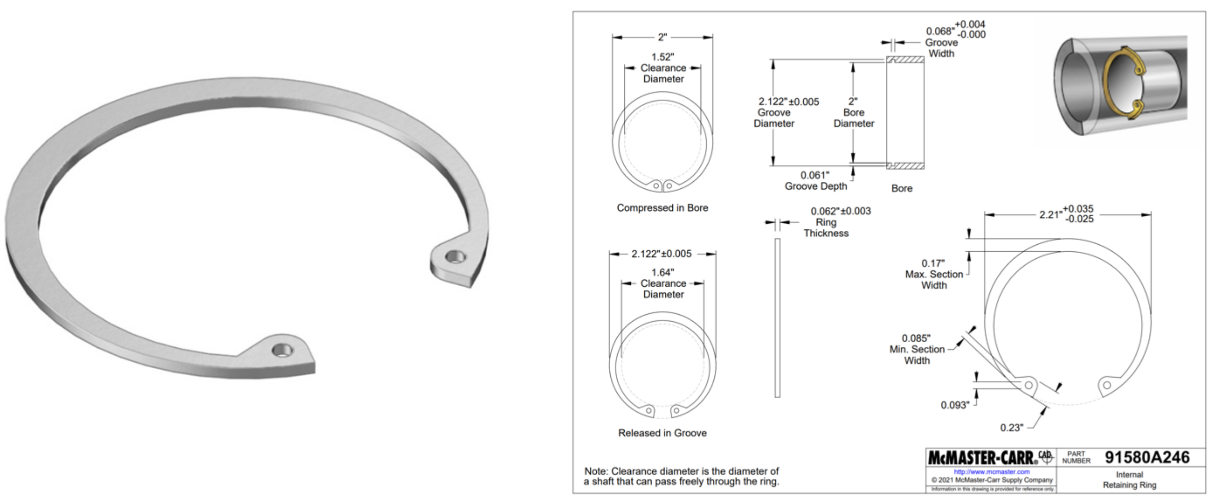


Figure 0.19: Screenshot of Internal Retaining Ring for 2” ID

Figure 0.20: Screenshot of 2” and 2.5” Nominal Schedule 80 Aluminum Pipe, Respectively

8.3 Additional Engineering Analysis and Calculations

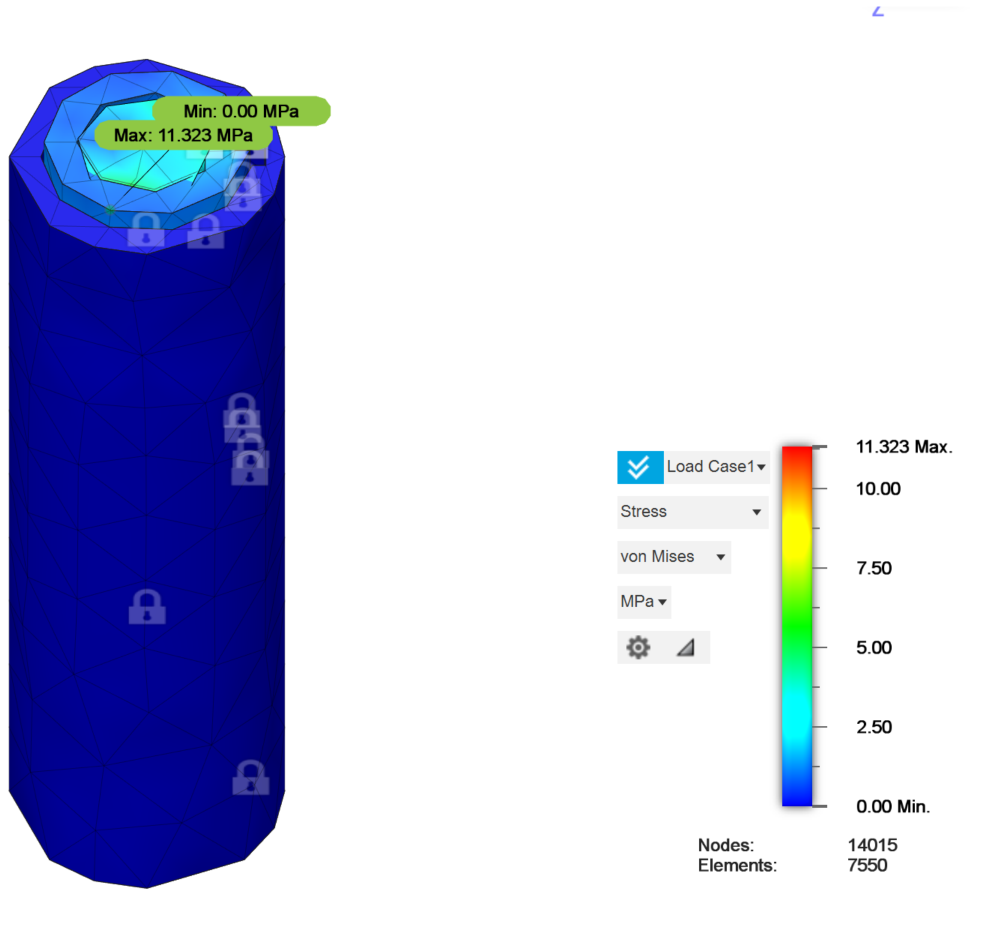


Figure 8.3.1: Stress Concentration Diagram for Coupling Device.

8.3.1 Updated Housing Bending and Applied Stresses

The team decided on a 2" NPT aluminum schedule 80 pipe for the main housing. This pipe has a greater diameter and thickness than the pipe from report three. Calculations were performed with the new parameters; we computed lower bending stress and thus a higher safety factor with our new pipe.

The thrust from the propeller will inevitably cause internal stresses in the housing between our electric motor and lower unit. Failing to consider internal stresses in the housing can lead to catastrophic failure if the material reaches its yield stress. After the yield point, the deflection transitions from elastic to plastic deformation, permanently damaging the system. Proper engineering analysis can prevent these types of failures.

While the boat is in motion, there will be drag forces present on the housing, helping to negate the thrust forces in the opposing direction. For this reason, the scenario where the boat has no velocity and propeller is producing maximum static thrust will be the highest load which the housing will see.

The shaft housing needs to be designed as a hollow tube to contain and protect the drive shaft, along with support hanging weight and thrust forces from the lower unit. The orientation of forces on this structure allows us to treat this system as a cantilever fixed on one end. Where the motor shaft housing is pinned rigidly at the top, at this point the deflection angle will be zero. The thrust force is applied at the bottom of the shaft, causing bending and shear forces along the length of the shaft, which must be considered before finalizing our bill of materials.

The independent variables driving these calculations include the maximum static thrust force, shaft housing length, and the pipe outer and inner diameter. The moment about the fixed point of the shaft housing is found using the static thrust F applied at a length L away from the top:

$$M = FL$$

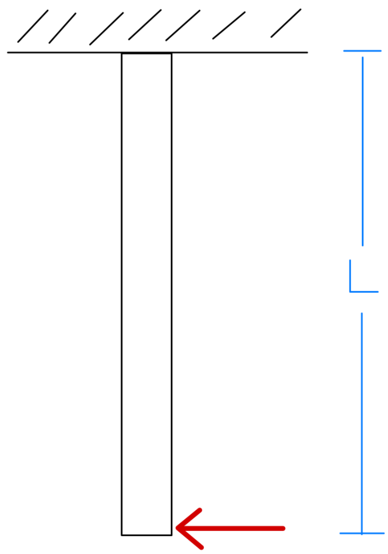


Figure 8.3.2: Moment Diagram

As a result of the long lever arm from the shaft housing, the bending stress in the drive shaft housing is a crucial calculation. The equation for bending stress is dependent on bending moment, distance from the shapes centroid, and the polar moment of inertia of the cross-sectional geometry. Polar moment of inertia represents an object's ability to resistance torsional deformation. To calculate the polar moment of inertia for a hollow shaft, the equation is as follows:

$$I = \frac{1}{4}\pi({r_o}^4 - {r_i}^4)$$

This yields a result in units of m^4. From here, we have enough information to find the maximum bending stress of our housing, which came out to be 93.38 MPa. The excel computations which led to these results can be seen below.

Bending Stress Calculation				
Description	Value	Unit	Variable	Equation
Max Static Trust Force	2201.75	N	F	
Shaft Housing Length	0.508	m	L_s	20 in
Pipe Outer Diameter	2.375	in	d_o	
Pipe Inner Diameter	1.939	in	d_i	
Pipe Outer Diameter	0.060325	m	d_o	in*2.54/100
Pipe Inner Diameter	0.0492506	m	d_i	in*2.54/100
Pipe Outer Radius	0.0301625	m	r_o	
Pipe Inner Radius	0.0246253	m	r_i	
Distance to Neutral Axis	0.0301625		c	
Polar Moment of Inertia	3.613E-07	m^4	I_c	$I_c = \frac{1}{4}\pi({r_o}^4 - {r_i}^4)$
Bending Moment	1118.4877	Nm	M	$M = F*L_s$
Bending Stress	93386329	Pa	σ	σ = c*M/I
Bending Stress	93.386329	MPa	σ	Pa*10^-6

Figure 8.3.3: Bending Stress Calculations

This is by far the most substantial value of stress we have in the housing, and therefore will indicate the material strength and thickness of the housing required. Given the yield strength of 240MPa for 6061 aluminum, we will have a safety factor greater than two.

Continuing with bending calculations, we can determine the maximum deflection of our housing. This evaluation can ensure that the driveshaft will remain sufficiently straight between the motor and the bevel gears, along with that our lower unit will have sufficient clearance from the boat's transom. Using the lever length, applied force, the young's modules of the prescribed material and the polar moment of inertia, we apply the formula for max deflection of a beam fixed on one end:

$$\delta = \frac{F * L^3}{3 * E * I}$$

When computed for our given system, the magnitude of the deflection is determined to be 0.00386m, a reasonable value.

To uphold a through engineering analysis of our system, the analysis of shear stress was included in our evaluations. Shear stresses are the result of forces parallel to the surface, making the material want to slide along itself. It is a function of the applied force, maximum first moment, the polar moment of inertia and the cross-sectional width. The calculations can be followed below, which produced a value of 4.58MPa, well under the maximum design stress of the aluminum housing.

Shear Stress Calculations				
Description	Value	Unit	Variable	Equation
Cross Sectional Area	0.0009531	m^2	A	A = π(r_o^2 - r_i^2)
Width of Cross Section (b)	0.0110744	m	b	2*(r_o-r_i)
Max First Moment	8.339E-06	m^3	Q_{max}	(2/3)*(r_o^3-r_i^3)
Max Shear Stress	4589191.3	Pa	τ_{max}	V*Q_{max}/(I_c*b)
Max Shear Stress	4.5891913	MPa	τ_{max}	

Figure 8.3.4: Shear Stress Calculations

8.3.2 Coupling Key Calculations

To transfer power from the motor output to the lower unit input the team designed the coupling as seen in figures 8.6 & 8.14. The coupling needed to have a D shaft cavity on one end and 17 tooth spline connection on the other. It was also essential to integrate a key to use as a mechanical fuse, protecting both shafts and the expensive custom couplings. The calculations seen below were performed to find an adequate key for the operating torque and part geometries.

Key Calculations			
Shaft Diameter: D =	1.5	in	
Torque on Gear: T =	442.8	in lbs	
Hub Length: L_H =	6	in	
Key Material:	SAE 1018		
Design Factor: N =	2		
Yield Strength of Key: s_y =	54000	psi	Table 11-4
Results			
Key Width: W =	0.375	in	Table 11-1
Key Height: H =	0.375	in	Table 11-1
Minimum Key Length: L_{min} =	0.11662222	in	L_{min} = (4TN)/(DWsy)

Figure 8.3.5: Key Calculations

8.4 First Complete Prototype

As our project involves the collaboration between our team, the steering team, and the Solar Racing Team, creating full prototypes of the design is unrealistic. Instead, certain parts are created such as the splines for the coupler using a 3D printer to determine the proper spline profile and shape before committing to creating the final part using the wire EDM machine.

8.4.1 Prototype Spline Coupler

To attach the lower unit shaft to the shaft of the motor we are required to transition from a splined shaft to a D-shaft from the motor manufacturer. The spine shaft has been particularly troublesome, as it is an unconventional 17 tooth shaft that does not have a readily available coupler. To design the profile of this part, we used multiple dimensions imported into Fuision360 as well as spline software in Autodesk Inventor. After some trial and error, we were able to design a piece which fits snuggly on the input shaft of the lower unit. We now have determined the spline profile, of which the final product will be created using the wire EDM machine.

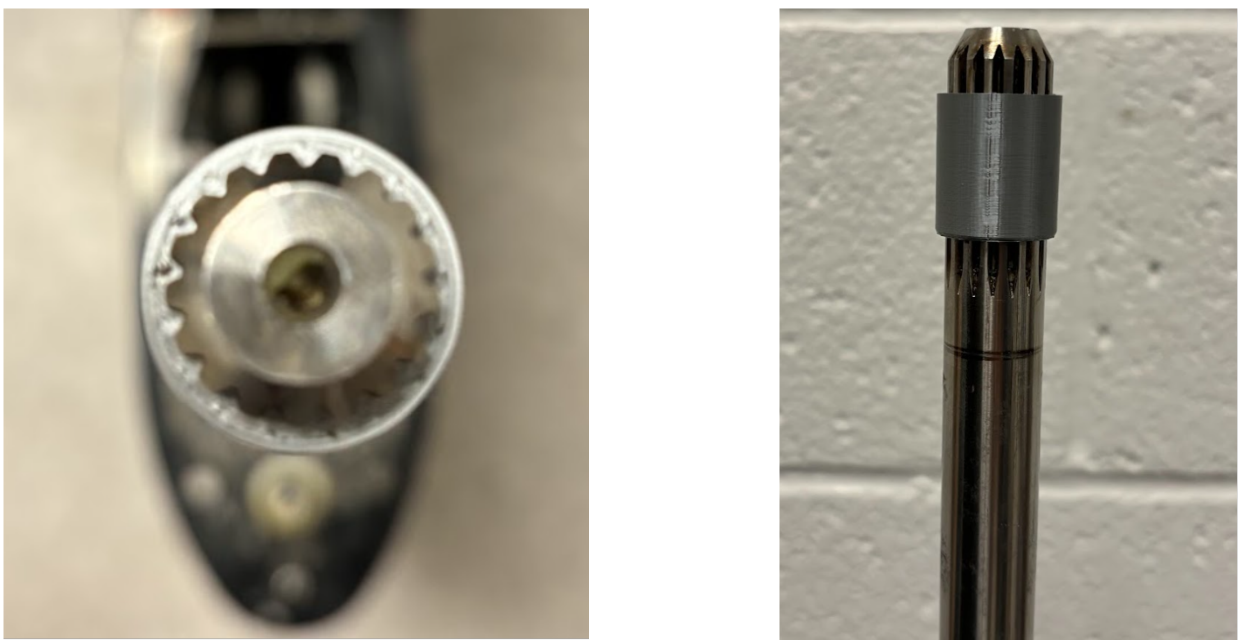


Figure 0.1: Prototype Spline Coupler

8.5 Revised Electrical Design

8.5.1 Outboard propulsion electrical diagram

In this section, we discuss the necessary changes that were made to the electrical schematic for the outboard electric motor controller. The original one was presented in Chapter 5 was a prior year's schematic, and this is the updated motor controller diagram that has been received from the team.

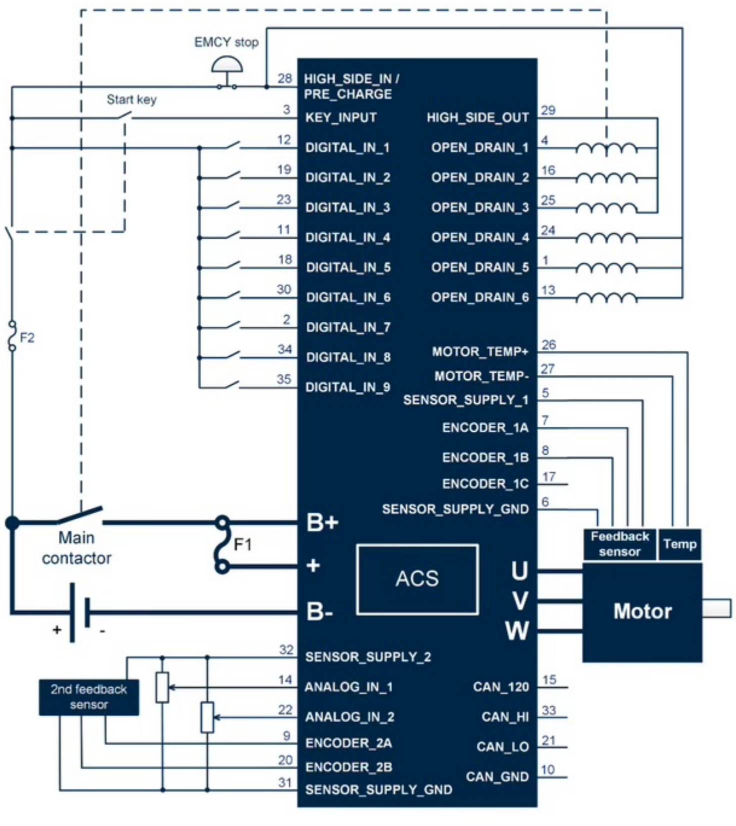


Figure 18 Typical wiring of ACS 35 pin standalone I/O controller with 12 V feedback sensor

Figure 0.21: Updated Electrical Schematic for outboard propulsion system.

In the schematic we are still utilizing the DHX P40 motor with the VESC STR- 500 motor controller.

8.6 Standards and Compliance Update

8.6.1 Codes and standards applied to an electric outboard.

The project is subject to the following codes:

- ASTM G52-20 Standard practice for exposing and evaluating metals and alloys in surface seawater. This standard is relevant to our project because we will be operating in seawater. The outboard must be able to withstand exposure to seawater with minimal corrosion.
- ASTM 1470-19 Standard Practice for Fastener Sampling for Specified Mechanical Properties and Performance Inspection. This standard is relevant as the fasteners that are being used to mount the bevel gear and motor must be able to tolerate 4 hours of run time minimum without failure. This is also relevant for the fasteners that mount the propulsion system to the boat due to the forces faced during operational use.
- ASME B1.20.1 Standard on Pipe Threads covers dimensions and gaging of the world's most common pipe threads including NPT. This standard is relevant to our project because all pipes(casing) and flanges have NPT threads. This standard was not cited in section 5.5, the team added it to this section because these threads are a focal point of our project.

8.7 Initial Prototype Test Data

No complete prototype has been built, and therefore no actual testing has been conducted yet due to cost and scale of project but testing of certain parts such as sizing of props as well as testing the coupler have been done. The coupler spline and D shaft connections were 3D printed to ensure proper fitment to their respective shafts, this way the team could avoid machining an expensive part that didn't fit.

8.8 Revised Costed Bill of Material

Component	Source	Part Number	Quantity	Price	Dimensions	Purchased?
Flange 2.5"	McMaster	44705K235	2	$ 163.80	Type: 2.5"	Yes
Reducing Flange	McMaster	44705K727	1	$ 95.59	2-1/2 x 2 NPT	
Flange 2"	McMaster	44705K234	1	$ 65.34	Type: 2"	Yes
Casing 2.5"	Online Metals	4371	1	$ 61.07	12 inch ID: 2.323" OD: 2.88"	
Casing 2"	Online Metals	1231	1	$ 88.83	6 feet ID: 1.939" OD: 2.38"	
Bearings in casing	McMaster	2780T45	2	$ 65.70	ID: 0.75" OD: 2"	Yes
Bearing outside casing	Amazon	VXB Brand 28985/28920	2	$ 168.84	ID: 2.375 " OD: 4"	Yes
Snap rings	McMaster	91580A246	4	$ 13.68	Released in Groove OD: 2.122"	Yes
Bolts for Flange to P40	McMaster	93190A387	4	$ 19.08	1/2"-20 2" Long	
Nuts for Flange to P40	McMaster	90715A170	4	$ 10.76	1/2"-20 Thread Size	
Nuts for Lower Unit Plate	McMaster	93625A350	10	$ 6.20	M10 x 1.5 mm thread	
Bolts for Lower Unit Plate	McMaster	91287A376	10	$ 19.78	M10 x 1.5mm 50mm L	
Material for Lower Unit Plate	Public Metal Works		1	$ 85.00	6061 Aluminum 18" x 7"	
Coupling	Public Metal Works		1	$ 27.00	Steel Round Bar	
Propeller	Wholesalemarine	19640A40	1	$ 150.00	10-3/8 x 13P Propeller	
Mounting Hardware	McMaster	91251A016	1	$ 7.86		
Lower Unit	Mercury		1	$ 250.00		Yes
Total				$		1,039.14

Table 8.1: Costed Bill of Materials

8.9 Revised Timetable

9 Deliverable	Deadline
Project Proposal	9/12/2023
Determine type of propulsion (Inboard or Outboard)	9/19/2023
Progress Report 1	9/29/2023
Coordinate preliminary designs with steering team	10/09/2023
Complete the product design specification (PDS)	10/19/2023
Finalize general requirements for steering and propulsion joint functionality	10/25/2023
Progress Report 2	11/03/2023
Determine the motor to be used for the propulsion	11/10/2023
Finalize a design and constraints	11/18/2023
Complete the final CAD file for the propulsion system	12/15/2023
Progress Report 3	12/23/2023
Have a completed list of items to buy, and order all	02/11/2024
Determine any items to be manufactured and have them done by this date	02/12/2024
Finish prototype, and prepare for combination with steering	03/02/2024
Progress Report 4	03/08/2024
System mounted on boat for initial testing	03/25/2024
Initial testing of prototype	04/10/2024
Fix any issues and finish testing	04/28/2024
Progress report 5	05/10/2024

Table 8.2: Revised timetable

8.10 ASME Engineering Code of Ethics

8.10.1 Outboard Propulsion System

The design, construction, and testing of our outboard propulsion system met several applicable criteria of the ASME Code of Ethics. The following canons are applicable to our project:

- Canon 1: Engineers shall hold paramount the safety, health, and welfare of the public in the performance of their professional duties.
- Canon 2: Engineers shall perform services only in the areas of their competence; they shall build their professional reputation on the merit of their services and shall not compete unfairly with others.
- Canon 4: Engineers shall act in professional matters for each employer or client as faithful agents or trustees and shall avoid conflicts of interest or the appearance of conflicts of interest.

To meet the criteria of canon 1, we designed the system to be safe and ensure the safety of the operator as well as those in close proximity to the system. All mechanisms are properly designed and are made to endure the forces necessary. Systems such as the bevel gear system are properly shrouded in a commercially available lower unit to provide proper structural strength and a safe enclosure.

For canon 2, we are following the rules and regulations that are in place by the governing organization, Solar Splash, to ensure that our design is not competing unfairly with the other teams. This includes the selection of motor and battery systems to ensure that the peak and nominal voltages are not excessive and do not overpower the competition. The boat is designed in a way that follows all the rules and does not take any shortcuts to provide an unethical advantage. In addition, we are designing though the knowledge gained in our prior years of education and experience. When we need guidance, we seek professional academic help instead of operating outside of our expertise.

Finally, for canon 4, we are under the employment of the Stony Brook Solar Racing Team and are required to meet certain criteria for the new propulsion system. These include criteria for the minimum speed of the boat in both the endurance and sprint events. We are also under the rules and regulations of our motor manufacturer, DHX, and are required to properly display their product in a way that provides a proper display of their product as a sponsor of our project.

8.11 Revisited Team Member Evaluation

Kai: In Report 1 I researched two commercially available electric outboards and two electric inboards. These were compared in a chart of existing models. In Report 2 I designed a transmission system and a shaft coupling. Neither of these designs were included in the final design of Report 3. In Report 3 I helped begin the lower unit plate design but mostly focused on calculations. I completed static and dynamic thrust calculations, bearing load analysis, bolt stress calculations, propeller selection, and lower unit selection. I also researched and selected each component and created the costed BOM. I wrote and edited many parts of the report including 7.1, all writing for my designs and market research, 4.1, 2.3, etc. In report 4 I updated the housing stress calculations and calculated key geometries for the coupler at the expected torque. I also wrote the overview which summarizes major changes done since report three and why. Finally, I updated engineering standards and the costed bill of materials.

Alexander: In Report 1, most of my time was spent completing Chapter 1, including a summary of the project, the main objective and how it will be solved, and researched the societal factors that will be involved along with the challenges our group will encounter during production of the propulsion system. For Report 2, I developed three CAD models including a U-Joint Coupling to connect the drive shaft to the propeller shaft, an outboard system design that protrudes through the rear of the boat, and a direct drive system with an aluminum outer casing to protect the drive shaft from corrosion and debris. Benefits as well as downsides were listed for each model. In report 3, I developed the final CAD design that will be used and designed the motor mount collaboratively so that it would be accessible for a steering team. I created 3D CAD drawings to display each component and where they are located. In report 4, I developed the final 2D CAD drawings for each new component to be used in the final design. I also provided a stress analysis for the coupling device by using a stress concentration diagram. This summary reveals which areas of the shaft are to experience the greatest amount of load and is used to help distribute the load uniformly. Finally, I created an animation to reveal how the steering system will operate when connected to the propulsion system.

Cole: In Report 1, I spent much of my time performing patent analysis. The patent summary statement and the summary chart are also of my doing, along with some information from Chapter 1 (predominantly the "Problems and Objective" section). Report 2, I focused on my designs of the inner workings for the bevel and chain drive lower unit assemblies. I completed the comparisons for both the preliminary and revised versions of this subassembly. Report 3, I helped considerably with the calculations and analysis. Evaluating the batteries, housing bending, along with the hull drag and galvanic corrosion. Moreover, I was highly active with group meetings, collaborations with steering team, and the overall conceptual design in our system. I consistently proofread and participate in other sections. For report 4, I spent the bulk of my time working on the complete CAD design, regularly collaborating with steering, including the long session which resulted in the final tiller arm. I also came up with the of concept and CAD of the coupler system. I contacted local metal suppliers, sourcing the stock aluminum and steel for our group as well as for steering. The spline and D-shaft iterations and printings were also of my doing. In the written report, I proofread the other sections, regularly adding information where I deemed fit.

Soroush: In report 1 I worked on creating the initial timetable for the project as well as conducting research on two different methods of propulsion and the benefits and downsides of each. In addition to that work in chapter 1 such as the skills table was also done. In report 2 I came up with two CAD designs, a chain drive propulsion system, and a pod motor system, these two designs were refined in chapter 5 of report 2. I also found two ASTM standards that are relevant to our project and worked on multiple Pugh Matrices. In report 3 I worked on the plate weld calculations as well as gathering electrical circuit diagrams from the Solar Racing Team's existing boat. I also worked on creating the bill of materials and gathering the 2D CAD drawings of components purchased. In report 4 I worked on the CAD design as well as helping in the integration of the steering deign with ours. This required many revisions to our design and theirs to allow for the required tolerances and functionality of both systems together. I also worked on the cost calculations and helped in the creation of the bill of materials.

Perception	**Cole**	**Alexander**	**Kai**	**Soroush**
Cole	25%	25%	25%	25%
Alex	28%	24%	24%	24%
Kai	25%	25%	25%	25%
Soroush	28%	24%	24%	24%

Table 8.3 Evaluation Matrix

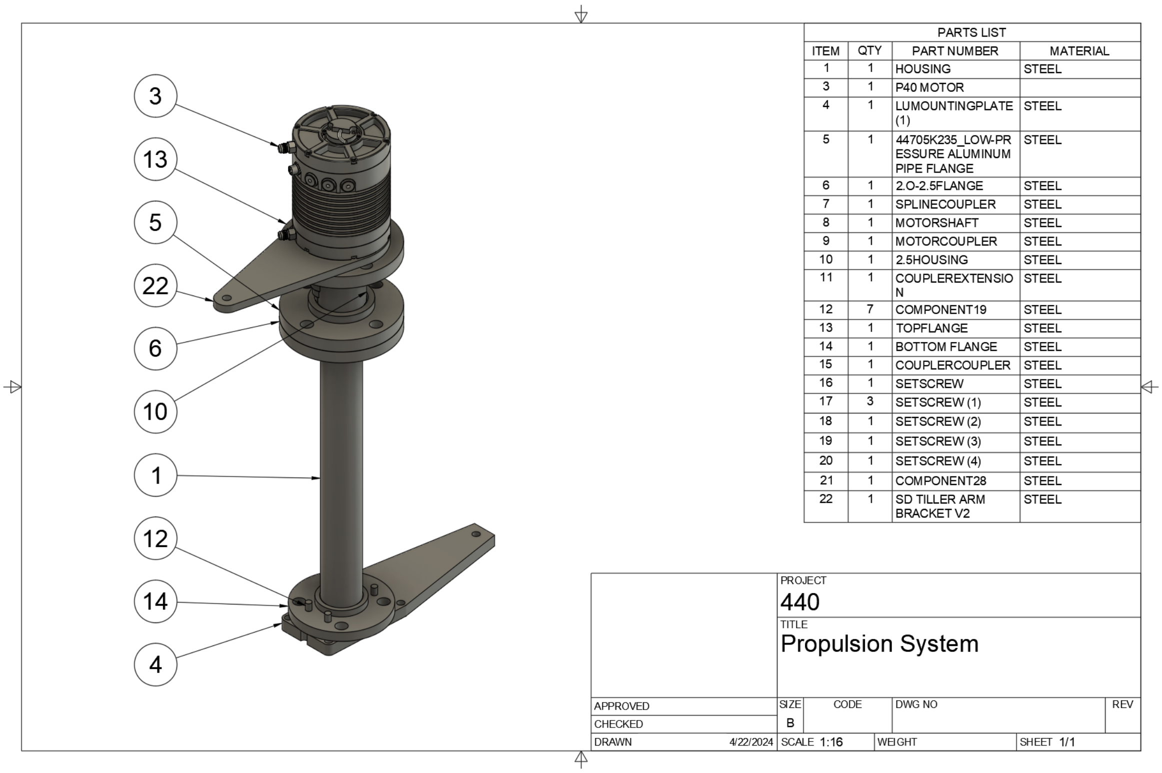
Chapter 9. Final Prototype Build and Test

9.1 Overview

Following Report 4, our team found necessary changes to not only improve the efficiency of our prototype, but to also enhance compatibility with the steering system. The major revisions included welding the coupling device. Our previous steel round bar coupler was designed to mount onto the input shaft of the lower unit and conjoin with the "D" shaft of the motor using a complex keyed sleeve system. After testing the initial part, we discovered that there was a lapse in communication and that the shaft's spline profile was sent to the EDM, rather than the negative designed to be the internal spline profile. The coupler was an identical match to that of the lower unit shaft, were too tight to be mounted. After several hours of attempting to hammer the two pieces of steel together, our team decided it would be best to completely re-do the spline piece. This time around, Professor Machtay offered to weld the spline and the D couplers together, eliminating the need for keys and set screws. To facilitate this, we added beveled edges to the faces being welded, to increase the penetration of the weld. The final coupler was hardened via heat treatment.

Additionally, the team relocated the bearing and snap ring placement to the ends of the aluminum housing. This facilitates the machining process for snap ring grooves and allows the team easier access to the internal bearings if needed. Some other changes included switching the housing from a pipe to a tube, as the initial pipe was not entirely concentric. The plate bolted to the lower unit was cut and sanded as well to reduce the total weight and to enhance the hydrodynamic property of our design. Finally, after attempting to attach our aluminum housing into the tapered roller bearing of the steering system, we found the outer diameter of our shaft was too large. The team removed 0.002” through sanding to fit properly inside the bearing.

9.2 Updated Components



PARTS LIST

ITEM	QTY	PART NUMBER	MATERIAL
1	1	HOUSING	STEEL
3	1	P40 MOTOR	
4	1	LUMOUNTINGPLATE (1)	STEEL
5	1	44705K235_LOW-PRESSURE ALUMINUM PIPE FLANGE	STEEL
6	1	2.O-2.5FLANGE	STEEL
7	1	SPLINECOUPLER	STEEL
8	1	MOTORSHAFT	STEEL
9	1	MOTORCOUPLER	STEEL
10	1	2.5HOUSING	STEEL
11	1	COUPLEREXTENSION	STEEL
12	7	COMPONENT19	STEEL
13	1	TOPFLANGE	STEEL
14	1	BOTTOM FLANGE	STEEL
15	1	COUPLERCOUPLER	STEEL
16	1	SETSCREW	STEEL
17	3	SETSCREW (1)	STEEL
18	1	SETSCREW (2)	STEEL
19	1	SETSCREW (3)	STEEL
20	1	SETSCREW (4)	STEEL
21	1	COMPONENT28	STEEL
22	1	SD TILLER ARM BRACKET V2	STEEL

Figure 9.1.1: Revised Full Assembly of Propulsion System

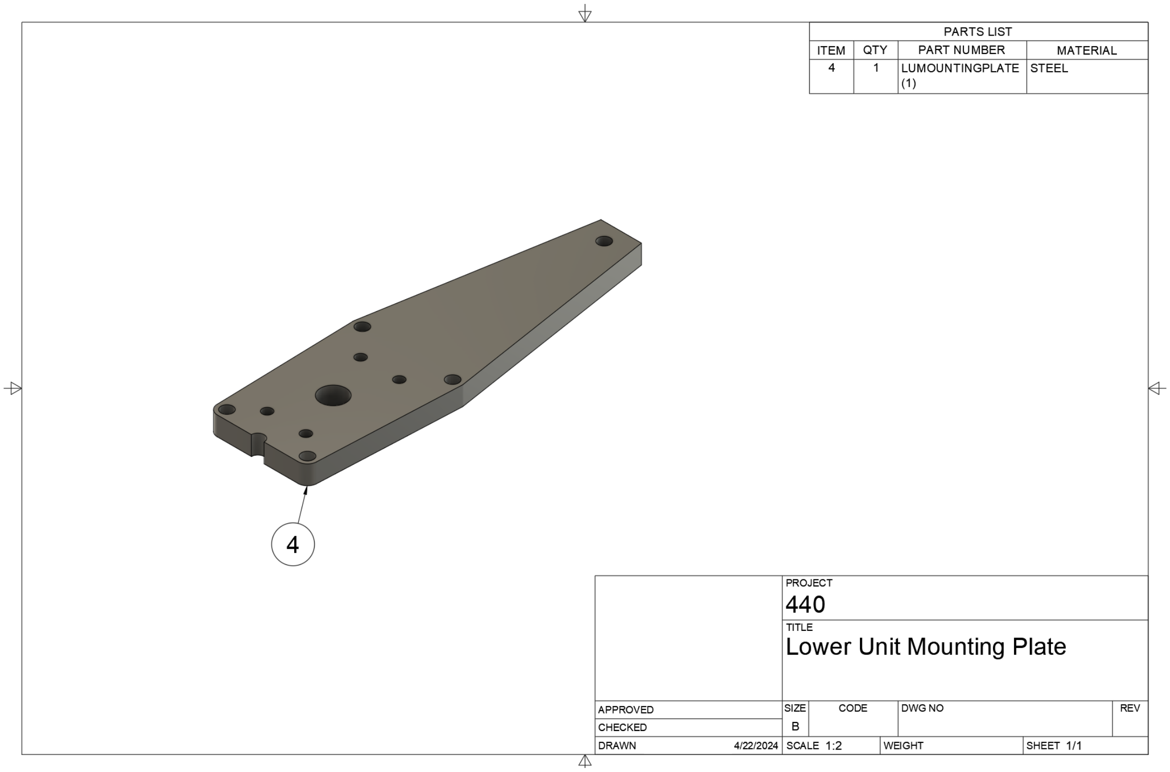


Figure 9.1.2: Revised Lower Unit Mounting Plate

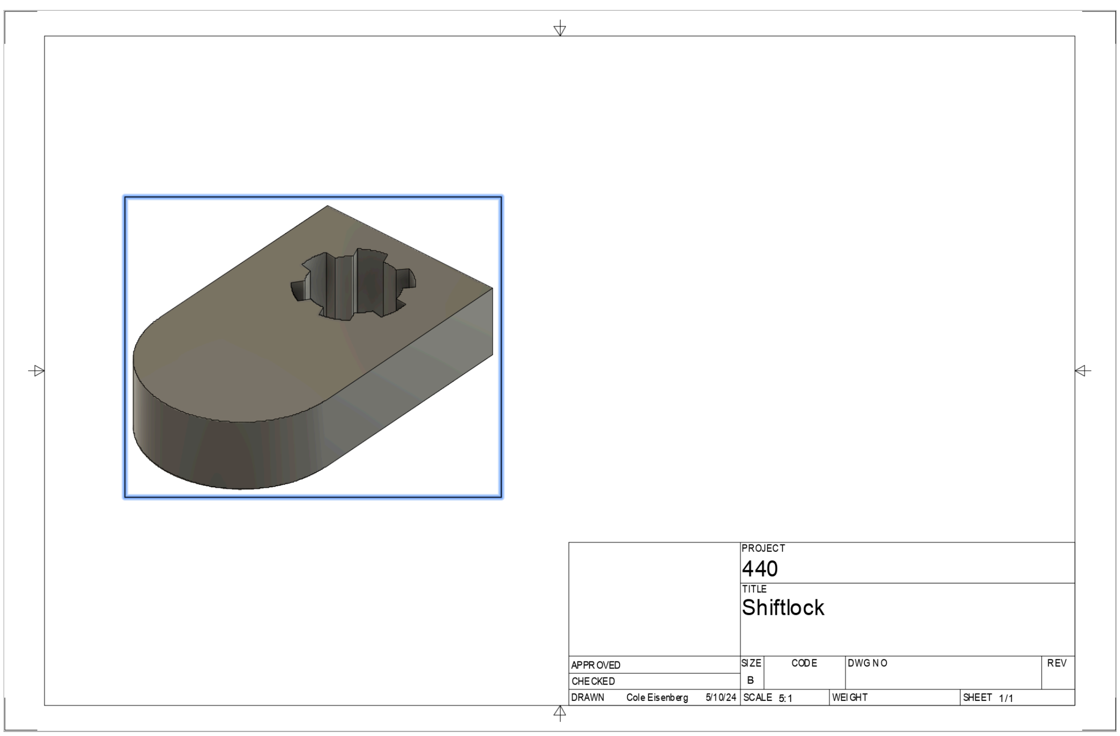


Figure 9.1.3: Press Fit Shifter Knob Locking Mechanism

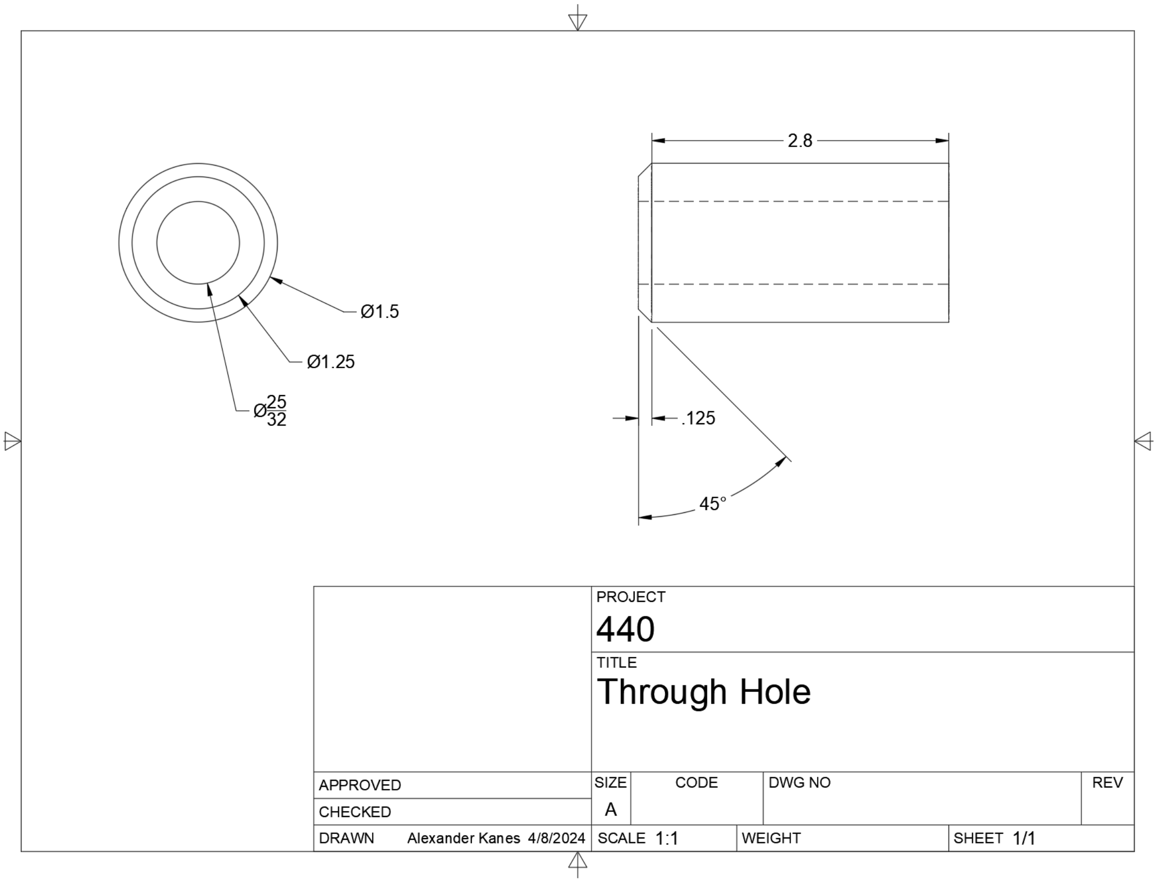


Figure 9.1.4: Revised Coupler with Bevel

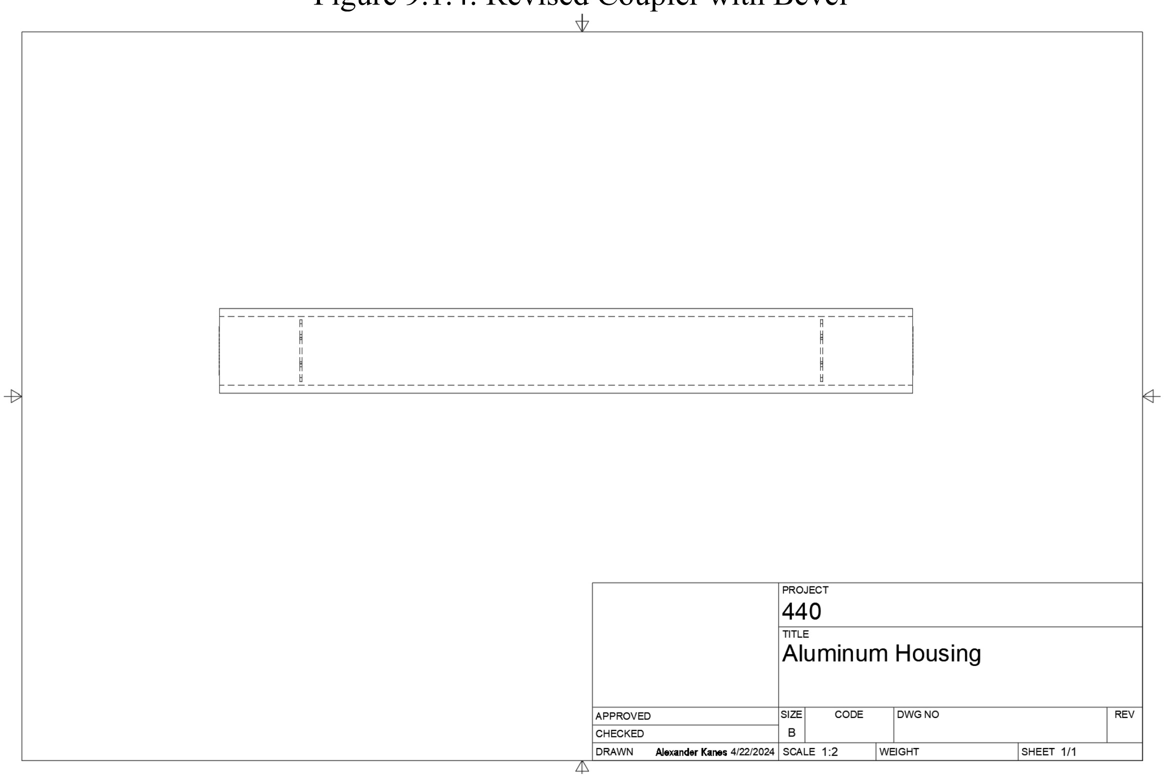


Figure 9.1.5: Revised Aluminum Tube Housing

Figure 9.1.6: Newly Purchased Mercury Propeller

Following Report 4, the Black Max Mercury Propeller was our newly purchased component. This propeller fits perfectly into our design with a 10” diameter and 17” pitch. Additionally, the horsepower rating for this propeller (25-60 HP outboards) matches the output power of the P40 motor making it suitable for competition.

○ 9.3 Final Electrical Design

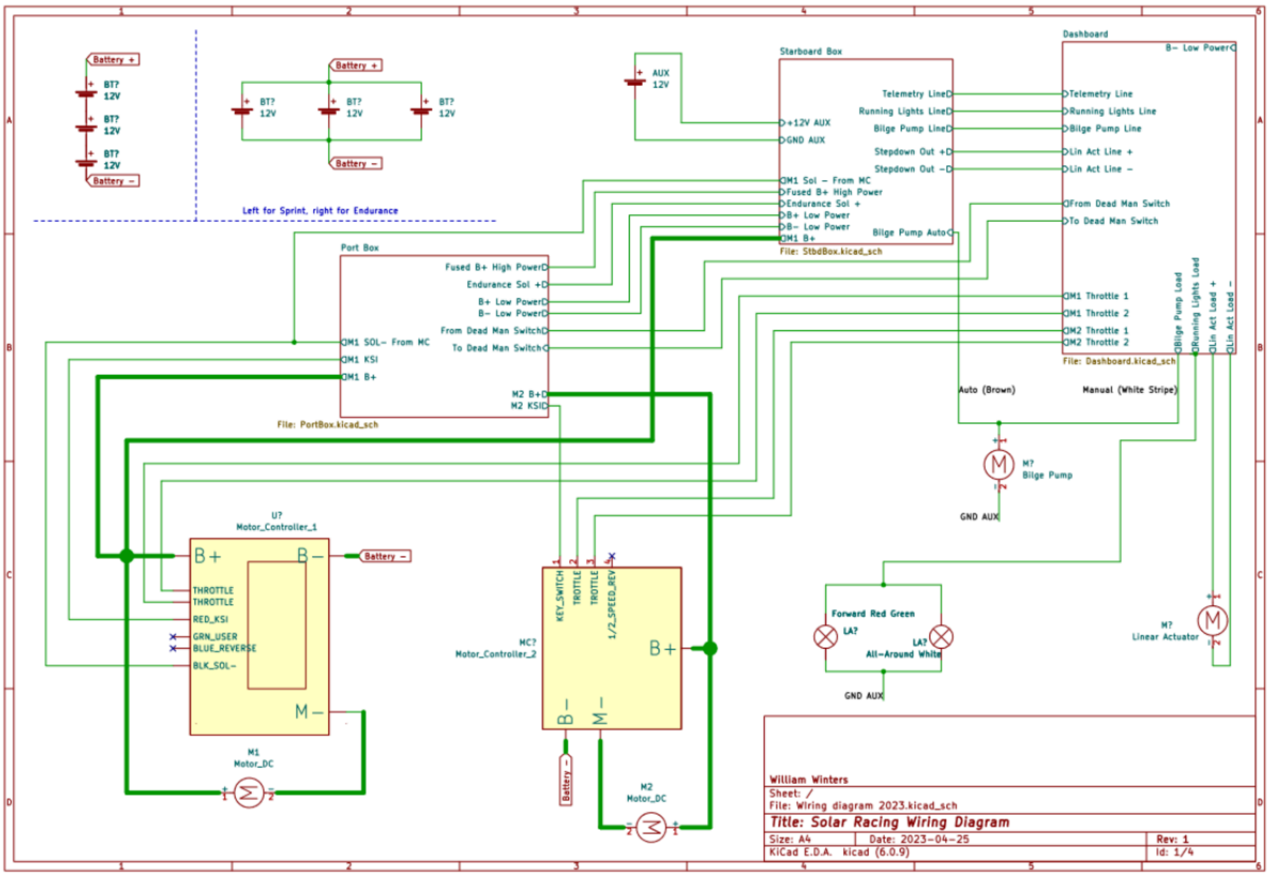


Figure 9.3.1: Systems Overview Wiring Diagram

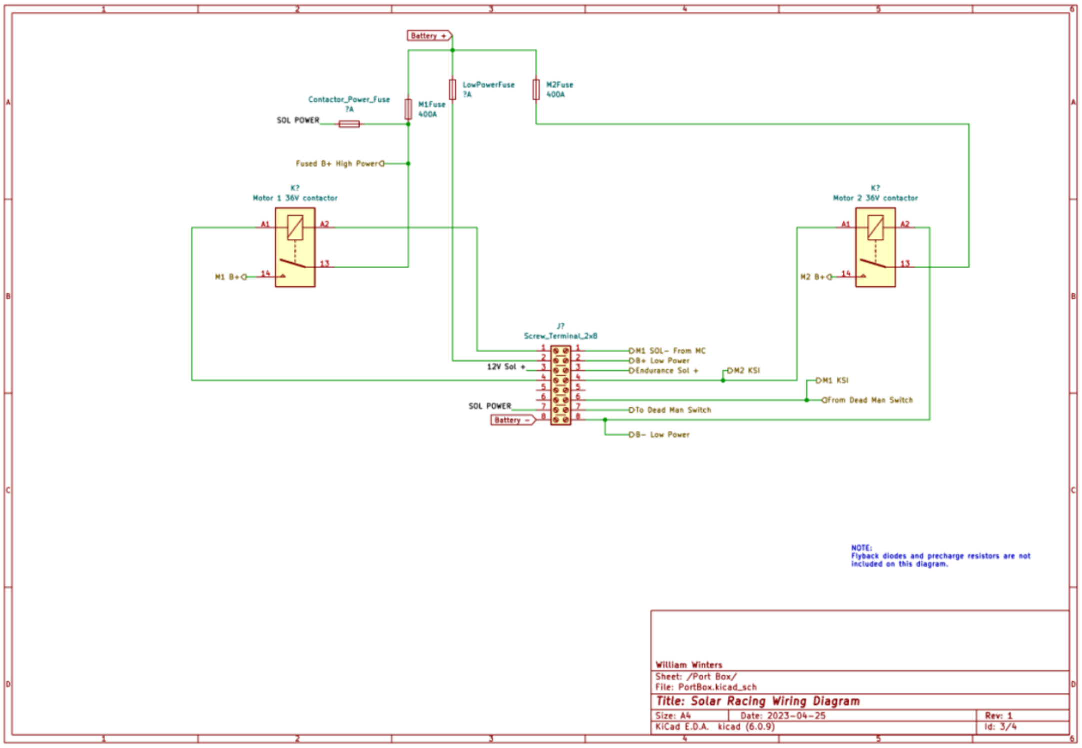


Figure 9.3.2: Port Electrical Box Wiring Diagram

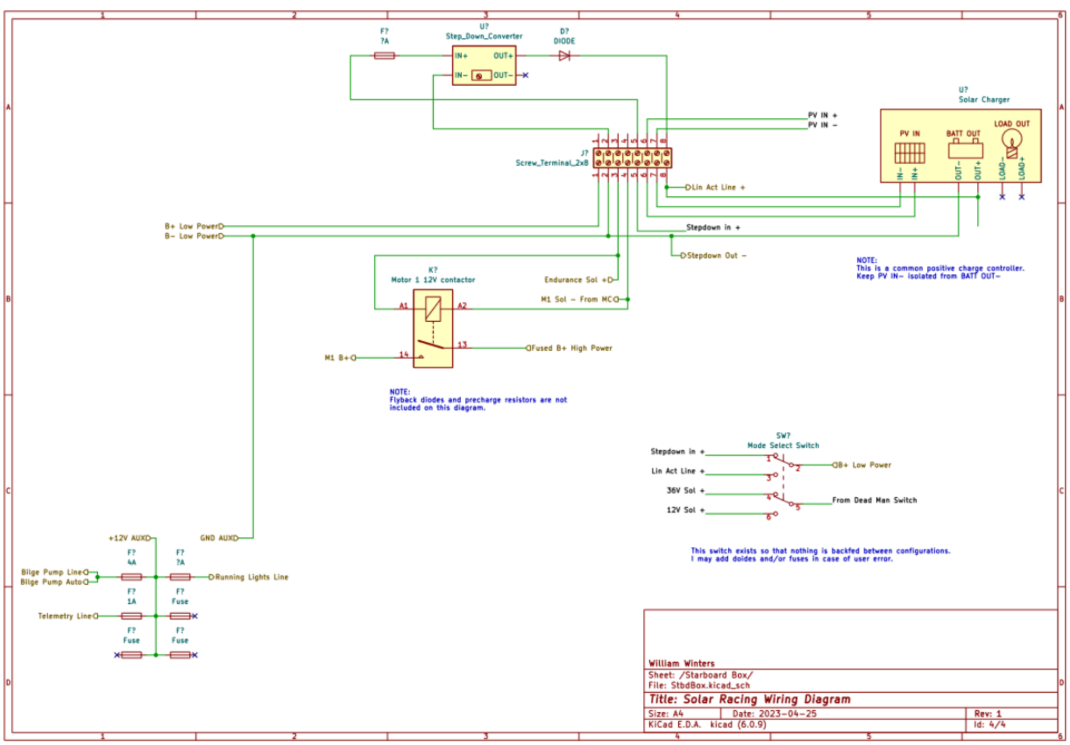


Figure 9.3.3: Starboard Electrical Box Wiring Diagram

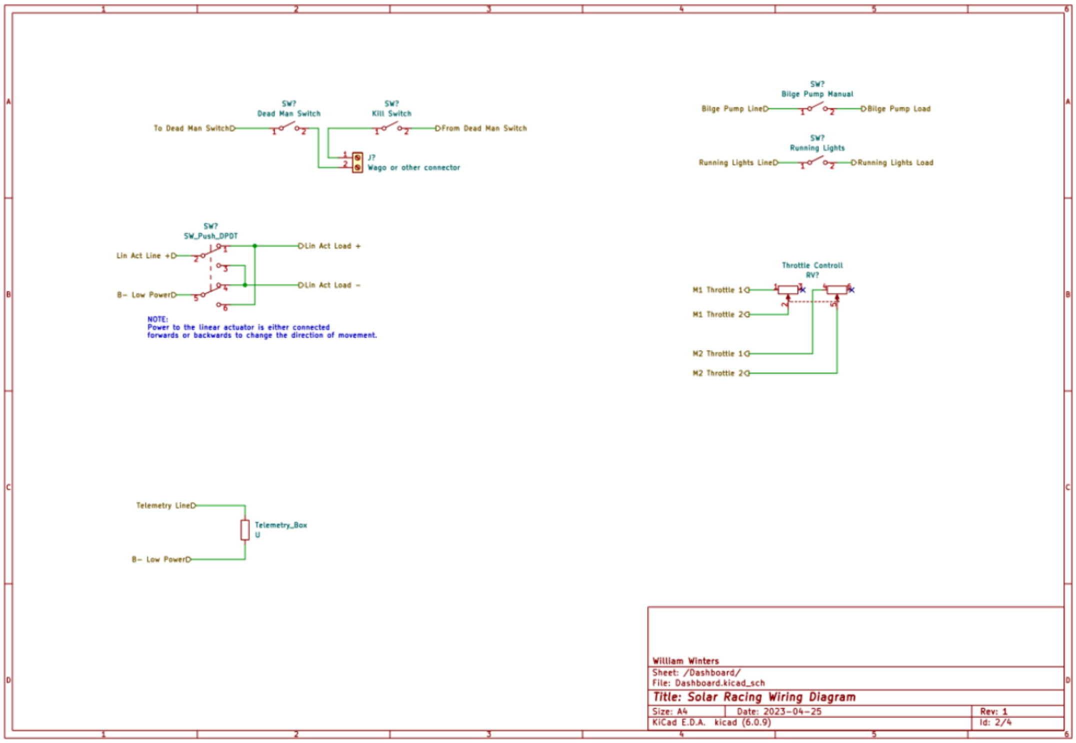


Figure 9.3.3: Dashboard Electrical Diagram

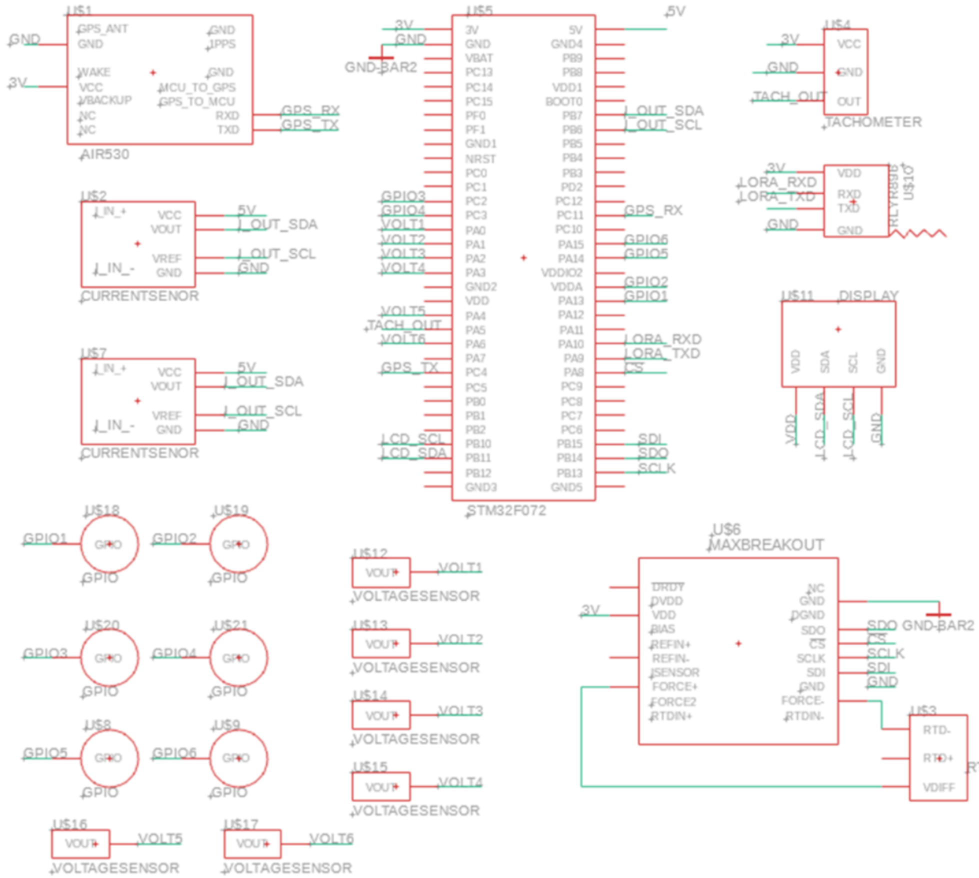


Figure 9.3.5: DAQ Hardware Schematic

9.4 Consistency of the Final Design with the Project Requirements and PDS

Table 0.1: Compliance with Functional Requirements

Req. #	Requirement	Description	Compliance
FR_01	Power	Source voltage to the motor may not exceed 36VDC	The source voltage is controlled via the motor controller and does not exceed 36 VDC.
FR_02	Speed	The goal of the new propulsion system is to push the boat more than 30 mph. Power is controlled using a throttle in the form of a lever.	Due to issues faced with the manufacturer and the motor controller, full power has not been achieved, and a max speed of 22 mph was seen at 80% throttle, which is an increase compared to the prior design. The throttle is controlled via a knob.
FR_03	Steering	The propulsion system must be able to rotate/move so steering team can attach their mechanism using a shaft that is rotated with hydraulics to 30 degrees each direction.	The steering system was able to successfully connect to the propulsion system via the hydraulics and achieved the expected 30 degrees in each direction with ease.

Table 0.2: Compliance with Packaging Requirements

Req. #	Requirement	Description	Compliance
SE_01	Vibration	The system must be able to withstand vibrations caused by waves, wind, and speed.	The design was able to handle the vibrations successfully. The 8+ hour drive to competition in Virginia Beach was a great test of this, where the system was still fully tight and secure when we arrived.
SE_02	Waterproof	All submerged areas of the propulsion system must be waterproof to ensure no damage to components and keep all occupants of the boat safe.	The system maintained a watertight structure through the tests and no water egress was detected.

Table 0.3: Compliance with Service Requirements

Req. #	**Requirement**	**Description**	**Compliance**
PA_01	Saltwater	All materials used below waterline must be able to withstand saltwater corrosion or be resistant for at least 12 hours before getting cleaned.	The lower unit as well as the lower unit plate had no corrosion, however the bolts that connected the lower unit to the plate experienced surface corrosion. This is an easy issue to solve and will be resolved before next competition.
PA_02	Maintenance	All moving parts must be able to be fixed/maintained upon failure with relative ease of access.	Most of the moving parts are easy to remove with exception to the bearing in the main tube, however maintenance on those components is not of frequent worry.
PA_03	Assembly	All parts must be easy to assemble and disassemble as well as not be too complicated to put together.	The design in initial assembly was not easy to put together due to certain clearances not being perfect, but after the initial assembly the disassembly and subsequent reassembly were much easier. Assembly is slightly complicated due to the integration of the propulsion with steering system,

- ### 9.5 New Knowledge Gained

Alexander: Throughout this project, I've encountered numerous challenges that required me to learn new aspects of machining. For example, determining the spline type of the lower unit shaft involved learning new features of Autodesk Inventor CAD software. I've discovered spline standards that have identical diameter and pitch measurements to that of the shaft. By calculating these parameters, I found an exceptional match for our coupler EDM to be manufactured. Both the courses found on Autodesk University and YouTube broadened my understanding of special features like these and were very helpful throughout our project. In another example, to securely fasten the bolts into the lower unit plate the team used a press fitting machine, a device in which I have little experience. With the assistance of a team member, we successfully pressed bolts into the lower unit connecting the flange.

Soroush: Starting this project, I had a decent skillset in CAD software used specifically in Fusion360, however I was able to further my knowledge greatly throughout this project. For our project we had to design a coupler that had to withstand the forces from the rotating motor shaft and lower unit shafts. Failure of this coupler would be disastrous as that is the mechanism that allows us to connect the motor to the lower unit and thus provide the propulsion necessary to move the boat. This design process required the use of FEA software to determine if the material and coupler dimensions were sufficient to take this load. Using trial and error as well as YouTube videos on this subject I was able to learn how to use this feature in fusion and correctly assist in the design process of the coupler. I was also able to gain further experience with other elements of the project in a more hands on aspect such as attempting precision machining of the flanges. Using the mill and lathe to manufacture parts precisely and accurately such as the flanges was a great experience and allowed me to further skills that I had previously learned in courses like MEC 225.

Kai: I was able to utilize many of the skills learned in Machine Design throughout the project. In 410 you are given a list of parameters and are expected to plug them into the given equations. It is a much greater challenge when you must find or interpret those parameters and use the correct equations with no guidance. I performed bearing load calculations, bolt stress calculations, and key calculations to help select viable components. Another important part of our project was propeller selection. The Propeller Handbook by Dave Gerr is loaded with information and calculations for choosing and understanding boat propellers. I learned how to select pitch and diameter of the ideal propeller for a boat. The book also had information on finding static and dynamic thrust of a boat, which were important figures in our stress calculations. The entire team and I spent countless hours on Fusion 360 working towards our final design, this was a learning process with a lot of trial and error and of course many YouTube videos. The greatest CAD challenge I faced with the team was designing the spline pattern to couple with the lower unit output shaft. After we reached a final design and received our components it was time to create our prototype. This involved learning or in some cases relearning because it had been a while since MEC 225 how to use the lathe, threading machine, drill press, band saw, Dremel, hydraulic press, and countless hand tools.

Cole: Bringing it back to the basics, engineering statics proved to be very useful during the design of this project. While I had learned it all in the past, no one on the team had ever applied it in a real-world situation. Determining the allowable shear stress of the shaft housing was very important, as plastic deformation during operation would be catastrophic. Solving for polar moment of inertia, bending moment, and then bending stress, we were able to calculate the minimum pipe thickness to remain within the given factor of safety. A more involved skill which we learned about was tolerancing, and the different types of fits between components. In the solar boat machine shop, one of the preliminary tasks was to manufacture a concentric bushing for assembly, locating the bottom pipe flange in reference to the shaft on the lower unit. We wanted to achieve a slip fit, aiming for an RC2 clearance fit, between 0.0003" and 0.0012" of clearance. After the final cut, the ID of our hole measured 0.002" larger than the shaft, technically a RC5 fit, however upon testing we were satisfied with the insignificance of freedom between the pieces. In a similar fashion, the other end of the spectrum when we tried to fit the ID of the steering bearing over the OD of the main shaft housing. After attempting to mate the pieces via lubrication, utilizing material properties i.e. the coefficients of thermal expansion, and a whole lot of percussive persuasion (hammering), we landed at the conclusion that the force fit between the pieces had too much interference. To remedy this, knowing that we had more than enough material to not worry about compromising structural integrity, we sanded material off the outside of the pipe, repetitively testing the fit until the bearing was able to be persuaded onto the pipe.

○ 9.6 Final Prototype

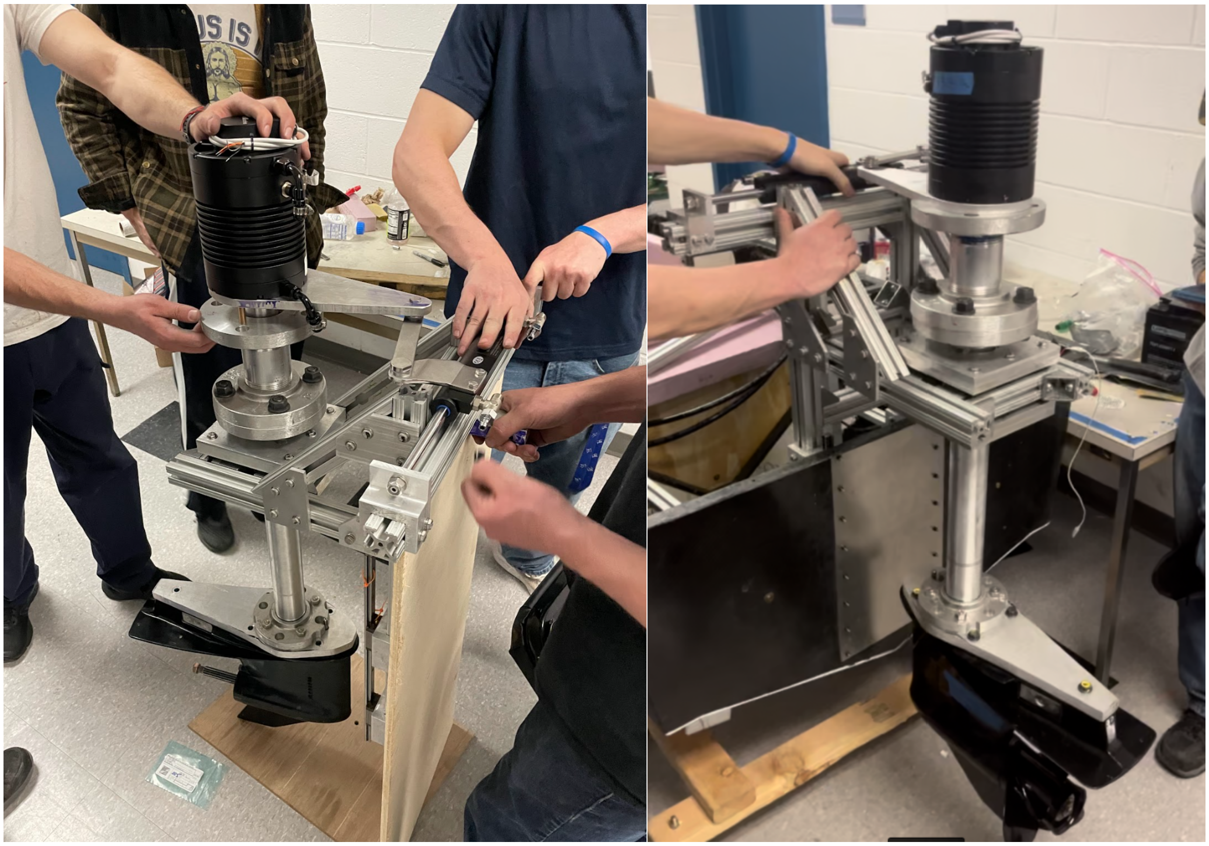


Figure 9.6.1: Final Assembly

During production of the assembly shown above, the team started by bolting the aluminum plate through the holes of the lower unit. All holes in the mounting plate were located using a precision pin (RC2 fit) we manufactured on the lathe, which we covered in paint and used as a stamp. The profile of the lower unit mounting surface was traced onto the plate and cut using a belt saw and sanded for enhanced hydrodynamic flow. An aluminum pipe flange was placed on top of this plate, located using a lathe machined concentric bushing. The bushing references the ID of the flange to the OD of the input shaft, making sure when the main housing and bearings are installed, we won't experience misalignment and binding of the shaft. The flange is secured to the mounting plate using wheel studs pressed through the plate. The heads of these bolts are counterbored to maintain a planer mounting surface.

The retaining rings and internal bearings are installed into the 2.0" main housing, and then the housing is threaded directly to the flange on the plate, via the external NPT pipe threads we've cut into both ends. The main housing is slid into the set of large roller taper bearings, and the bearings are compressed using steering team's mechanism. This locks the housing and lower unit in place. The top 2" flange is threaded onto the top of the main housing. If the prior steps are performed correctly, there should be ½" clearance between the top of the bearing assembly and the bottom of the flange. If not, the bearings must be loosened, and the tube adjusted accordingly.

When the main housing is fully assembled, the coupler is placed on the top of the input shaft. The coupler housing assembly, including the two flanges, 2.5" pipe, steering tiller arm, and the P40 motor which has already been attached, is threaded together separately, and bolted to the top of the main housing using the four large pieces of hardware. The tiller arm is used as a sort of wrench, as spinning it while resisting the spin in the lower unit will tighten all the flanges simultaneously. The procedure is moving according to plan if while tightening the flanges, you find that it becomes incredibly tight with ~15 degrees to go. From here, you use all the resources at your disposal, inviting friends over to achieve the torque necessary for the final push. The tiller arm is to be verified as 180 degrees with the lower unit mounting plate using a laser straight edge.

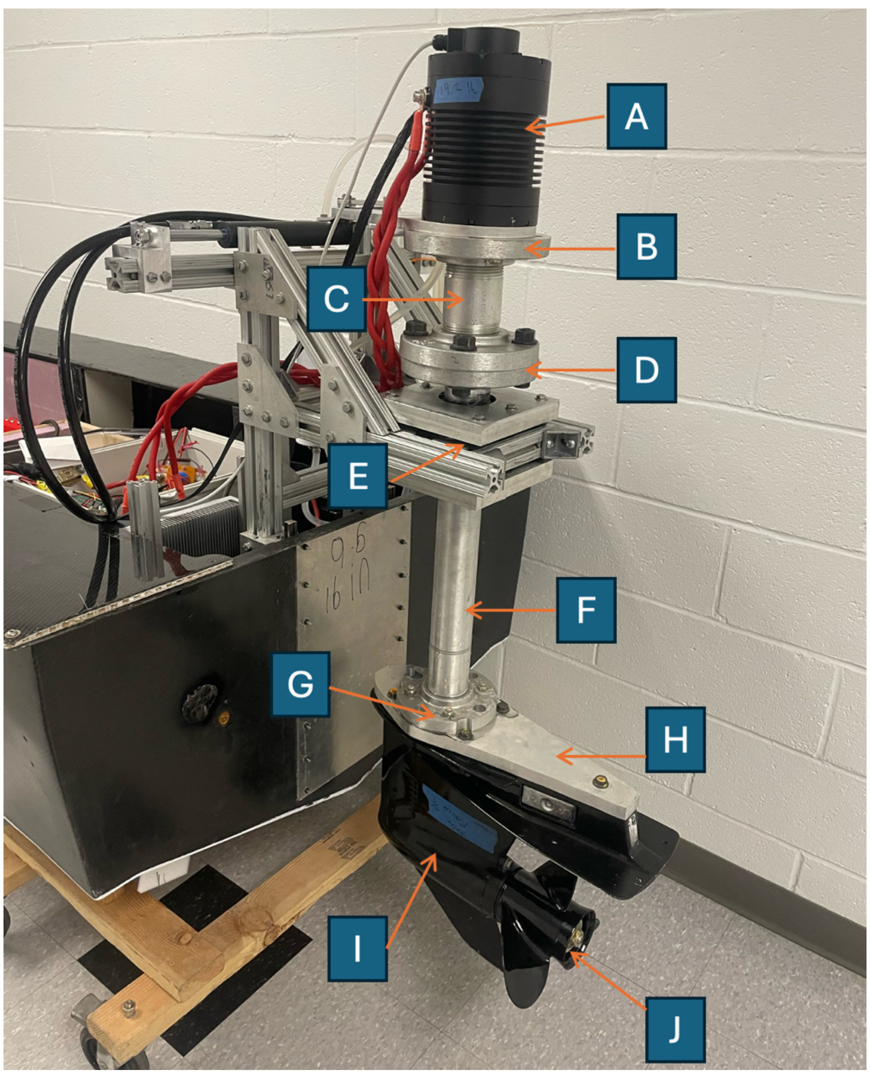


Figure 9.6.2: Labeled Final Assembly

Label	Part
A	P40 Motor
B	2.5” flange to tiller plate for steering connection
C	2.5” OD tube for coupler housing
D	2.5” to 2” ID flange conversion for lower tube
E	Roller taper bearing housing to secure propulsion system
F	2” OD tube with internal bearings to secure lower unit shaft
G	2” NPT flange to attach tube to lower unit
H	Lower unit mounting plate
I	Commercial Mercury lower unit
J	Mercury Black Max propeller

Table 9.7.1: Labels for Figure 9.6.2

The propulsion system assembly process was slightly difficult due to certain constraints that had to be met for our system to function with the steering team system. A main issue that we faced was in the initial assembly of the coupler. The original coupler was made with an incorrect CAD file resulting in a part that was off by a few thousandths of an inch. This was a very small but detrimental error. We initially tried to heat the coupler and hammer it on to the shaft, but this did not work after hours of doing so. Eventually we decided that we would have to request a new part to be made with the proper stock size. The new coupler functioned perfectly upon completion. Another issue was during the final assembly with the steering team. During this process we had to insert our 2” tube into the two roller taper bearings that were press fit into their system. Unfortunately, due to the tube not being the original designed tube, the two parts did not fit. We tried to push the parts together but even with the whole team it did not work. Upon measuring it we noticed that the parts were not too far off and that sanding the tube would be the best solution. This worked and we were able to assemble the two subsystems together with no further issues.

Overall, the boat does a great job of demonstration functionality as per the PDS requirements. The only parts that do not fully follow are the saltwater corrosion resistance, which is an issue that will be fixed as soon as the new hardware arrives. The assembly/maintenance PDS requirement is also in a grey area where the initial assembly was slightly difficult but is now not as difficult to do so due to experience. Certain components like the bearings to keep the lower unit shaft in line with the coupler are hard to access, but maintenance is not required or frequent for those components.

In the future the few improvements that we would make would concern the prop as well as certain hardware components. The hardware that we used to mount the lower unit plate to the lower unit had some corrosion that occurred during the saltwater testing. This was expected as we were not able to purchase bolts that were corrosion resistant in time, and plans have been made to replace those. The more important issue is the prop. The propeller we currently have has a 17” pitch, but we needed a 47” pitch. Due to time constraints as well as cost constraints we were not able to purchase a custom prop for our application. Talking to the team, they do have plans to eventually purchase a custom-made prop which will solve this issue. The prop is a significant limiting factor in how fast the boat can travel and is currently on of the main issues. Finally, the lower unit has a gear ratio that is significantly reducing the RPM of the prop from the motor. This is an issue as it does not allow us to use the full power due to the high torque. Finding a lower unit or gearbox that does not have this reducing gear ratio would be of great help.

○ 9.7 Final Test Data

The first time the boat hit the water was in Virginia Beach at the PEP competition. The top recorded speed of the boat at the PEP competition was verified by NAVY and Austin Giordano at a speed of 22 MPH. This was done while the InMotion motor controller had two speeds, on and off, and was verified by a speed gun that the NAVY used to test the boats. Most of our products withstood the harsh salt environment well, except for the non-zinc coated hardware we were forced to use due to supply issues at the hardware store. These hardware pieces had minimal, non-integrity compromising surface corrosion.

After the competition we were able to take one more day for testing at Lake Ronkonkoma. The new tune on the motor controller was significantly more modulated than the preliminary testing day, however this time the motor controller seemed to cut out before we reached full rpms. The onboard GPS also seemed to have been having electrical issues, so data acquisition from this avenue was not an option. Halfway through testing, we came up with the idea of data acquisition via an iPhone running a GPS app. Using this strategy, we were able to record the final half an hour of testing, which yielded the velocity distribution as seen in Figure 9.7.3. On this day, the speed was less than we had hoped, however we again attributed this to the faults in the motor controller.

In terms of power, the batteries were able to output a maximum value of 48.5 VDC. This slightly exceeded project limitations with a voltage requirement of 36 VDC. However, the motor was still able to run efficiently for a prolonged period. The steering requirement was satisfied as the propulsion system was able to be mounted smoothly without much interference. Although there was a slight squeak when turning, this did not affect the overall performance of the boat and can be addressed with lubrication. Additionally, our initial waterproof expectations were met. All submerged components of the propulsion system did not experience corrosion or erode after testing. Bolts used to attach the plate to the lower unit were slightly rusted but had no impact on overall performance. For the vibration requirement, the boat was able to withstand a subtle rattle within the aluminum shaft housing. The vibration did not cause any parts to loosen and had no effect on the boat's efficiency.

Figure 9.7.1: Voltmeter Reading of Battery (VDC)

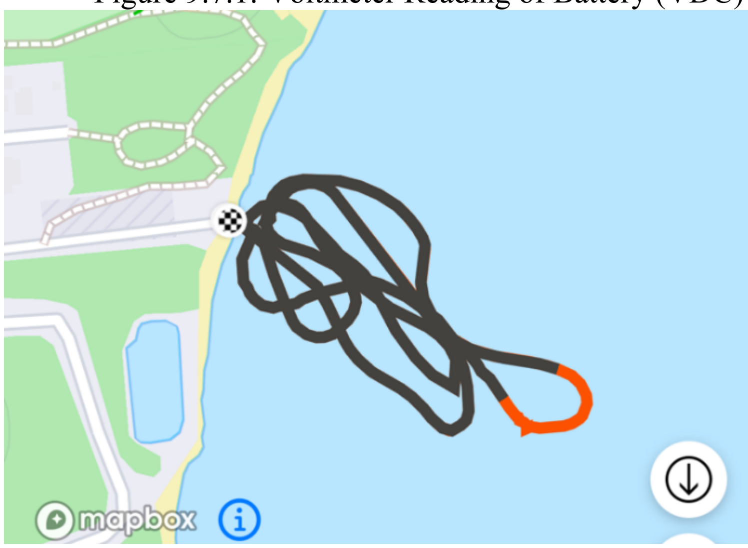


Figure 9.7.2: Boat Travel Path

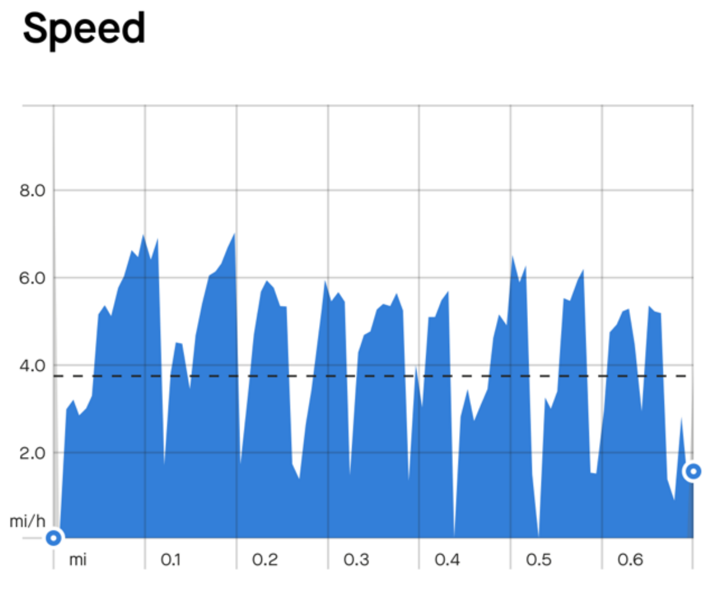


Figure 9.7.3: Velocity Distribution

9.8 Final Costed Bill of Material

Part	Vendor	Price per part	Quantity	Total Cost ($)	Link
Lower Unit	Mercury	0	1	0	N/A one member provided a lower unit
Propeller	Boat Propeller Warehouse	173.99	1	173.99	https://www.boatpropellerwarehouse.com/catalogs/p/all/mercury_propellers-black_max-17_pitch-right_hand_rotation/28717/black-max-10-x-17-mercury-rh-propeller-48-73144a45
Steel Round Bar (Coupling)	Online Metals	50	1	50	
Aluminum Plate	Online Metals	193.42	1	193.42	
Motor	DHX	N/A	1	Covered by Solar Racing Team	https://www.dhxelectricmachines.com/motors
6138k72 bearing	McMaster-Carr	39.70	2	79.40	https://www.mcmaster.com/catalog/129/1388/6138K72
8828T321 thrust bearing	McMaster-Carr	156.18	1	156.18	https://www.mcmaster.com/catalog/129/1395/8828T321
5038K58 Housing	McMaster-Carr	129.80	1	129.80	https://www.mcmaster.com/catalog/129/70/5038K58

44705K233 Flange	McMaster-Carr	48.97	1	48.97	https://www.mcmaster.com/catalog/129/66/44705K233
91580A237 Snap Rings	McMaster-Carr	5.40	4	21.60	https://www.mcmaster.com/catalog/129/3702/91580A237
93190A387 Bolts for flange to P40	ACE Hardware	4.77	4	19.08	https://www.mcmaster.com/catalog/129/3536/93190A387
90715A170 Nuts for flange to P40	ACE Hardware	1.076	4	10.76	https://www.mcmaster.com/catalog/129/3594/90715A170 (Pack of 10 only)
93625A350 Nuts for lower unit plate	ACE Hardware	0.62	10	24.50	https://www.mcmaster.com/catalog/129/3595/93625A350
91287A376 Bolts for lower unit plate	ACE Hardware	1.978	10	19.78	https://www.mcmaster.com/catalog/129/3541/91287A376
Total	-	-	-	$690.06	-

Table 9.8.1: Final Bill of Materials

- ### 9.9 Project Timetable

Deliverable	Deadline
Project Proposal	9/12/2023
Determine type of propulsion (Inboard or Outboard)	9/19/2023
Progress Report 1	9/29/2023
Coordinate preliminary designs with steering team	10/09/2023
Complete the product design specification (PDS)	10/19/2023
Finalize general requirements for steering and propulsion joint functionality	10/25/2023
Progress Report 2	11/03/2023
Determine the motor to be used for the propulsion	11/10/2023
Finalize a design along with constraints	11/18/2023
Complete the final CAD file for the propulsion system	12/15/2023
Progress Report 3	12/23/2023
Have a completed list of items to buy, and order all	02/11/2024
Determine any items to be manufactured and have them done by this date	02/12/2024
Finish prototype and prepare for conjoining with steering	03/02/2024
Progress Report 4	03/08/2024
System mounted on boat for initial testing	03/25/2024
Initial testing of prototype	04/10/2024
Attend PEP Preparatory Event	04/14/2024
Fix any issues and finish testing	04/28/2024
Progress report 5	05/10/2024
Attend Solar Splash Racing Event	06/04/2024

Table 9.9.1: Final Project Timetable

- ### 9.10 Infomercial

https://www.youtube.com/watch?v=Iy5ZV1E94Bk

- ## 9.11 Ethical Dilemmas

Soroush: Canon 4 of the ASME Engineering Code of Ethics states:

Engineers shall act in professional matters for each employer or client as faithful agents or trustees and shall avoid conflicts of interest or the appearance of conflicts of interest.

A main issue that has been faced in this project is regarding the InMotion motor controller. The product arrived later than expected, within a few days of our PEP competition and was bricked on the way. Upon arrival and setup, the team realized that the controller would not function with our motor.

The manufacturer had forgotten a key tool to relay information from the computer to the controller as well as not providing us with the diagnostic software. This created an issue as we knew that there were issues but could not properly diagnose them.

These issues made their way to Virginia Beach where the team worked all night and the day before competition to not qualify for the event. This caused some issues and animosity towards the supplier as they had ruined our chance of being able to compete in the competition. As a sponsor we were supposed to display their company logo however some members did not want to do so and wanted to remove their logo from the boat.

However, after a long day of working with InMotion over a phone call to diagnose the issue, we were finally able to get the boat to run and made a test pass, at reduced power, to a top speed verified by the NAVY of 22mph. The dedication of us and the team, as well as the company, to fix this issue allowed us to fix the boat and allowed us to see the results of our hard work.

Alexander: Canon 5 of the ASME Engineering Code of Ethics states:

"Engineers shall build their professional reputation on the merit of their services and shall not compete unfairly with others."

In preparation for the 2024 Solar Splash event, our team studied results from previous years and noted that the University of Michigan was a clear favorite. Their boats were complex and had very high-power outputs yet managed to adhere to horsepower limitations. I thought it would be very difficult to compete with such a highly developed team without having prior experience with outboard motors. During the initial stages of our project, I thought it was a good idea to purchase a motor with an 80 HP rating along with a battery that can support it. We believed that exceeding the limit by a few horsepower wouldn't be an issue and would give our team the edge in a competition.

After discussing with the Solar Racing team president, we quickly realized not only would we have to purchase new parts such as a new battery and propeller to support higher torque, but it simply would not be fair to competitors and ultimately would hurt our reputation as engineers. It is essential that we adhere to regulations for our own advancement towards becoming professional engineers.

The following week, my team and I met to discuss certain revisions regarding the motor. The club president has finalized the purchase of a P40 motor, and we designed our system based on the motor's power output. We developed a strong, lightweight propulsion system that supports our motor and performed up to our expectations.

Kai: Canon 1 of the ASME Engineering Code of Ethics states:

"Engineers shall hold paramount the safety, health and welfare of the public in the performance of their professional duties."

When designing an electric boat with 48VDC, human life, and a big body of water involved safety is paramount. All electrical connections must adhere to Electric Code Requirements to ensure the safety of the driver, team, and public. A kill switch and fire extinguisher must be quickly accessible for the driver in case of an emergency.

The integrity of the propulsion system is another important aspect of team safety. We are dealing with a motor spinning at 2500 rpm which turns a propeller at approximately half that speed with twice the amount of torque. We were careful to make all the necessary stress calculations to verify the components could handle such power. When doing land tests, we sectioned off a large area around the propeller, if someone were to fall on the propeller even moving at half power it could be deadly. Safety is a number one priority at Stony Brook Solar Racing.

Cole: Canon 6 of the ASME Engineering Code of Ethics states:

"Engineers shall act in such a manner as to uphold and enhance the honor, integrity and dignity of the profession."

While trailering the boat to Virginia Beach, we spent a lot of time in the public view. With an elaborate looking boat in tow, people were understandably curious. Driving to the competition, I must've talked to minimum 10 strangers who stopped to look and ask questions. I can say that fielding the question "does it have tesla batteries" multiple times in the same day gets tiresome. Despite this, I took it as my responsibility to uphold the Stony Brook image, and the values of engineers, enthusiastically explaining the workings of our propulsion system and how, yes, it probably would make for a good bass fishing or duck hunting rig.

Another moment which tested the honor and dignity of engineering profession happened during the PEP event. There was on the order of a hundred people, students, faculty and Navy employees in the parking lot for the boat ramp, all hanging out. A group of students from another team had brought a case of an adult beverage, sharing it with some of the members of the team. While many of us are of age, our team decided against partaking with the other group, as be inebriated while wearing school logos and doing important work is not a good light to display Stony Brook or engineers in general. As a group, we decided to represent Stony Brook and the engineering field with honor and professionalism.

o 9.12 Teamwork Evaluation

Kai: While it can be difficult to work with a team for such a long period of time, I can confidently say our team began as friends and came out better friends, that includes not just propulsion but also steering and the entire Solar racing team. We each have our busy periods when it comes to work, athletics, or family but I believe the workload was balanced nicely on the propulsion team. One incident that comes to mind when our team was squabbling and dysfunctional was at the very beginning stages of design when selecting a bevel gear system to transition power from the vertical motor shaft to a horizontal propeller shaft. Some members of the team wanted to purchase a bevel box and waterproof it while others wanted to go the commercial lower unit route. Personally, I was pushing for the commercial lower unit citing it was the most cost effective and efficient route. In the end that is the direction we went, and I hope my boating experience helped in that decision. I've worked on many outboard motors and knew how difficult it would be to manufacture a waterproof, hydrodynamic, bevel gear box. Austin Giordano was a huge help to the propulsion team and helped steer us through many tough decisions.

Soroush: Throughout this project the team maintained proper communication through the form of group chats with individual group, as well as other members of the Solar Racing Team such as the Steering senior design team. Weekly meetings were attended by all, and if one had a conflict they would always mention in the chat. Issues were discussed and resolutions were made only when all members agreed fully. An issue faced was in the design of the coupler where the wrong stock material as well as incorrect cad was sent to be machined resulting in a coupler that did not fit on the splines of the lower unit shaft. This problem was initially attempted to be resolved by trying to force the coupler to fit on the shaft. However, after hours of hammering, we concluded that this process would be impossible. Some members wanted to redo the coupler while others wanted to just run with the coupler as it was (this is because the coupler, while not having full contact with the splines, was very difficult to remove, meaning that it most likely would not have fallen of during the competitions). However, this problem was addressed by Austin, and we had a new coupler manufactured that properly fit on the splines. The team throughout the project displayed great team effort and all members put in the effort in different parts of this project to allow for its completion.

Alexander: Over the course of two semesters, it is appropriate to say that both the propulsion and steering teams worked efficiently and were able to settle disagreements maturely. Since it was necessary that the designs of both teams co-align, there were a few dimensional discrepancies regarding the placement of the lower unit and the motor. To address these concerns, we scheduled night meetings at the library to exchange new dimensions and ensure that both were acceptable. A specific example of my individual contribution to resolving these debates took place as the steering team noticed that their aluminum frame would interfere with the metal rails protruding from the boat's rear. I suggested that their system be raised ½ inch higher and reversing the orientation of the support rails. Once they confirmed, the propulsion system was able to mount within the steering system with no interference from the metal rails. Overall, the propulsion team operated very smoothly and held Zoom meetings to discuss wherever a miscalculation was discovered. Each member contributed greatly and showed effort throughout the entire project.

Cole: The past year with this group has been a keystone of my college career, and I am incredibly appreciative that I got to do it with the team I did. At no point was there communication lost between any of the team members, and when issues arose, they were resolved promptly. On several occasions when I felt that other members weren't pulling their weight, I found best results with asking what's going on, rather than jump straight to accusing. Sometimes there could be personal issues behind the scenes, or maybe something as simple as they don't know where to start. It's always better to address the issue rather than dwell on the problem, letting animosity rise, in turn watching the grades fall. At the end of the day, I go to college to learn. The great group of people around me supported me in that mission, and this project has helped me and my team develop into more qualified engineers.

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Appendix A