The College of New Jersey

SOLAR SPLASH TECHNICAL REPORT

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Boat #8

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TCNJ THE COLLEGE OF NEW JERSEY

Executive Summary

The TCNJ Solar Electric Boat team designed and fabricated a solar powered racing watercraft to compete in the 2023 Solar Splash World Championship of Collegiate Solar Boating. This year's boat underwent a complete drivetrain, steering, and electrical system redesign to outfit a novel hull profile from the preceding iteration. The electrical system and drivetrain support an outboard dual-motor setup capable of swapping between sprint and endurance configurations without disassembly of the powerhead. The sprint configuration utilizes both motors and an aggressive surface-piercing propeller on a short driveshaft with a motor controller bypass switch for maximum speed and acceleration on pure battery power. The endurance configuration powers only one motor, transmitting power to a deepwater propeller with efficient electrical controls to travel a maximum distance on solar and battery power. A cable steering system with a custom paddle throttle was designed on an adjustable steering column for two riding positions to optimize the center of gravity across both events. All systems were integrated, and initial testing on TCNJ's Lake Sylva yielded promising results.

This year's hull began construction in 2021 with a decision to deviate from previous hull designs and create a custom foam hull. The long and slender design made from fiberglass-reinforced foam aims to reduce weight and increase speed. Changes were continuously made to integrate the other mechanical sub assemblies within the hull. The hull geometry and careful placement of items within the boat intends to achieve a planing hull during the sprint and slalom events and a displacement hull during the Endurance event. Initial testing has been conducted to evaluate the performance of the hull in preparation for competition in 2023.

The main goals of the 2022-2023 team's solar, electrical, and power electronics system was to validate the 2022 teams' solar system design, design a safe, simple, efficient and effective circuit, and utilize the 100 pounds of batteries allotted to each team to power the motors and accompanying motor controllers. The teams' solar system was able to achieve the maximum power output of 480 Watts under "one sun" condition and utilize the output to both charge the batteries and power the electrical systems. The proper rating of all elements found within the circuit was of utmost importance to ensure the safe operation of the boat.

The team also focused on designing a simple and clearly defined electrical system. This was completed by creating a readable electrical schematic with an accompanying design description. Each element of the system is explained in a clear and concise fashion to ensure that the design process could be repeated with ease.

Data acquisition took advantage of sensors that had been purchased previously and used at competition in 2021. Among these key instruments, an Intersense Inertiacube 4 inertial measurement unit (IMU) provided critical feedback regarding the pitch of the hull and outboard motor system. This feedback allowed for design optimization during testing and troubleshooting to develop solutions between design changes and improve results. Feedback was also expanded through the use of a Garmin Montana 600 GPS which provided critical speed information that was related to the recorded RPM of the boat using an onboard tachometer.

After two years, the new lightweight hull design accompanied by a full mechanical assembly redesign has yet to be showcased at the Solar Splash competition. After months of design, manufacturing, and testing the team sets out to compete at Champions Lake in 2023. With a revamped dual motor drivetrain, robust steering system, and effective electrical circuit, the team's hard work along with knowledgeable guidance will drive the team to a successful competition experience.

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I. Overall Project Objectives

A. *Solar System*

The 2022 solar system design was validated and successfully implemented into the electrical system. A maximum power output of 480 Watts under "one sun" condition was achieved and the output was utilized to charge batteries and power the motors directly.

B. *Electrical System*

The electrical system was built to be a safe, simple, efficient, and effective circuit.

C. *Power Electronics System*

The power electronics utilize 100 pounds of batteries to power the motors and motor controllers.

D. *Hull Design*

The hull design utilizes the existing hull, partially constructed in 2021-2022 but never fully tested. Interior accommodations were made for the 2023 subsystems. Final modifications achieved a displacement hull for the endurance event and a planing hull for the sprint and Slalom events.

E. *Drivetrain*

The drivetrain was designed to switch between events with minimal disassembly. A dual motor configuration was utilized for the sprint event with a belt-driven output shaft. Shift collars were used to couple active motors with appropriate gearing ratios and achieve the desired output RPM for each event.

F. *Steering*

The steering subsystem was designed to be adjustable and ergonomic with integrated throttle. Steering remains lightweight for improved performance and minimal weight impact. The steering mechanism was designed to reliably achieve 30 deg of propeller rotation in either direction.

G. *Data Acquisition and Communications*

The goals for onboard data acquisition and communications systems revolved around a minimalist approach to save weight on these non-critical systems. Rather than including a computer capable of transmitting telemetry data to the shore, the team aimed to develop a sufficient dashboard display and control system with a supporting lightweight and ergonomic verbal communications system to transmit messages to the team on shore.

II. Solar System

A. Current Design

The Solar Panels utilized were donated to the 2011-2012 Solar Splash Competition team. The team received two SunPower E19/240 AC Solar Panels, pictured in Fig. 2.1 and the data sheet can be found in Appendix F. The panels are capable of outputting both AC and DC power; however, for this application, only DC power is utilized. The panels remain in great physical condition and continue to comply with all Solar Splash competition rules and regulations, see competition rules section 8.4.

Fig 2.1- SunPower E19/240 AC Solar Panels

Two Smart Solar MPPT 75|15 IP43 will be reused from TCNJ Solar Splash inventory. These components are fully functional and have been validated through their use in competition, with the same solar panels, by the 2020-2021 TCNJ Solar Splash Competition team. The MPPT can be seen in Fig. 2.2 and the data sheet can be found in Appendix G.

B. Analysis of Design Concepts

The solar panels are used to directly propel the boat by either connecting them directly to the motor or connecting them in parallel with batteries, where the electricity from the solar panels will both charge the batteries and power the motor (Endurance event). The solar panels can also be used indirectly by charging the batteries on shore and using the stored energy of the batteries in an event (Sprint and Slalom events) [2].

Fig. 2.2- Smart Solar MPPT 75|15 IP43

Maximum power point trackers (MPPTs) are used to extract the maximum available power from a high DC solar panel voltage. The extracted energy is optimized for charging a battery bank Another feature of the MPPTs is decreasing the dependence of the system on sun condition. This feat is met by the components ability to monitor the voltage and current output of the solar panel allowing it to most efficiently harvest the energy [3].

C. Testing and Evaluation

The solar system was tested by attaching the solar panels, in parallel, to each of the motors to validate the functionality of the panels. The system was also used to charge one of the 12 Volt batteries to validate its on-shore and off-shore charging capabilities.

III. Electrical System

A. Current Design

The following design description is based on the sprint, endurance and complete electrical system design seen in Appendix E:

1) *Electrical Schematic Notation Explanation*
    a) *NO and NC*: The relays, manual switches and micro switch found within the schematic use the notation NC, normally closed, to refer to the gate that is powered if there is no external input given to the system i.e., flipping a switch or having current running through a relay. The use of NO, normally open, means the opposite of NC, normally closed.
2) *Configurations*
    a) *Endurance Normal:* The Endurance Normal configuration (see Endurance Set-Up) of the electrical system utilizes two different voltage sources to power a motor controller and motor. The current from the first voltage source, solar panels, first travels to the maximum power point trackers (MPPT). The current then runs in parallel with the batteries. The combined voltage sources are used to power the dual function motor controller (Sprint/Endurance MC) and the accompanying motor (Sprint/Endurance Motor).
    b) *Endurance Live:* The Endurance Live configuration of the electrical system is activated by the Endurance By-pass. This configuration utilizes the solar panels as the single voltage source to power a motor. The current from the voltage source (solar panels) is used to directly power the dual function motor (Sprint/Endurance Motor) in the endurance by-pass configuration.
    c) *Sprint Normal:* The Sprint Normal configuration (see Sprint Set-Up) of the electrical system utilizes a single voltage source to power a matched pair of motor controllers and motors. The current from the voltage source (batteries) is used to power both motor controllers (Sprint/Endurance MC and Sprint MC) and the accompanying motors (Sprint/Endurance Motor and Sprint Motor).
    d) *Sprint Live:* The Sprint Live configuration of the electrical system is activated by the (Sprint By- pass). This configuration utilizes a single voltage source to power a set of motors. The current from the voltage source (batteries) is used to directly power both motors (Sprint/Endurance Motor and Sprint Motor) bypassing the motor controllers.
3) *Configuration Activation*
    a) *Endurance Set-up:* Endurance Set-Up is a manual process of arranging wires within the electrical circuit. The process involves ensuring the full connections of the solar panels and MPPTs with the main system. The arrangement does not utilize the sprint motor and motor controller (Sprint MC and Sprint Motor) so all of their electrical connections are removed. The next step of the process is ensuring that the dual function motor controller (Sprint/Endurance MC) is electrically connected to a 5K ohm potentiometer located on the dashboard.
    b) *Endurance By-pass:* The Endurance By-pass activation method is controlled by the manual switch on the dashboard of the boat labeled “Endurance By-pass”. The activation of this switch changes the configuration of the boat from Endurance Normal to Endurance Live. When this switch is closed from its normally open position, current is allowed to flow through the accompanying relay circuit. The flow of current through this subsystem causes the batteries and MPPTs to be broken from the circuit on their negative terminal side. The relay circuit also switches the flow of current from the solar panel to feed directly to the dual

function motor (Sprint/Endurance Motor), skipping the MPPTs and the motor controllers.

c) *Sprint Set-up:* Sprint Set-Up is a manual process of arranging wires within the electrical circuit. The process involves removing the solar panels and MPPTs from the main system. The arrangement also calls for both motors to be fully operational so all electrical connections with both motors should be completed. The next step of the process is ensuring that the dual function motor controller (Sprint/Endurance MC) is electrically connected to the 25K ohm 2 ganged potentiometer (only used for its 0-5K Ohm range). The Endurance By-Pass Switch's connection to the system is also removed on both terminals. The final step in the process is confirming that the batteries are connected directly to ground.

d) *Sprint By-pass:* The Sprint By-pass activation method is controlled by a manual switch on the dashboard of the boat labeled "Sprint By-Pass" which is also in series with a lever arm micro switch mechanically connected to the throttle, meaning the mechanical connection cannot be seen on the electrical schematic. The activation of the manual switch allows the lever arm micro switch to act as the single break in this subsystem. The throttle in its fully pressed position compresses a spring loaded lever of the micro switch; therefore redirecting current from its break position (NC) to complete the accompanying relay circuit (NO) used to propagate change throughout the main system. The relay circuit removes both motor controllers (Sprint/Endurance MC and Sprint MC) by switching the current to flow directly from the negative terminal of the motor to ground.

e) *On/Off:* The On/Off is controlled by the manual switch on the dashboard of the boat labeled "On/Off". The activation of this switch allows current to flow through the entire system. When this switch is closed from its normally open position, current is allowed to flow through the accompanying relay circuit. The flow of current through this subsystem causes the completion of the circuit therefore allowing current to flow through the entire system.

f) *Dead Man Switch:* The Dead Man Switch (DMS) is controlled by the manual switch on the dashboard of the boat labeled "DMS". The deactivation of this switch prevents current from flowing through the entire system. When this switch is opened from its normally closed position, current is unable to flow through the accompanying relay circuit. Without flow through the relay circuit, the entire system is shut down.

B. Analysis of Design Concepts

The first major decision in the design of the electrical system was the number of different circuits. The system could contain either two specialized circuits, one for each event type (Sprint/Slalom and Endurance), or one circuit with the ability to be manipulated into different configurations based on the event type. One closed circuit was chosen for the design based on the constraints of the motor selection. Based on this constraint, regardless of the number of closed circuits there would need to be electrical adjustments between events; this is because the motors, motor controllers and batteries would need to be eclectically connected and disconnected from different systems. Another factor in the decision was that carrying another circuit board would only further increase the complexity of the design and would increase the weight of the system.

The next set of decisions required was balancing the use of relays and manual alteration of the single closed circuit. By-pass systems would need to be designed for both the sprint and endurance events which would require the design of a relay system because offshore changes to the system are required. The balancing of the two alteration methods comes with the onshore changes to the system. The use of a relay system for changes to the circuit between events (i.e., conversion of circuit form sprint configuration to endurance or vice versa) increases the electrical complexity of the system; however, it simplifies the manual preparation process of the team. The use of a checklist to alter the circuit onshore has the opposite benefits and drawbacks as the relay system. The use of a manual checklist was chosen to be the best method to make these changes.

The decision mentioned above was based on a cost-benefit and risk analysis of the two methods. The use of solenoids in a high current circuit (~500 Amps) leads to a cost increase of over $500 which would cause over a 100% budget increase. There are also many risks inherent to the use of an electrical relay; with the first concern being that there is more room for human error to lead to hazardous situations. The relay system is connected to a manual switch on the dashboard of the boat which means that the operator may mistakenly alter the configuration of the boat during an event which could lead to electrical shorts, and/or current overload on electrical components. Another risk factor electrical relays can bring results from the increased complexity they bring to a system. The introduction of more electrical components naturally leads to more opportunities for the system to fail, i.e., increased number of failure modes: improper rating of components, overheating of the electrical circuit due to increased heat dissipation and component defects. There is also a performance increase to the system, because decreasing the number of electrical components in the system decreases the system losses. Based on the aforementioned reasons, the decision was made to use a manual alteration checklist to change the circuit configuration (Sprint and Endurance).

The design decisions and constraints were used to narrow the scope of the design and allow for a strong design foundation. The majority of the electrical parts of the design are fixed in nature; the real difficulty inherent to the project comes from finding compatible parts through careful analyses of specifications sheets. The first step in implementing the design was conducting thorough research into how each of the electrical components operates. After understanding the function of these parts, their electrical connections can be determined by inspection or using typical set-ups found in many of the referenced data sheets. The by-pass systems and manual alterations of the circuit was the final step of the process. These systems were added with the purpose of optimizing the design; for example, consider the sprint by-pass system, the motor controllers are cut from the system at max motor speed so that the system can become ~7% more efficient (power consumption of the motor controller is ~7%). The by-pass systems were designed in a logical manner, meaning that the component(s) that needed to be bypassed were connected to a relay system. The next step was determining which branch of the circuit should be opened/closed based on the goal of the circuit configuration. The process of adding and removing electrical connections would then need to be controlled by the skipper so a manual switch was attached to the relay circuit so that manual input could be used to make real-time electrical changes. The previously mentioned design strategies were used to create numerous design iterations, using Lucidchart, leading to the current design iteration.

C. Testing and Evaluation

The electrical system was tested using a multimeter to measure continuity for all electrical connections. The actuators were also tested for functionality by ensuring that the proper branches of the circuit were not powered by the battery when the actuators were activated, again, using a multimeter.

IV. Power Electronics System

A. Current Design

Twelve 12 Volt lead acid Odyssey PC625 18Ah batteries will be reused from previous TCNJ Solar Splash Competition teams, supplemented by at least four replacements for failing batteries The batteries were tested and confirmed to remain fully operational. The batteries will be contained, with equal distribution, within two large battery boxes. The batteries also continue to comply with all Solar Splash competition rules and regulations, see competition rules sections 7.4.1 and 7.10.2. The battery can be seen in Fig. 4.1 and the data sheet can be found in Appendix A.

Fig. 4.1- 12V lead acid Odyssey PC625 18Ah batteries

One supplemental 12 Volt lead acid Powersonic PS-1270F1 7Ah will be reused from previous TCNJ Solar Splash Competition teams, supplemented by one replacement in case of failure. The batteries were tested and confirmed to remain fully operational. The battery will be contained within a Pelican Box. The supplemental battery is used to power both the bilge pump and tachometer. The battery complies with all Solar Splash competition rules and regulations, see competition rules sections 7.4.3 and 7.14.7. The data sheet can be found in Appendix A.

Two Curtis PMC 1221B-5702 motor controllers will be reused from previous TCNJ Solar Splash Competition teams. These components are still fully functional and have been validated through their use in competition, with the same motors, by the 2020-2021 TCNJ Solar Splash Competition team. The motor controller can be seen in Fig. 4.2 and the data sheet can be found in Appendix H.

Fig. 4.2- Curtis PMC 1221B-5702 motor controller

B. Analysis of Design Concepts

Batteries are used as a rechargeable source of electrical energy and are used for a wide variety of industrial, automotive, and home applications. A battery bank is an assembly of individual batteries with the purpose of storing electrochemical energy (this section assumes all batteries in the bank are identical). Batteries can be assembled in parallel, series, or both based on their application. Parallel configuration leads to the voltage difference across the battery bank to be equal to a single battery's electromotive force (EMF) and the amp hour capacity of the bank is double the value of an individual battery. Series configuration leads to the voltage difference across the bank to be double a single battery's EMF but the capacity remains constant [4].

Motor controllers are used for a variety of reasons including: preventing cold cranking, operator safety, and boat speed regulation. Motor controllers are used to control the output speed and torque of a motor by controlling the power directed to the terminals of the motor through pulse width modulation (PWM). PWM is a method of controlling the average power delivered by an electrical signal. The signal between the supply (voltage source) and load (motor) is rapidly switched on and off creating an average based on the frequency of each switch. The frequency of each signal is determined through the use of a potentiometer placed between the throttle pins of a motor controller, pins two and three. The motor controller reads the voltage drop/current i.e., resistance between the two pins (largest resistance for full motor output) and alters the average strength of the PWM signal accordingly.

C. *Testing and Evaluation*

The power electronics system was tested through a series of land and water tests. The sprint and endurance systems were tested for speed control on land for both types of speed control (throttle and potentiometer mounted on the dashboard). The sprint circuit's functionality was validated on land by first powering the circuit and using the battery monitor to measure a max current output of 448 Amps across the rotating motors at 36 Volts. The endurance circuit's functionality was validated as the motor was receiving power and was rotating the propeller at the desired 550 RPM.

V. Hull Design

A. *Current Design*

A well designed and constructed hull is critical for the success and functionality of the entire solar boat. All the components of each subsystem must fit accordingly within the dimensional parameters of the hull and its respective buoyancy properties. Previous Solar Boat teams at TCNJ have used a diverse assortment of hull designs since 1999 when the school first participated in this competition. Most recently a Bateau Fast Skiff 14' Low Sheer Hull was used and the advantages of that design were incorporated into the current hull design which features a long and narrow hull designed to reduce drag and generate better overall performance.

B. *Analysis of Design Concepts*

This year's hull was originally created by the 2021-2022 TCNJ Solar Boat team. The team was challenged with designing and manufacturing a new hull from scratch in order to reduce weight and develop a competitive hull shape. The 2022 team created a slim hull in order to effectively reduce the size and weight while modeling a similar style to the three winning boat teams at the 2021 competition. Keeping in mind the dimensions needed to fall within the design constraints of the competition, the team designed the boat to be just under fifteen feet long and three feet wide. Full scale two dimensional drawings were drafted to create the current hull using two inch thick extruded polystyrene foam. The final hull shape was generated using five main bulkheads that served as structural supports and a mold for the foam to be curved around. Once built, the model was fiber-glassed and epoxied over to solidify the shape and strengthen the hull.

More specifically, the long and slender shape is accomplished through five independent sections of the boat. These sections were the first to be laid out during assembly and were the framework for constructing the entire hull. Fig. 5.1 shows the construction of adding foam around the framework of the bulkheads from last year.

With the exception of the plywood transom plate, these foam stations were all shaped as trapezoids and were titled A through D spanning from the bow to stern. The first station A was the shortest and most narrow of the four which increased in beam and depth as the distance from

Fig. 5.1- 2022 hull construction

the bow increased until reaching the last third of the boat where the width narrowed again. Each section is different in length and width and influences the available space for placing objects throughout the boat. A detailed SolidWorks model of the hull was created and provides the dimensions of each section as seen in Fig. 5.1. The hull construction must also ensure that the boat has a minimum flotation safety factor of 20% to assure that the boat will not sink in the event the craft becomes completely submerged. Appendix B elaborates further on the flotation of the boat and provides calculations to verify the necessary flotation requirement.

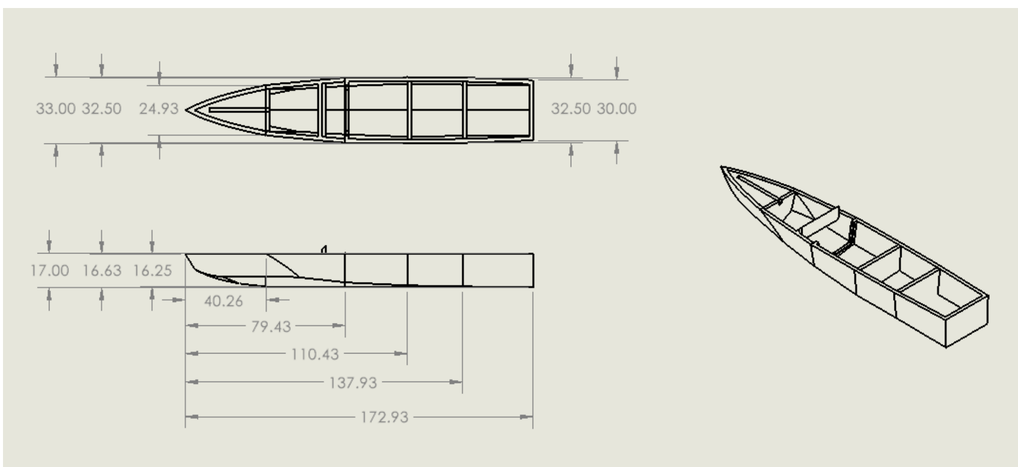


Fig. 5.2- Hull dimensions

1) *Hull Modifications:* Although the majority of the hull construction had been completed, there were still improvements that needed to be made. Improvements began with perfecting the surface finish of the boat through sanding and fiberglassing which then led to the integration of the mechanical sub assemblies. A new dashboard was created, foam was removed to create additional space for the steering and electrical systems, and mounting locations for the steering cables and solar panels straps were added.
2) *Weight Management:* The efficiency and performance of the boat is heavily dependent on the weight distribution throughout each event of the competition. There are two hull orientations that achieve the objectives of each event with a goal of obtaining a displacement hull for endurance event and a planing hull for the sprint and slalom events. To accomplish these two configurations the center of mass must be shifted around the center of flotation which is an inherent property of the hull. Both critical points are measured from the bow, and the center of mass can be altered by moving the location of

components within the boat. A displacement hull is attained by shifting the center of mass in line or slightly ahead of the center of flotation in the direction of the bow. On the contrary, a planing hull is obtained when the center of mass is favoring the stern and located behind the center of flotation. Appendix K shows the two configurations for the sprint and endurance events that achieve a planing and displacement hull, respectively.

a) *Center of Flotation:* Prior to considering weight configurations that account for the weight influence of all components onboard, the center of flotation needed to be determined. As mentioned earlier, the center of flotation is a geometric property of the hull that is a function of the beam of the hull at various distances the distance from the bow. The method of solving for this critical point is an approximation method that employs Simpson's Rule. First the boat must be divided into twelve sections of equal length. From there each section length was multiplied by the according Simpson's multiplier, and beam. The total product of all three was divided by the total of the beam and Simpson's multiplier product to yield the center of flotation. Appendix I shows this process resulting in a final value of 96.8 inches from the bow.
b) *Center of Gravity:* A full inventory of items to be included within the boat was compiled and weight tables were created for both events. With the weights of all the stored components known, the location of each item was quantified to determine the moment that each part generated. By summing the product of the weight of each object and its distance from the bow, the overall moment generated on the boat relative to the bow was found. From there, the total weight of all the objects could be divided by the total moment created to find the equivalent center of mass. The results can be seen in Appendix J which yields a center of mass 114.87 inches from the bow for the sprint event and 112.91 inches from the bow for the endurance event.

C. *Testing and Evaluation*

Basic testing has been performed on the hull thus far to verify the team's expectations which include measuring the boats stability and pitch when stationary and accelerating. It was found that the boat has a waterline of 7.25 inches at the transom and 6.5 inches at half the boat's length. When a load of 10 kilograms was applied to one side of the boat while stationary, a roll angle of 9 degrees was observed. Additionally, the pitch of the boat when stationary was calculated to be 1.3 degrees. An inertial measurement unit (IMU) was also used to test the pitch of the boat at various speeds to develop graphs that show the relationship between pitch and acceleration.

VI. Drivetrain

A. *Previous Design*

The drivetrain design of the 2022 team utilized a single Motenergy ME0909 motor for both the sprint and endurance events. This motor was attached to two sets of pulleys, each one corresponding to a different drive ratio. One belt was shared between the two sets of pulleys, which would be installed on either the sprint or endurance drive ratio depending on which event was taking place, and a tensioner would be used to secure the proper ratio in place.

This design was incomplete. Namely, the characteristics of the motor in use were optimized for endurance, compromising the sprint performance with a non-ideal operating speed of the selected drive ratio. Additionally, the tensioning system used to tighten the belt to each drive ratio was never completed, contributing to the reasons the 2022 team did not compete. Regarding the design concept for the powerhouse and lower unit, the idea was to swap the assembly between events. However, the tube lengths and positional characteristics were unsuccessful, and this design was also left incomplete.

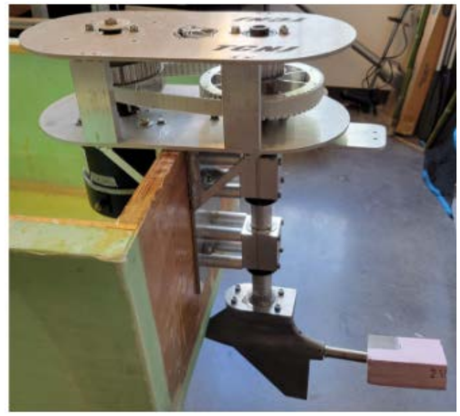


Fig. 6.1- 2022 TCNJ Solar Splash drivetrain

B. *Analysis of Design Concepts*

1) *Drivetrain Overview:* The current drivetrain uses two Lynch LEM 200-D126 motors, both of which are active for the sprint, while only one is active for the endurance. The decoupling of the second motor is performed electrically as well as mechanically.

There are six pulleys that form two drive ratios, one for each event. The drive ratio for sprint/slalom is a high-speed 15:11 ratio that has both 30-tooth input pulleys on the motors driving two conjoined 22-tooth pulleys on the output shaft. The drive ratio for endurance is a low-speed 1:3 ratio that has one 20-tooth input pulley on a single motor driving one 60-tooth pulley on the output shaft. To switch between these two drive ratios without disassembling any components in the powerhead, a unique selectable drive system was designed. This system utilizes a series of clamping shift dogs that mate with teeth on the pulleys, allowing the engaged pulleys to drive the shafts while the disengaged pulleys spin freely.


Fig. 6.2- 2023 TCNJ Solar Splash drivetrain

The only component of the drivetrain requiring any disassembly between events is the lower unit/powerhouse, which will be swapped out for either the shorter sprint tube or the longer endurance tube based on the respective event.

2) *Motors*: The boat is powered by two Lynch LEM 200-D126 axial gap DC brushed motors. On their own, each one of these motors produces 6.91 kW (9.27 hp) and 18.30 Nm (13.50 lb-ft) of torque at 3,600 RPM. When combined for the sprint competition, the two motors output a total of 13.82 kW (18.53 hp) and 36.6 Nm (26.99 lb-ft) before taking


Fig. 6.3- Two Lynch LEM 200-D126 motors

into account any external loads or inherent losses acting upon the system. Each motor has an efficiency of 81% and a rated current of 250 A. Additional specifications can be found on the data sheets in Appendix N.

3) *Powerhead*
    a) *Belts and Pulleys:* Belt and pulley selection was based on the drive ratios of previous TCNJ Solar Splash teams that were successful with the motors currently in use. For the sprint, this resulted in two 30-tooth pulleys at the input (one on each motor) driving a conjoined pair of 22-tooth pulleys at the output. For endurance, this resulted in a single 20-tooth pulley at the input driving a 60-tooth pulley at the output. A combination of new and reused pulleys were used, with all being supplied by BRECOflex. All pulleys are of AT10 pitch, and were modified as necessary to accommodate the shift dogs, bushings, and custom driveshafts.

Fig. 6.4- Belt and pulley system

    To match these pulleys, AT10 belts were also supplied by BRECOflex, specifically ones from their increased-strength Move-series. These belts are tensioned using a set of eccentric tensioners. In working with BRECOflex's engineering department, the company verified the validity of the overall system's geometry, and deemed the hypothetical stresses sufficient given the nature of the competition.

    b) *Selectable Drive System:* One of the main goals with this year's drivetrain was to minimize the need for disassembly. To accomplish this, the powerhead features a unique selectable drive system in which the sprint and endurance drive ratios can be interchanged without removing any belts and pulleys from the boat. One 30-tooth pulley stays permanently affixed to its respective input shaft, as it is only used in the sprint configuration. The other pulleys are all free-spinning until engaged with a shift dog that clamps to the driveshaft.

Fig 6.5- Double-sided shift dog on output shaft, engaged with sprint drive ratio

    On the input shaft without the fixed pulley, the 30-tooth pulley at the top has a separate shift dog from the 20-tooth pulley at the bottom. This is due to the input shafts' design, which features a larger diameter at the top to incorporate a shaft coupler into the shafts themselves to mate them to the motors. On the output shaft, which is uniform in diameter throughout, one double sided shift dog can either engage with the 22-tooth pulley set at the top or the 60-tooth pulley on the bottom. To keep free-spinning pulleys from sliding down the shaft when not in use, clamping shaft collars hold them up without engaging them.

4) *Powerhouse*
   a) *Lower unit:* The new endurance output tube was lengthened to meet the team's specifications, while the sprint output tube was shortened. Specifically, the endurance tube was lengthened to where the center of the propshaft would be one propeller diameter under the waterline, whereas the sprint tube was shortened to where the center of the propshaft would line up with the bottom of the transom. The standoffs were also redesigned to relocate the output tube farther away from the hull and incorporate more robust mounting points.

Fig. 6.6a- Sprint output shaft and lower unit, supported by standoffs

Fig. 6.6b- Endurance output shaft and lower unit, supported by standoffs

   b) *Propeller:* The propeller for the sprint configuration is a single-piece four-blade propeller measuring 10 inches in diameter. This propeller is surface-piercing, operating to its fullest potential when the boat is planing and the propshaft is level with the waterline. The propeller for the endurance configuration is a modular propeller measuring 24 inches in diameter that can run with two or four blades. This propeller operates to its fullest potential when deep under the water, allowing the boat to achieve displacement hull characteristics.

Fig. 6.7- Sprint propeller

C. Testing and Evaluation

To ensure proper functionality of each major component group in the drivetrain, they were tested in series on dry land before being tested in the water as a full assembly. Motors were bench tested alone to ensure proper functionality. Once verified, the motors were attached to the Aluminum 6061-T6 frame and run again to inspect for undesirable vibrational characteristics. Next, the belt and pulley systems were installed, and the drivetrain was run at various speeds in both the sprint and endurance configurations without experiencing failure. The final dry test involved attaching the lower unit assembly and running the motors once more to ensure proper alignment of all the drivetrain's components. So far, only the sprint configuration has been tested in the water, successfully propelling the boat and remaining intact as expected.

Fig. 6.8- Initial water test

VII. Steering

A. Previous Design

The 2022 team designed a cable steering system using a pitman arm and handlebars with an integrated twist throttle. Though the design was lightweight, it lacked reliability and mechanical advantage. Without wet tests or competition performance to verify the previous design, an entirely new system was implemented to address and improve steering performance.

B. Analysis of Design Concepts

1) *Steering Overview:* The current steering system utilizes cable steering originating at a quadrant attached to the steering column, routing through a series of pulleys, and terminating at an outboard steering knuckle attached to the lower unit. The angularly and telescopically adjustable butterfly steering wheel is mounted on a three-section shaft supported by the dashboard and intermediate plywood support (Fig. 7.1). The system meets design goals by outputting a 30° turning radius with an ergonomic and intuitive pilot interface based on anthropometric measurements and human strength data [5]. Position adjustability enables a sprint riding position and endurance riding position to optimize weight distribution. The system is lightweight and low profile, allowing it to operate under the solar panel while enabling full lateral leg mobility for the pilot. With all custom parts made from 6061 T6 Aluminum, the design was readily manufacturable while retaining a high strength to weight ratio, contributing to a minimum safety factor of SF=2 [7].

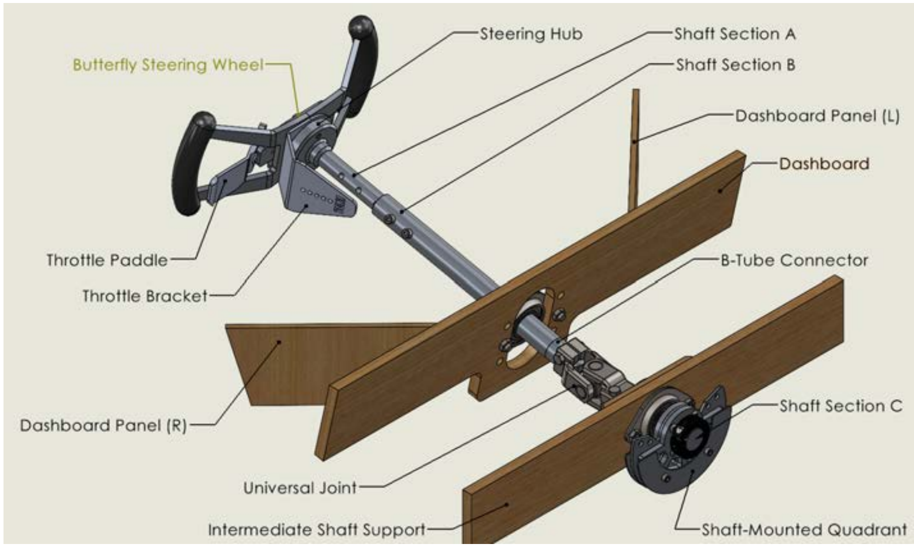


Fig. 7.1- Steering column assembly with labeled components

2) *Steering Column*: The steering column is constructed from three separate shaft sections. As pictured in Fig. 7.1, Shaft Section C slots through a flange bearing in a rigid plywood support, housing the quadrant on one side and a universal joint on the other side. The universal joint allows for angular adjustment of the upper steering column without changing the position of the quadrant and causing undesired tension changes in the steering cables. Shaft Section B is an aluminum tube slotted through a flange bearing in the dashboard that can be mounted in three different positions to adjust the steering angle between events. Shaft Section A is slid inside Section B with multiple pinholes indexed to matching holes in Section B for telescopic adjustments. The butterfly steering wheel is secured to Section A with a keyed steering collar and head nut on the protruding threaded end of Section A.

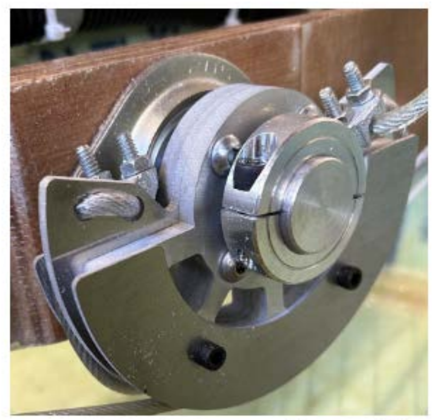


Fig. 7.2- Quadrant manufactured from water-jetted aluminum plates

3) *Quadrant:* While quadrants are traditionally mounted at the transom of a boat [6], the quadrant in this design serves the role of the drum in a drum and cable steering system. The quadrant is constructed from layered water-jetted aluminum to create parallel channels for opposing cables (Fig. 7.2). Because the butterfly steering wheel only turns 90° in either direction, the quadrant only needs 180° of effective radius, rather than a full circle. Selecting a 90° turn of the steering wheel to cause a 30° turn of the propeller, the size of the steering knuckle was set at 7in leading to a 2.33in radius quadrant to achieve the desired 3:1 steering ratio. A key and keyway secures the quadrant to the steering column.

4) *Cables and Hardware:* Steering cables originate on opposing ends of the quadrant and are routed through a series of pulleys before joining again on the starboard side below the gunnel (Fig. 7.3). Hardwood blocks were epoxied and fiberglassed in place on the interior foam-core portions of the boat to mount pulleys. The cables enter separate sections of stacked PEX tubing passing through the dashboard and ending at the C bulkhead to protect the pilot from exposed moving cables. Turnbuckles are utilized on both cables to increase tension and align the steering wheel angle with the quadrant angle. After passing through the transom, the top cable is sent directly to the steering knuckle, while the lower cable is routed to a pulley on the port side before reaching the steering knuckle. Springs connect the eye hook on the knuckle to the terminus of the cable to dampen feedback and retain tension upon turning. Because entire lower units are swapped between events, eye hooks are removed from the steering knuckle and re-installed in the new lower unit's identical steering knuckle.

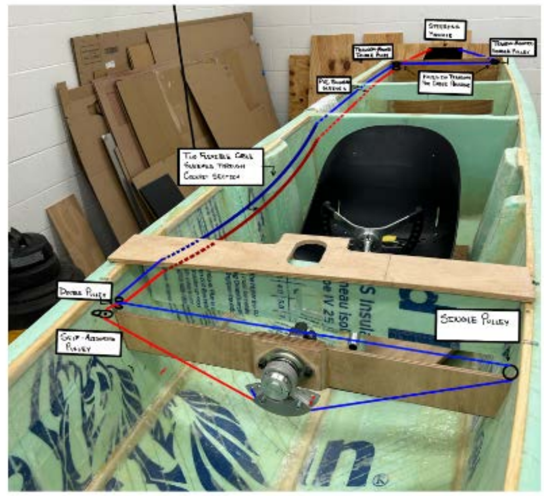


Fig. 7.3- Cable routing path illustration originating from opposing sides of quadrant

5) *Steering Knuckle and Lower Unit:* Two separate lower units were manufactured to be replaced between events. The sprint lower unit is short to align the center of the propeller with the surface of the water, while the endurance lower unit is significantly longer to penetrate deep into the water. Identical steering knuckles are welded to the top of both units so they are equally compatible with the rest of the steering system. The aluminum tubes of the lower unit that house the driveshaft are secured to the transom by clamping blocks on standoffs for alignment purposes. After being indexed to the proper height, the sections of the tubes with nylon bushings (lubricated by graphite powder) are secured in the two clamping blocks. When the steering knuckle is pulled in either direction by the cables, the entire lower unit is allowed to rotate within the clamping blocks, thus changing the direction of propeller and thrust (Fig. 7.4). This design allows for the powerhouse only to be rotated while the motors remain fixed to the transom.

Fig. 7.4- Cables penetrate transom and attached to steering knuckle on lower unit

6) *Throttle:* As pictured in Fig. 7.5, a paddle throttle was designed and fabricated to be mounted on the butterfly steering wheel. The throttle was designed

Fig. 7.5- Butterfly steering wheel with custom paddle throttle

to place the pilot-actuated paddle in the gap of the steering wheel spokes where the fingers would naturally extend. The paddle throttle works exclusively with the butterfly style steering wheel because of its limited grip locations. The location of a throttle on a traditional hand over hand steering wheel would become unpredictable as the pilot places their hands in different positions to complete turns. The butterfly steering wheel forces the pilot to consistently locate and constantly grip the steering wheel exactly where the throttle will be located for safe operation.

C. Testing and Evaluation

The steering system was tested on dry land and water to ensure functionality. Initial tests utilized a lightweight nylon cable for kayak steering, but load testing concluded that the static rope was stretching, causing an unacceptable level of tension loss in the system. The nylon rope was replaced with vinyl-coated steel cable that withstood load testing without losing tension. On dry land, it was verified that a 90° turn of the butterfly steering wheel caused a 30° rotation of the steering knuckle and propeller in the desired direction for both the sprint and endurance lower units. The throttle proved to adequately control speed with micro adjustments. A full pull of the throttle consistently turned the potentiometer lever arm far enough to compress the microswitch for motor controller bypass (Fig. 7.6).

Fig. 7.6- Steering and throttle functionality in wet tests (microswitch not pictured)

VIII. Data Acquisition and Communications

A. Previous Design

The most recent 2021 TCNJ Solar Splash competitive entry utilized a telemetry system to track speed, voltage, battery current, and roll. The system was integrated with the circuit board, utilizing MATLAB, LabVIEW, and a Panasonic ToughBook. Verbal communications systems were previously utilized in the form of two way radios with no additional attachments.

B. *Analysis of Design Concepts*

1) *Telemetry:* With the circuit undergoing a complete overhaul since the last competition, remote telemetry was eliminated from the system altogether. All data acquisition tools are visually accessible to the pilot through on-board displays in the dashboard. These acquisition tools include the Victron Energy BMV-712 Smart BAM030712000 Battery Monitor and RPM1204BHA DIGITEN 4 Digital LED Tachometer. This eliminates extra weight from the recording devices and ruggedized computer unit to process and transmit data.
2) *Communications*: Two way radio communication remains the communication method of choice for the current design. In an effort to provide simple radio controls, a microphone and earpiece were attached to the skipper life vest in a hands free position for transmitting and receiving messages (Fig. 8.1).

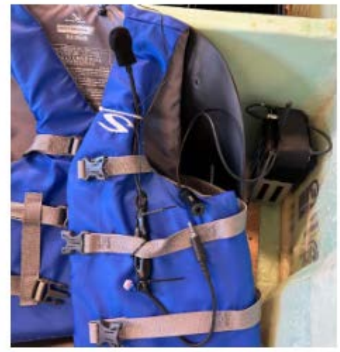


Fig. 8.1- Skipper life jacket with mounted microphone and earpiece. Cables connect to the steering wheel PTT and fixed radio box.

3) *Data Processing:* In addition to this electrical equipment, devices are used throughout testing to acquire raw data that can be processed for design optimization. The first is an Intersense Inertiacube 4 inertial measurement unit (IMU) that can be referenced in Fig. O.4 in Appendix O which provides digital feedback regarding the Euler angles of the boat [8]. A handheld Garmin Montana 600 GPS seen in Fig O.5 was also used to receive speed and time information during testing [9]. When both sets of data are combined and interpreted, relationships between the pitch and speed with respect to time can be established. Appendix O provides sample graphs of pitch vs time and speed vs time from the initial water test. The results gathered show that the boat maintains a steady pitch when moving forwards and changes pitch when turning and slowing down. As the team continues to test, similar graphs will be used to obtain critical relationships between the speed and power required to achieve a planing and displacement hull to prepare for success at competition.

Dry testing was also conducted in between water tests to continuously improve the boats design and performance. The objective of these tests was to ensure the expected result was produced prior to testing on the water. Observation notes and data were recorded during these tests while ensuring all subassemblies were integrated appropriately. RPM data was recorded and graphed as a function of time to prove the boat is mechanically capable of reaching high outputs in a timely manner. Although this was not a true acceleration test, a sample graph generated by the team through these tests can be found in Fig. O.3.

IX. Project Management

A. *Personnel*

The team consists of three senior mechanical engineering students and one engineering management/mechanical engineering senior. The goals of this year's project were divided into four subsystems: electrical, drivetrain, steering, and hull. Each team member was designated as the lead of their own subsystem and one overarching project manager organized the project and team efforts holistically. With such a small team size, every member assisted across designations and worked cross functionally on each subsystem under the direction of the system's lead.

B. *Gantt Chart*

A six phase Gantt chart was developed to plan, organize, and track progress on the project over the 12 months it took place (Appendix P). The phases included summer research and planning, project proposal, preliminary design, final design, winter manufacturing, and spring testing. The team held formal meetings at least once weekly with advisors to present progress and discuss the direction of the project, and could be found working on the boat daily in the design lab and machine shop.

C. *Critical Path Network*

Based on task dependencies, a critical path network was generated to identify project tasks whose delay would affect the project finish date (Appendix P).

D. *Project Budget*

A project budget was compiled and proposed to leaders of the TCNJ School of Engineering, who approved in full support. With a stock of raw materials and hardware at the team's disposal from previous project inventory, the team remained conservative with new purchases and prioritized repurposing of existing components wherever possible.

X. Conclusions and Recommendations

The greatest strength of the boat is the lightweight hull design that has yet to be showcased at the Solar Splash competition. With a competitive foundation established, the implementation of the subassemblies featuring a dual motor drivetrain, robust steering system, and effective electrical system further the team's success in satisfying the objective.

The team recommends increasing the size of the team to a minimum of five full time students. Larger teams would have the ability to increase focus on optimizing the design and would not have the large time constraint inherent to a competition project. The team also recommends diversifying the technical background of the team. The team spent a large amount of time researching curriculum already integrated within other majors e.g. computer engineering and electrical engineering; which means the design phase of the project can be started earlier. Additionally, getting more underclassmen involved would prove to be an asset for future teams. Not only would this lessen the workload on the team members, underclassmen would gain experience and benefit from being involved with a senior level engineering project.

Lastly, the team encourages future TCNJ students to perfect a single hull that can be used in several competitions. This would allow for time to be saved in hull construction every year and provide the team with more time to perfect the entire system through advanced testing and evaluation of the experimental data.

XI. References

[1] Solar Splash. Solar Splash Rules. Solar Splash, 2022.
[2] Gil Knier. Solar cells to solar panels arrangement. NASA Science, 2008.
[3] Ahmed G Radwan, Farooq Ahmad Khanday, and Lobna A Said. Performance evaluation of fractional character vector control applied for doubly fed induction generator operating in a network-connected wind power system. In Fractional-Order Modeling of Dynamic Systems with Applications in Optimization, Signal Processing, and Control. Academic Press, 2021.
[4]Shady Abdel Aleem, Abdelaziz, Almoataz Youssef, Ahmed F. Zobaa, and Ramesh Bansal. Decision Making Applications in Modern Power Systems. Electronic Tutorials, 2020.
[5] Alvin R Tilley et al. The measure of man and woman: human factors in design. John Wiley & Sons, 2001
[6] Glen-L Staff. Boatbuilding 101. Glen-L Marine Designs, unk.
[7] Robert C Juvinall. Fundamentals of machine component design. John Wiley & Sons, 2007
[8] “INERTIACUBE4.” InterSense, 18 June 2021.
[9] Garmin, and Garmin Ltd. or its subsidiaries. “Montana 600.” Garmin.

Appendix A: Battery Documentation

Appendix A.1: Main Battery Data Sheet

11/16/22, 5:49 PM ODS-AGM16CL

Home Where to buy Battery Catalog

888.379.2555

Batteries

Chargers and Accessories

Applications

Documentation

ODS-AGM16CL	PC 625
$181.99 plus free ground shipping anywhere in the US.	
Volume discounts and dealer pricing available.	
Add To Cart	

ODYSSEY Powersport Battery Model ODS-AGM16CL (PC625)
(with brass M6 side terminals)

Powersport vehicles need a powerful battery that's built to take the constant pounding that comes with the territory, whether it's is on land, sea, or snow.

The ODS-AGM16CL is a direct replacement for the YB16CL-B. Fits virtually all 2 stroke Sea Doo, Polaris, and Kawasaki sit down models. Four-stroke owners will want to look at the ODS-AGM28

Technical note for Sea-Doo installations

More to explore:
Odyssey chargers
ACI chargers
MicroStart jumpstarters and personal power supplies
Hella disconnect switches

Dimensions	
Length	6.70 in
Width	3.90 in
Height (terminals included)	7.0 in
Weight	13.2 lbs

https://www.odysseybatteries.com/odyssey/pc625.html 1/4

Shipping Weight	15 lbs

SPECIFICATIONS	
Voltage	12
Cranking Amps (5 second start)	540
Cold Cranking Ampms (CCA)	220
HCA	400
MCA	330
20HR Nominal Capaity (AH)	18
Reserve Capacity Minutes	26
Terminal	M6 Receptacle
Internal Resistance	7
Short Circuit	1800

Personal Watercraft		
Bombardier - Sea Doo		
1500	All Models (except GTX 4-Tec)	1988 - 2004
Kawasaki		
750	JH750 SS	1992 - 1997
750	JH750 ST	1995
750	JH750 Xi	1993 - 1999
750	JH750 XiR	1994
750	JS750 SX, ZX	1992 - 1995
750	JT750 XiR, ST, STS	1994 - 1995
650	JF650 X2	1986 - 1995
650	JF650 TS	1989 - 1996
650	JL650 SC	1991 - 1995
650	JS650 SX	1987 - 1995
550	JS550 SX	1986 - 1995
400	JS400	1976
300	JS300 TS, SX	1986 - 1991
Polaris		

All sizes	All models	All
Yamaha		
All sizes	All models	1987 - 2007
Utility Vehicle		
Kawasaki		
620	KAF620, Mule 3010 4x4 Advantage classic	2003
620	KAF620, Mule 3000, 3010, 3020	
620	KAF620, Mule 2500, 2510, 2520	
540	KAF540, Mule 2010, 2020, 2030	
450	KAF450, Mule 1000	
ATV		
Bombardier		
650	Quest	2002 - 2003
500	Traxter (All models), Quest	1999 - 2003
Kawasaki		
400	KLF400-B Bayou 400 4x4	1993 - 2000
400	KVF400-A Prairie 400 4x4 (CN)	1997 - 2000
400	KVF400-B Prairie 400 (CN)	1998 - 2000
300	KLF300-A Bayou	1986 - 1987
300	KLF300-B Bayou (CN)	1992 - 1999
300	KLF300-C Bayou 300 4x4 (CN)	1992 - 2004
300	KVF300-A Prairie 300, 4x4 (CN)	1999 - 2001
300	KVF300-B Prairie 300, 4x4 (CN)	1992 - 2002

West Coast Batteries
410 Leroy Drive
Corona Ca. 92879
Tel: 951.736.3530

Accessories

Appendix A.2: Supplemental Battery Data Sheet

SPECIFICATIONS (continued)

Model	Nominal Voltage	Design Life in float service 68°F (20°C)	Rated Capacity (AH)				Approx. Dimensions: inch (mm)								Approx. Weight		Terminal Type
			20-hr	10-hr	5-hr	1-hr	Length		Width		Height		Total Height				
		Years	1.80V/cell	1.80V/cell	1.75V/cell	1.60V/cell	inch	mm	inch	mm	inch	mm	inch	mm	lbs.	kgs.	
PS-1270	12	5	7.0	6.5	6.0	4.5	5.94	151	2.56	65	3.70	94	3.86	98	4.8	2.18	F1/F2

Appendix B: Flotation Calculations

With reference to Rule 7.14.2 [1], sufficient flotation must be provided onboard so that the craft cannot sink and a 20% safety factor must be included in the calculations. Governed by Archimedes Principle, the buoyant force F_B exerted on a submerged or floating body is equal to the weight of the fluid displaced by the body. Thus the buoyant force is the product of the specific weight of water, γ_{water} and the volume of water displaced by the body $\forall_{submerged}$.

$$F_B = \forall_{submerged} \cdot \gamma_{water} \qquad \text{[lbs.]}$$

The volume of the foam hull was determined to be 11.37 cubic feet and is denoted by. Using 62.428 pounds per cubic feet as the specific weight of water, the calculation for the buoyant force of the hull is demonstrated below.

$$F_{hull} = \forall_{hull} \cdot \gamma_{water}$$
$$F_{hull} = 11.37 \cdot 62.428$$
$$F_{hull} = 708.12\ lbs$$

The buoyant force of every object within the boat was calculated in the same manner and can be seen in the Tables B.1 and B.2 provided below. The sum of the buoyant force of each component was found to be 1001 pounds and is denoted as $F_{B,total}$. The maximum weight of the boat is approximated to be 561 pounds, and is denoted as W_{boat}. The ratio of buoyant force to total weight, referred to as the percent flotation, is provided below.

$$\%Flotation = \frac{F_{B,total}}{W_{boat}}$$
$$\%Flotation = \frac{1001}{561}$$
$$\%Flotation = 1.78$$

The results yield a percent flotation of 196.72% and 178.46% for the sprint and endurance configurations, respectively. Shown below is the inequality between the safety factors to ensure the flotation achieves the rule requirement

$$1.78 > 1.2$$ ✅

Table B.1- Sprint flotation calculation

Flotation Calculation - Sprint			
Component	Volume (ft^3)	QTY	Bouyant Force (lbf)
Hull	11.37		708.12
Stored Lower Unit	0.10		6.23
Stored Propeller	0.02		1.25
Steering Assembly	0.03		1.87
Seat	0.10		6.23
Skipper	0.00		0.00
Fire Extinguisher	0.27		16.82
Electrical Circuit	0.60		37.37
Batteries	0.10	6	37.37
Bilge Pump	0.06		3.74
Motors	0.09	2	11.21
Motor Mounting Assembly	1.96		122.07
Lower Unit	0.05		3.11
Propeller	0.01		0.62
Total Buoyant Force			**956.00**
Total Negatively Buoyant Force			**485.98**
120% Total Negatively Buoyant Force			**583.18**
Percent Flotation			**196.72%**

Table B.2- Endurance flotation calculation

Flotation Calculation - Endurance			
Component	Volume (ft^3)	QTY	Bouyant Force (lbf)
Hull	11.37		708.12
Solar Panel 2	0.33	2	41.10
Stored Lower Unit	0.05		3.11
Stored Propeller	0.01		0.62
Steering Assembly	0.10		6.23
Seat	0.10		6.23
Skipper	0.00		0.00
Fire Extinguisher	0.27		16.82
Electrical Circuit	0.60		37.37
Batteries	0.10	6	37.37
Bilge Pump	0.06		3.74
Motors	0.09	2	11.21
Motor Mounting Assembly	1.96		122.07
Lower Unit	0.10		6.23
Propeller	0.02		1.25
Total Buoyant Force			**1001.46**
Total Negatively Buoyant Force			**561.18**
120% Total Negatively Buoyant Force			**673.42**
Percent Flotation			**178.46%**

Appendix C: Proof of Insurance

The College of New Jersey

Statement of Liability - Permanent Statute

As an agency of the State of New Jersey, The College of New Jersey is bound by the same statutory provisions. Any agreement signed on behalf of the State of New Jersey by a State official shall be subject to all of the provisions of the New Jersey Tort Claims Act N.J.S.A.59:1-1 et. seq., the New Jersey Contractual Liability Act N.J.S.A. 59:13-1 et. seq., and the availability of appropriations.

The State of New Jersey does not carry public liability insurance, but the liability of the State and the obligation of the State to be responsible for tort claims against its employees, is covered under the terms and provisions of the New Jersey Tort Claims Act. The State shall be liable for injury proximately caused by the acts or omissions of its employees within the scope of their employment, pursuant to N.J.S.A. 59:2-2.

The Act also creates a special self-insurance fund and provides for payment of claims under the Act against the State of New Jersey or against its employees for which the State is obligated to indemnify against tort claims which arise out of the performance of their duties.

Claims against the State of New Jersey or its employees should be referred for handling to the Department of Treasury, Bureau of Risk Management, PO Box 620, Trenton, New Jersey 08625. Claim forms, along with contact information can be found at:
http://www.state.nj.us/treasury/riskmgt/

Appendix D: Team Roster

Tim Albano (Engineering Science, Senior) – *Steering Lead, Project Manager*

As the team member tasked primarily with steering, Tim's role is to design a lightweight, low profile, robust steering system

Chris Anfuso (Mechanical Engineering, Senior) – *Hull Design Lead*

Chris's primary role is to take the existing hull designed last year and suitably modify it to accommodate all the changes to the remaining subsystems of the boat.

Andrew Gutman (Mechanical Engineering, Senior) – *Drivetrain Lead*

Andrew is responsible for design and fabrication of the drivetrain which features a unique motor configuration for each of the competition's events.

Kyle Rosica (Mechanical Engineering, Senior) – *Electrical Systems Lead*

Kyle's primary responsibility is the design of the electrical system that provides the boat with optimal performance in all aspects of the competition

Appendix E: Electrical Schematic

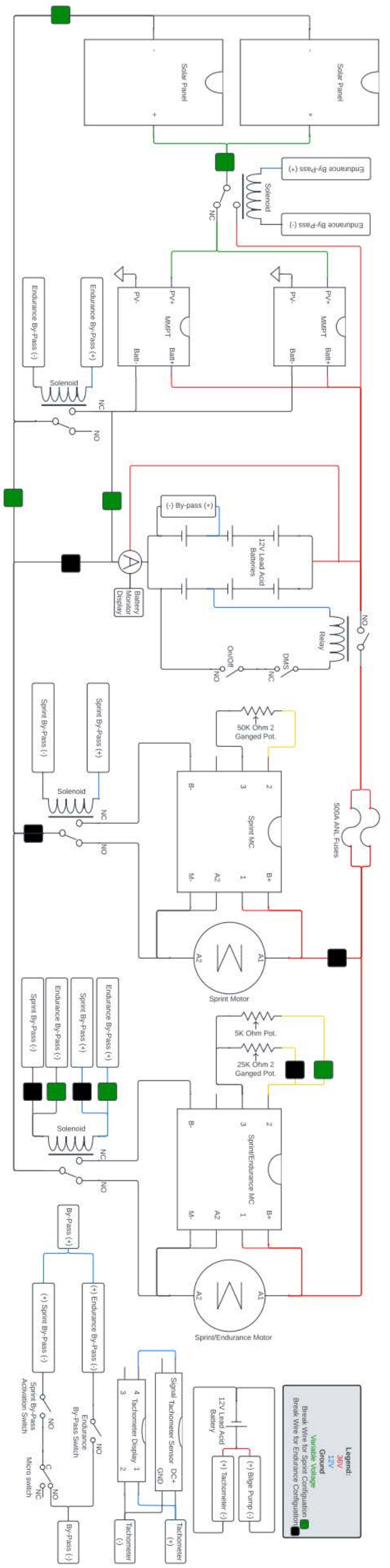


Fig. E.1- Complete electrical schematic

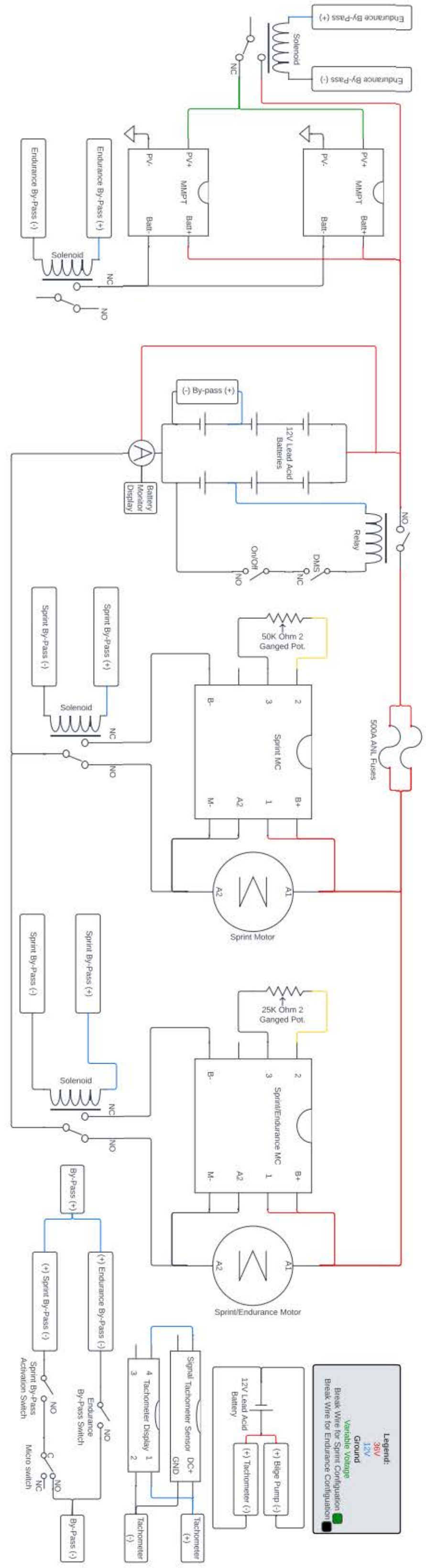


Fig. E.2- Sprint electrical schematic

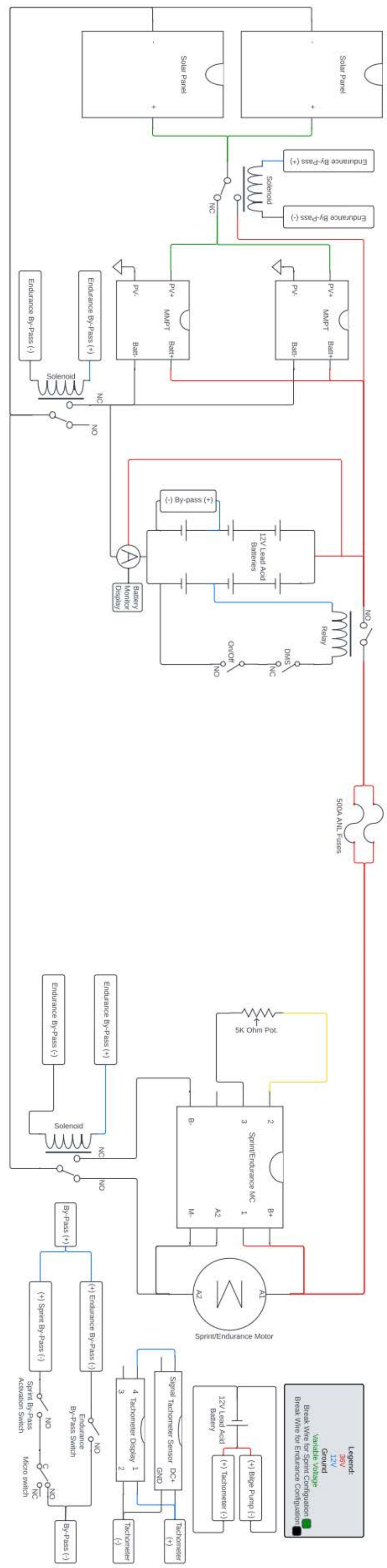


Fig. E.3- Endurance electrical schematic

Appendix F: Solar Panels Specifications

SUNPOWER

E19/240 AC SOLAR PANEL
MAXIMUM EFFICIENCY AND PERFORMANCE

MODEL: SPR-240E-WHT-U ACPV

DC ELECTRICAL DATA Measured at Standard Test Conditions (STC): irradiance of 1000W/m², AM 1.5, and cell temperature 25° C		
Peak Power (+5/-3%)	P_{max}	240 W
Efficiency	η	19.3%
Rated Voltage	Vmpp	40.5 V
Rated Current	Impp	5.93 A
Open Circuit Voltage	V_{oc}	48.6 V
Short Circuit Current	Isc	6.30 A
Temperature Coefficients Power	(P)	-0.38 %/K
Voltage	(V_{oc})	-132.5mV/K
Current	(Isc)	3.5mA/K
NOCT		45° C+/-2°C

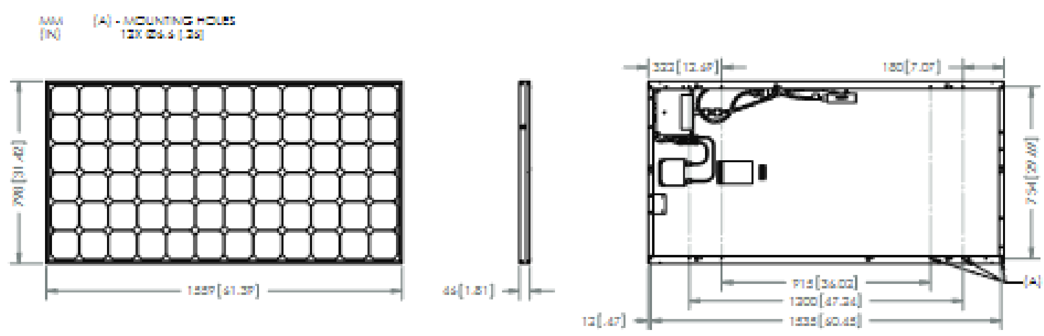
MECHANICAL DATA	
Solar Cells	72 SunPower® all-back contact monocrystalline
Front Glass	SunPower 240E solar laminates: High-transmission tempered glass with anti-reflective (AR) coating
Junction Box	IP-65 rated with 3 bypass diodes
Module Dimensions	1.26 x 6.10 x 5.04 in (32 x 155 x 128 mm)
Frame	Anodized aluminum alloy type 6063 (black)
Weight	37.6 lbs (17.1 kg)
AC Output Cable Length	34 in (863.6 mm)

AC ELECTRICAL DATA			
AC Output (Min/Nom/Max)	211 V	240 V	264 V
Oper Freq Hz (Min/Nom/Max)	59.3	60.0	60.5
Output Power Factor		0.99 Min	
AC Max Cont Output Current		0.94 A	
AC Max Cont Output Power		225 W	
Max Units Per Branch Circuit		17	
Max Overcurrent Protection		20 A	

TESTED OPERATING CONDITION	
Temperature	– 40° C to +85° C
Max load	550 kg/m² (5400 Pa), front (e.g. snow) w/specified mounting configurations 245 kg/m² (2400 Pa) front and back (e.g. wind)
Impact Resistance	Hail: 25 mm at 23 m/s

WARRANTIES AND CERTIFICATIONS	
Warranties	25-year limited power warranty 10-year limited product warranty
Certifications	ACPV Module Tested to UL 1703 and UL 1741, Class C Fire Rating

DIMENSIONS



CAUTION: READ SAFETY AND INSTALLATION INSTRUCTIONS BEFORE USING THE PRODUCT.
Go to www.sunpowercorp.com for details

sunpowercorp.com

Document # 001-73621 Rev**/ LTR_EN

Appendix G: Maximum Peak Power Tracker Specifications Sheet

victron energy BLUE POWER

SmartSolar Charge Controllers with load output

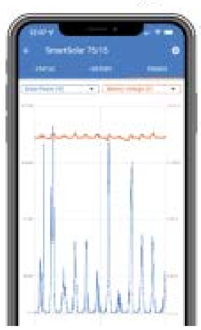
MPPT 75/10, 75/15, 100/15, 100/20-48 V

www.victronenergy.com

SmartSolar Charge Controller
MPPT 75/15

Bluetooth sensing
Smart Battery Sense

Bluetooth sensing
BMV-712 Smart Battery Monitor



Bluetooth Smart built-in
The wireless solution to set-up, monitor, update and synchronise SmartSolar Charge Controllers.

VE.Direct - For a wired data connection to a Color Control GX, other GX products, PC or other devices

Ultra-fast Maximum Power Point Tracking (MPPT)
Especially in case of a clouded sky, when light intensity is changing continuously, an ultra-fast MPPT controller will improve energy harvest by up to 30 % compared to PWM charge controllers and by up to 10 % compared to slower MPPT controllers.

Load output
Over-discharge of the battery can be prevented by connecting all loads to the load output. The load output will disconnect the load when the battery has been discharged to a pre-set voltage (48 V model: interface with a relay).
Alternatively, an intelligent battery management algorithm can be chosen: see Battery Life.
The load output is short circuit proof.

Battery Life: intelligent battery management
When a solar charge controller is not able to recharge the battery to its full capacity within one day, the result is often that the battery will continually be cycled between a 'partially charged' state and the 'end of discharge' state. This mode of operation (no regular full recharge) will destroy a lead-acid battery within weeks or months.
The Battery Life algorithm will monitor the state of charge of the battery and, if needed, day by day slightly increase the load disconnect level (i.e. disconnect the load earlier) until the harvested solar energy is sufficient to recharge the battery to nearly the full 100 %. From that point onwards, the load disconnect level will be modulated so that a nearly 100 % recharge is achieved about once every week.

Programmable battery charge algorithm - See the software section on our website for details

Day/night timing and light dimming option - See the software section on our website for details

Internal temperature sensor - Compensates absorption and float charge voltage for temperature.

Optional external battery voltage and temperature sensing via Bluetooth
A Smart Battery Sense or a BMV-712 Smart Battery Monitor can be used to communicate battery voltage and temperature to one or more SmartSolar Charge Controllers.

Fully discharged battery recovery function
Will initiate charging even if the battery has been discharged to zero volts.
Will reconnect to a fully discharged Li-ion battery with integrated disconnect function.

SmartSolar Charge Controller	MPPT 75/10			
Battery voltage (auto select)	12/24 V			12/24/48 V
Rated charge current	10 A	15 A	15 A	20 A
Nominal PV power, 12 V 1a,b)	145 W	220 W	220 W	290 W
Nominal PV power, 24 V 1a,b)	290 W	440 W	440 W	580 W
Nominal PV power, 48 V 1a,b)	n. a.	n. a.	n. a.	1160 W
Max. PV short circuit current 2)	13 A	15 A	15 A	20 A
Automatic load disconnect	Yes			
Max. PV open circuit voltage	75 V		100 V	
Peak efficiency	98 %			
Self-consumption – load on	12 V: 19 mA 24 V: 16 mA			26 / 20 / 19 mA
Self-consumption – load off	12 V: 10 mA 24 V: 8 mA			10 / 8 / 7 mA
Charge voltage 'absorption'	14,4 V / 28,8 V (adjustable)			14,4 V / 28,8 V / 57,6 V (adj.)
Charge voltage 'float'	13,8 V / 27,6 V (adjustable)			13,8 V / 27,6 V / 55,2 V (adj.)
Charge algorithm	multi-stage adaptive			
Temperature compensation	-16 mV / °C resp. -32 mV / °C			
Max. continuous load current	15 A			20 A / 20 A / 1 A
Low voltage load disconnect	11,1 V / 22,2 V / 44,4 V or 11,8 V / 23,6 V / 47,2 V or Battery Life algorithm			
Low voltage load reconnect	13,1 V / 26,2 V / 52,4 V or 14 V / 28 V / 56 V or Battery Life algorithm			
Protection	Output short circuit / Over temperature			
Operating temperature	-30 to +60 °C (full rated output up to 40 °C)			
Humidity	95 %, non-condensing			
Data communication port	VE.Direct (see the data communication white paper on our website)			
ENCLOSURE				
Colour	Blue (RAL 5012)			
Power terminals	6 mm² / AWG10			
Protection category	IP43 (electronic components), IP22 (connection area)			
Weight	0,5 kg		0,6 kg	0,65 kg
Dimensions (h x w x d)	100 x 113 x 40 mm		100 x 113 x 50 mm	100 x 113 x 60 mm
STANDARDS				
Safety	EN/IEC 62109-1, UL 1741, CSA C22.2			
STORED TRENDS				
Data stored	Battery voltage,current and temperature, as well as load output current, PV voltage and PV current.			

Appendix H: Motor Controller Specifications

Table C-1 ELECTRICAL SPECIFICATIONS, 1209B/1221B

NOMINAL INPUT VOLTAGE	24–36V, 36–48V, 48–72V, 48–80V, and 72–120V
PWM OPERATING FREQUENCY	15 kHz
KSI INPUT LEVEL	from 8 V to 1.5 × maximum battery voltage
STANDBY CURRENT	less than 20 mA
STANDARD THROTTLE INPUT	0–5kΩ ±10% (others available)

MODEL NUMBER	NOMINAL BATTERY VOLTAGE (volts)	CURRENT LIMIT (amps)	2 MIN RATING (amps)	5 MIN RATING (amps)	1 HOUR RATING (amps)	VOLTAGE DROP @ 100 AMPS (volts)	UNDER-VOLTAGE CUTBACK (volts)
1221B							
-57XX	36–48	550	550	375	225	0.25	21

Appendix I: Center of Flotation Calculations

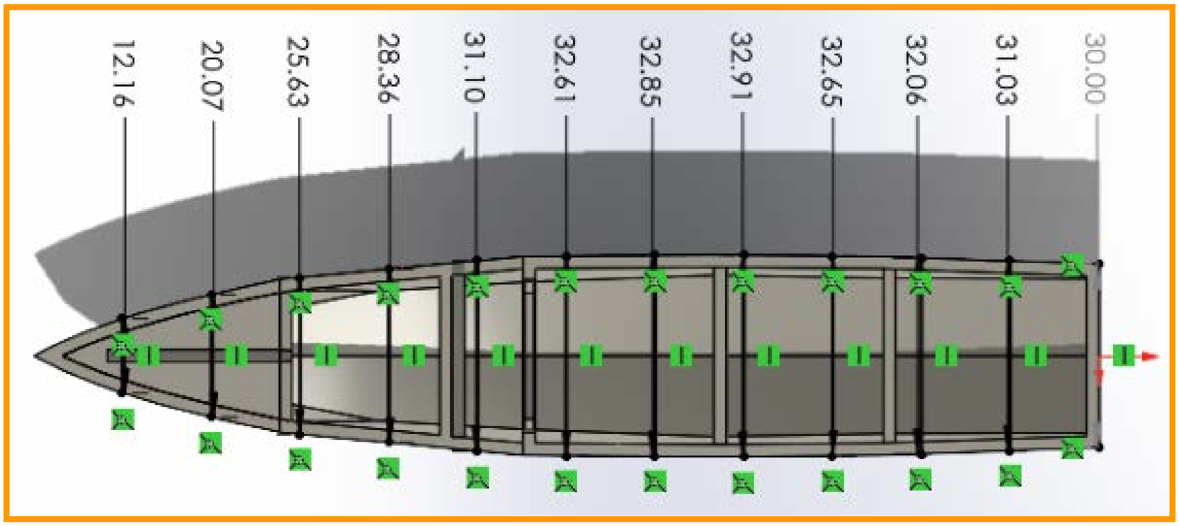


Fig. I.1- Equal sections of the boat used for Simpson's Rule calculation

Table I.1- Hull center of flotation calculation

Hull Center of Flotation					
Section	**Beam, B (in)**	**Simpsons Multiplier, SM**	**B*SM**	**Distance from Bow, X (in)**	**B*SM*X (in^2)**
0	0.00	1	0.00	0.00	0.00
1	12.16	4	48.64	14.41	700.90
2	20.07	2	40.14	28.82	1156.83
3	25.63	4	102.52	43.23	4431.94
4	28.36	2	56.72	57.64	3269.34
5	31.10	4	124.40	72.05	8963.02
6	32.61	2	65.22	86.46	5638.92
7	32.85	4	131.40	100.87	13254.32
8	32.91	2	65.82	115.28	7587.73
9	32.65	4	130.60	129.69	16937.51
10	32.06	2	64.12	144.10	9239.69
11	31.03	4	124.12	158.51	19674.26
12	30.00	1	30.00	172.92	5187.60
			983.70		**96042.07**
COF (in)					**97.6**

Appendix J: Center of Gravity Calculations

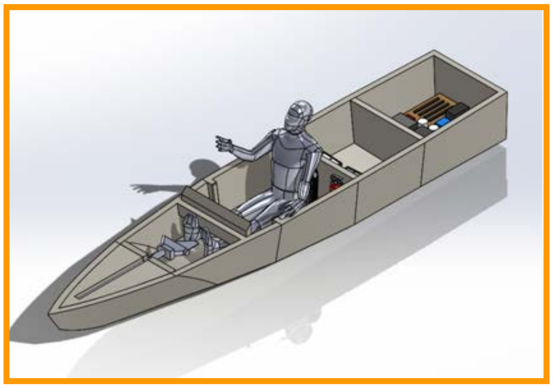
Table J.1- Sprint center of gravity calculation

Center of Gravity - Sprint			
Component	Weight	Distance from Bow (in)	Moment (lb-in)
Hull	29.99	112.45	3372.3755
Epoxy	15.00	112.45	1686.75
Stored Lower Unit	12.81	38.83	497.4123
Stored Propeller	0.28	58.25	16.31
Steering Assembly	6.30	65.00	409.5
Throttle Assembly	4.00	79.50	318
Seat	3.00	95.00	285
Driver	175.00	95.00	16625
Paddle	2.00	100.00	200
Fire Extinguisher	5.00	105.00	525
Electrical Circuit	35.00	155.43	5440.05
Batteries	85.00	87.50	7437.5
Bilge Pump	1.00	170.00	170
Motors	48.00	163.50	7848
Motor Mounting Assembly	55.00	172.00	9460
Lower Unit	8.40	178.00	1495.2
Propeller	0.20	184.00	36.8
	485.98		**55822.90**
COG (in)			**114.87**

Table J.2- Endurance center of gravity calculation

Center of Gravity - Endurance			
Component	Weight	Distance from Bow (in)	Moment (lb-in)
Hull	29.99	112.45	3372.3755
Epoxy	15.00	112.45	1686.75
Solar Panel 1	37.60	48.97	1841.272
Solar Panel 2	37.60	135.00	5076
Stored Lower Unit	8.40	38.83	326.172
Stored Propeller	0.20	58.25	11.65
Steering Assembly	6.30	65.00	409.5
Throttle Assembly	4.00	79.50	318
Seat	3.00	95.00	285
Driver	175.00	95.00	16625
Paddle	2.00	100.00	200
Fire Extinguisher	5.00	105.00	525
Electrical Circuit	35.00	155.43	5440.05
Batteries	85.00	87.50	7437.5
Bilge Pump	1.00	170.00	170
Motors	48.00	163.50	7848
Motor Mounting Assembly	55.00	172.00	9460
Lower Unit	12.81	178.00	2280.18
Propeller	0.28	184.00	51.52
	561.18		**63363.97**
COG (in)			**112.91**

Appendix K: Visual Representation of Weight Distributions



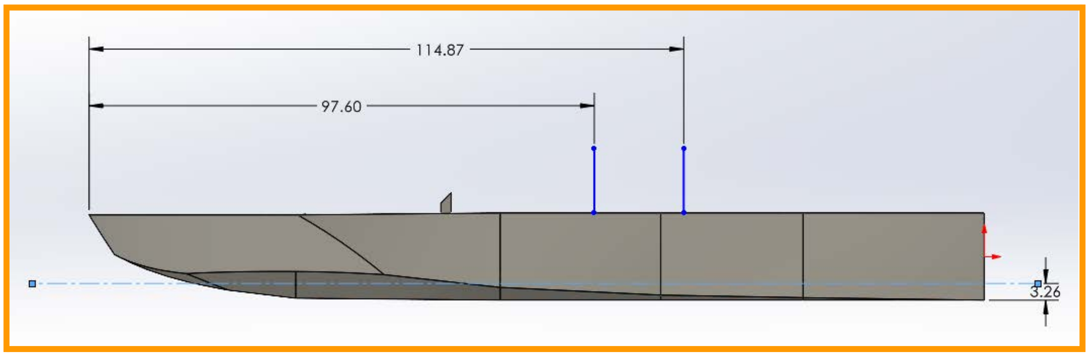


Fig. K.1 & K.2- Sprint weight distribution

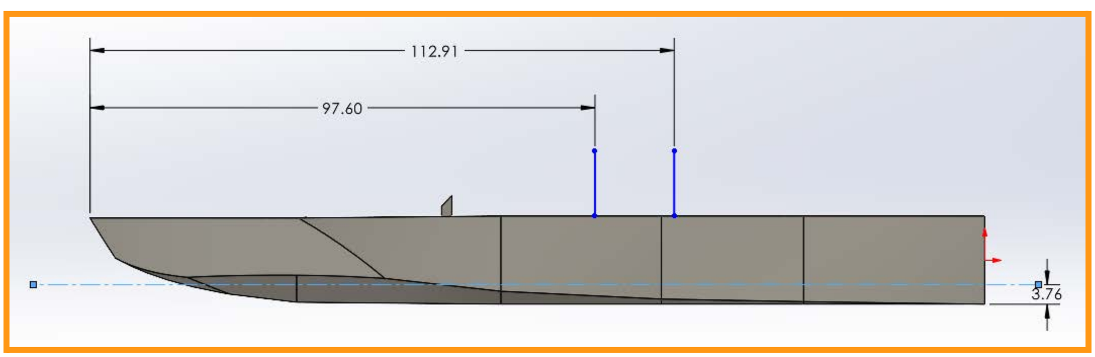


Fig. K.3 & K.4- Endurance weight distribution

Appendix L: Drivetrain Component Drawings

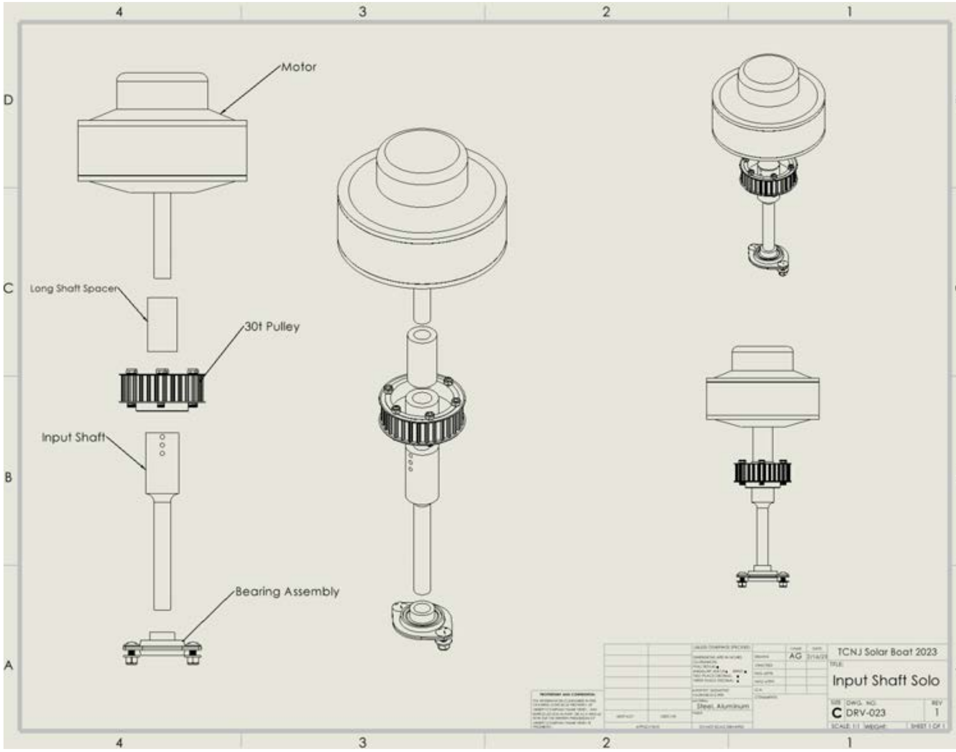


Fig. L.1- Input shaft with only one pulley

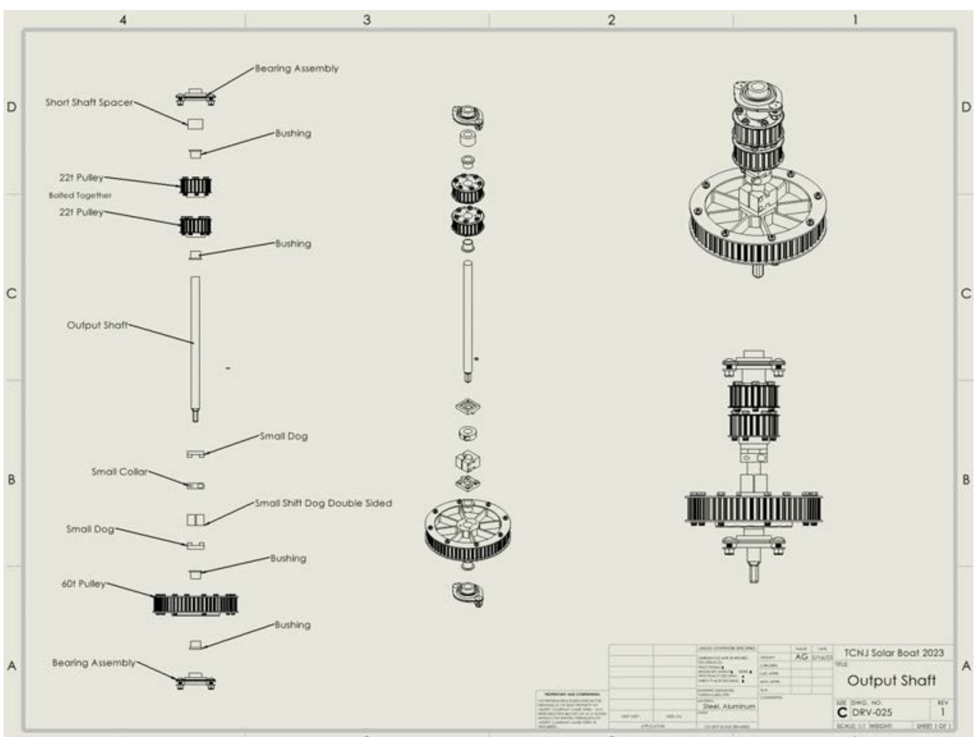


Fig. L.2- Input shaft with two sets of pulleys

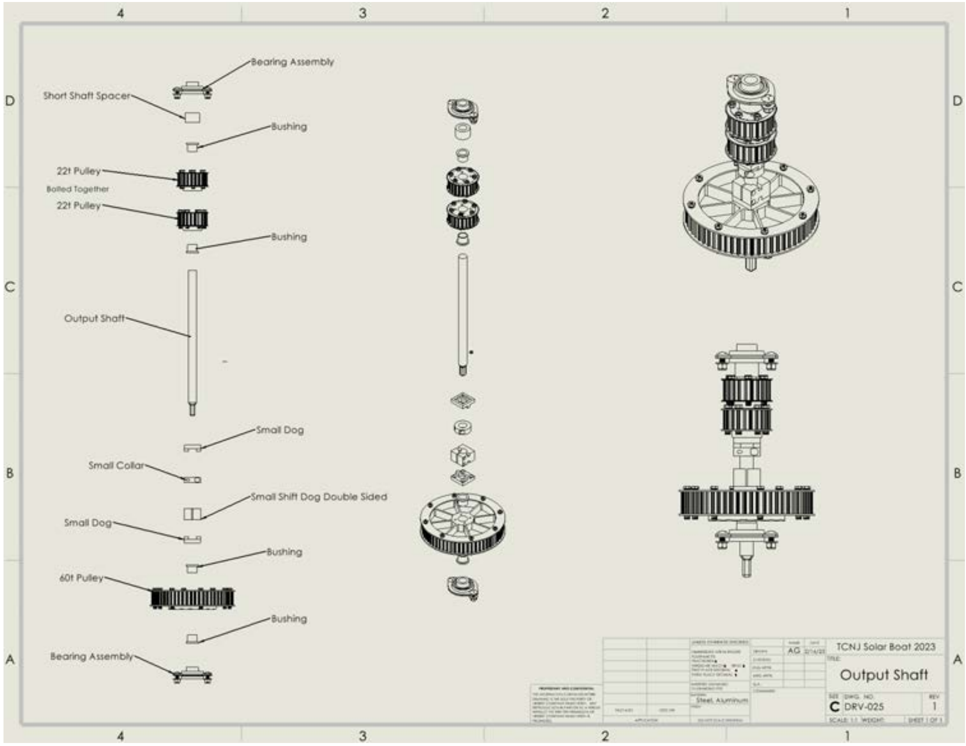


Fig. L.3- Output shaft

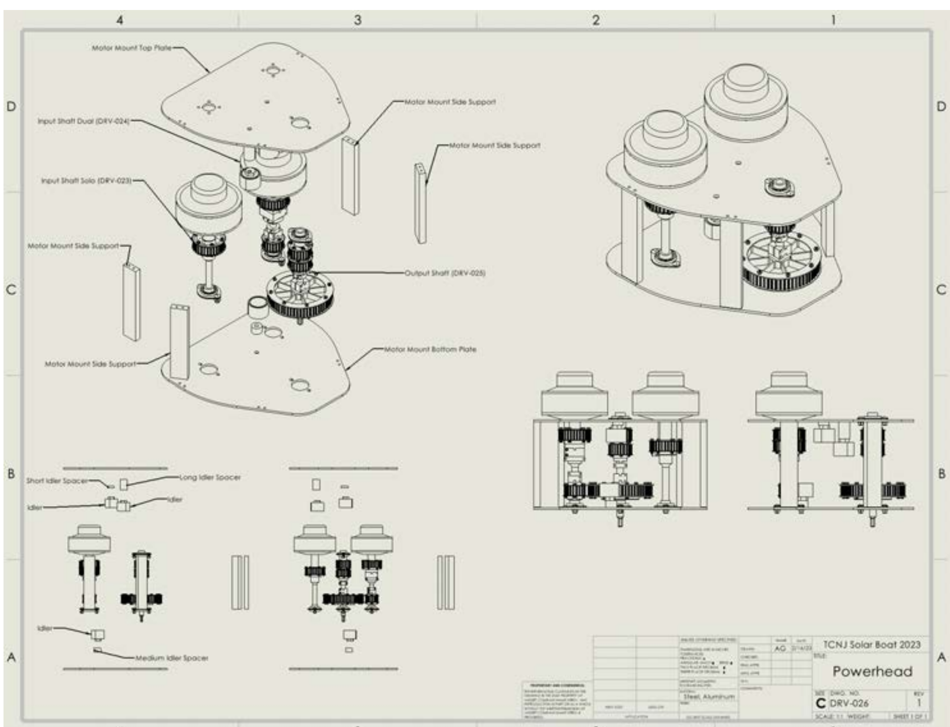


Fig. L.4- Full powerhead assembly

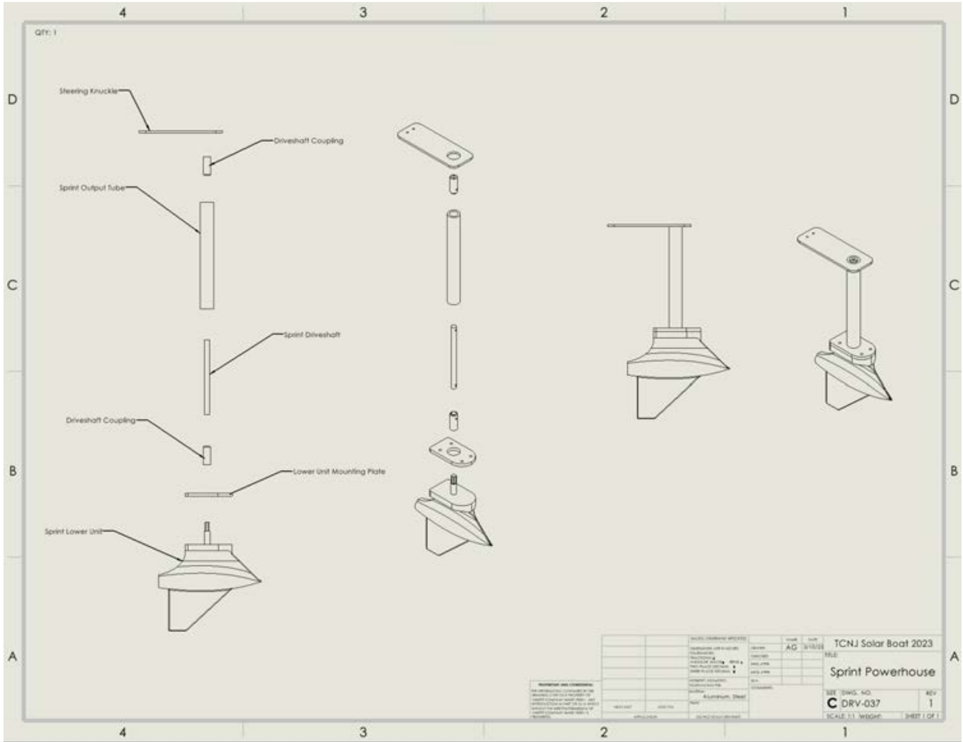


Fig. L.5- Sprint powerhouse assembly

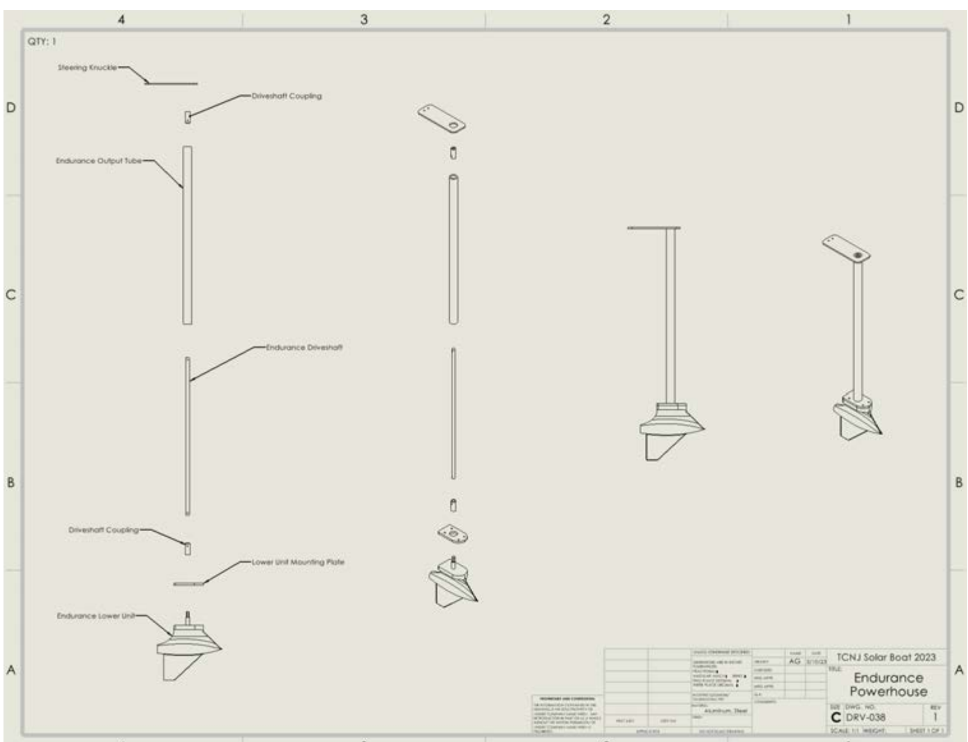


Fig. L.6- Endurance powerhouse assembly

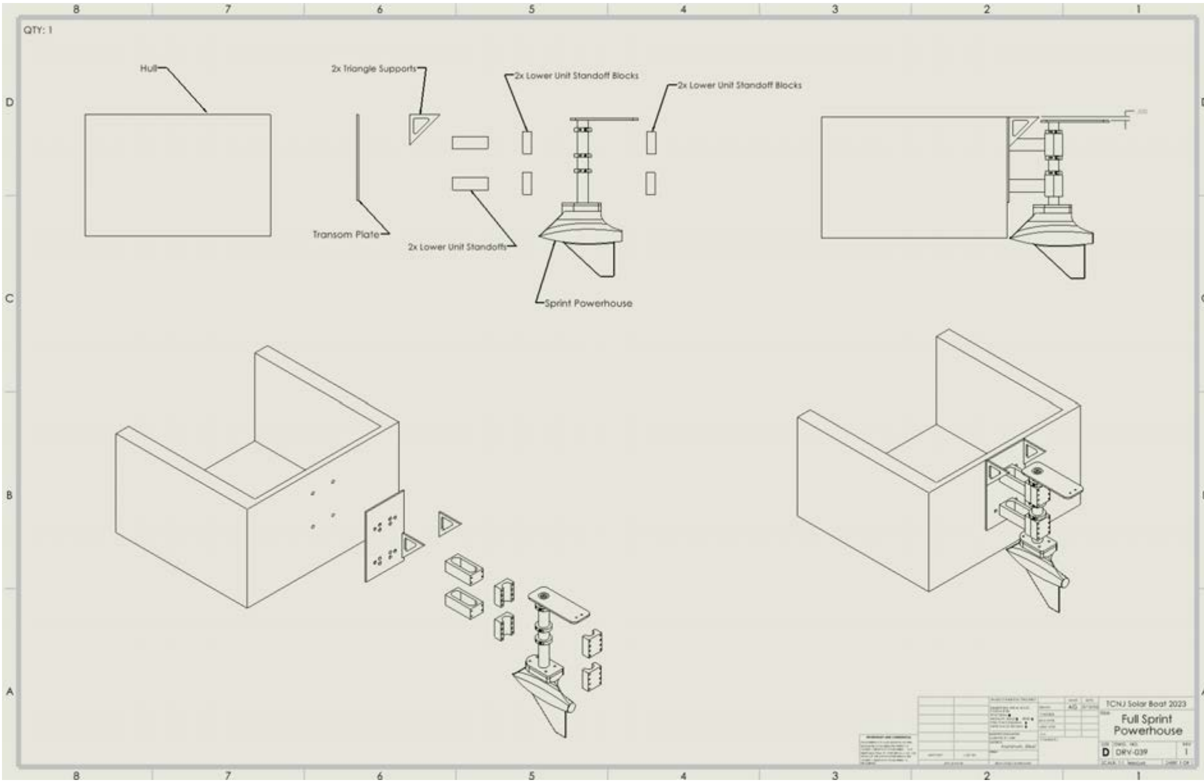


Fig. L.7- Sprint powerhouse assembly mounted to transom

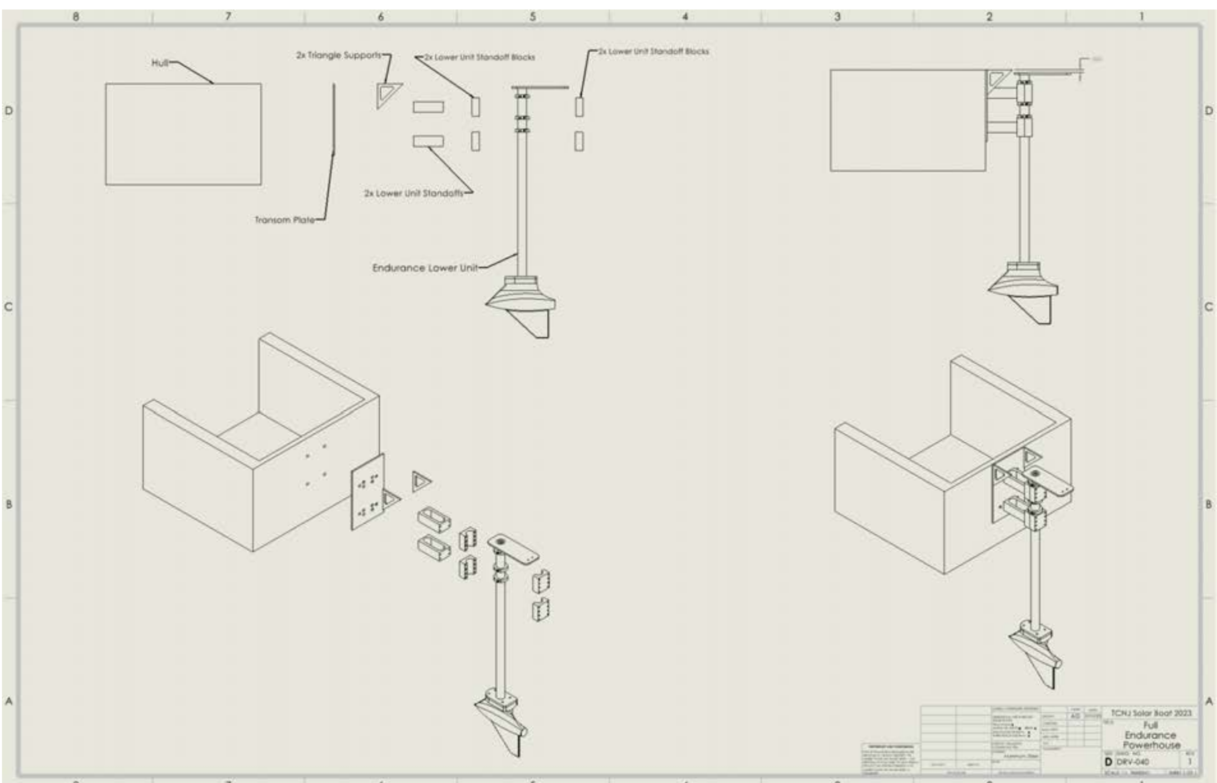


Fig. L.8- Endurance powerhouse assembly mounted to transom

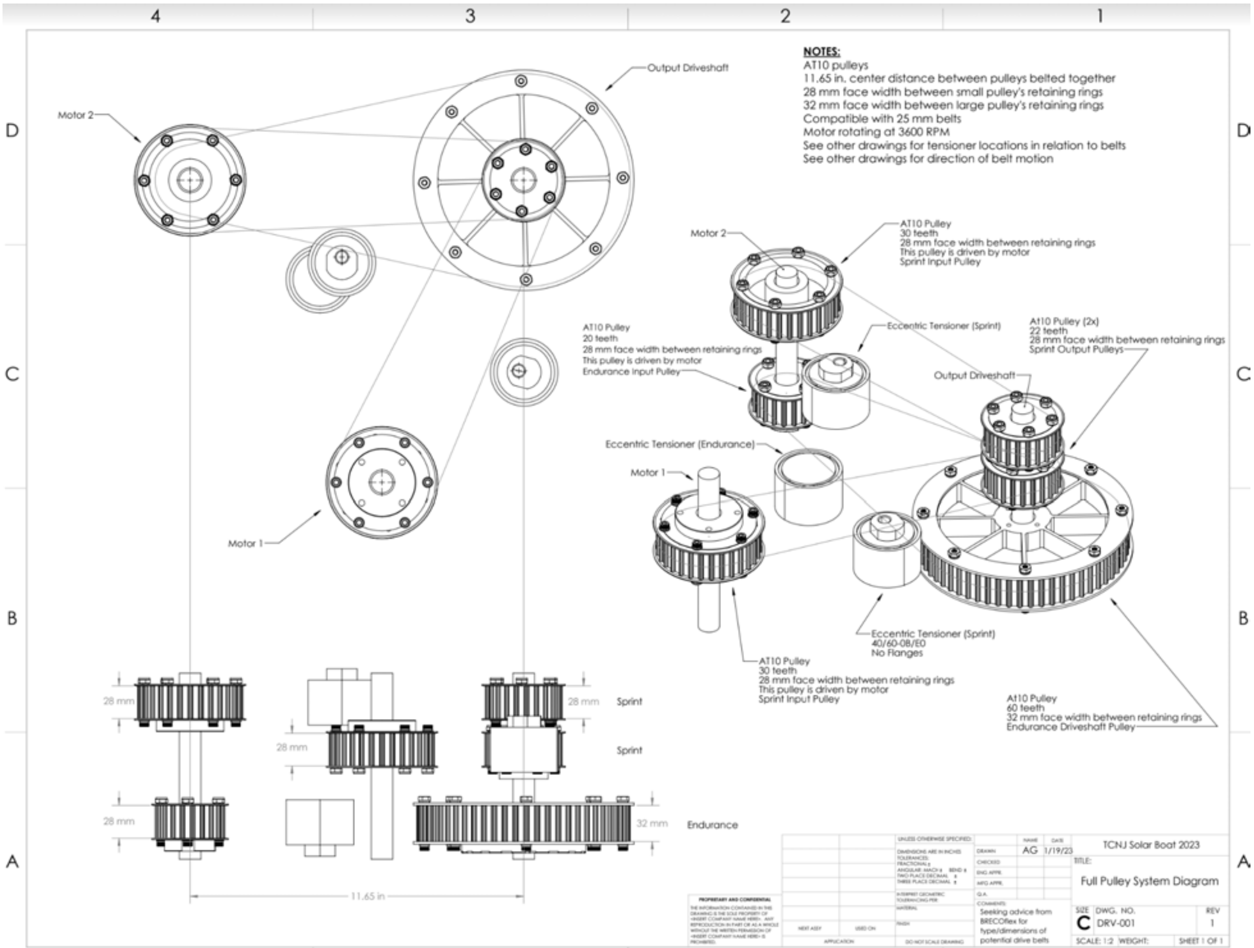


Fig. L.9- Full belt and pulley system

Appendix M: Belt Specifications

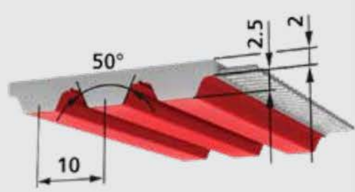
move-series®

AT10 Pitch Truly Endless "BFX"

AT10**move** is a next generation timing belt with enhanced performance properties. It is available as open-ended code M for linear drive application and truly endless BFX for power transmission applications.

Choose AT10**move** as a stiffer, more compact and longer lasting alternative to standard AT10, ATS15 and AT20 belts. Customers that switch from standard AT10 to **move**-series® see a significant increase in wear resistance, tensile strength, transmittable force and service life.

Truly Endless "BFX"



Specifications

Widths (mm)	25	32	50	75	100
Lengths	Standard lengths listed below. Additional lengths available up to 30,500mm. In between lengths available starting at a minimum of 1,400mm.				
Standard Material	TPUST1				
move Tension Member	Steel				
Belt Color	White / Red				

Standard Lengths

AT10**move** Pitch/Length Version	Number of Teeth
AT10 MOV / 720 BFX	72
AT10 MOV / 780 BFX	78
AT10 MOV / 840 BFX	84
AT10 MOV / 980 BFX	98
AT10 MOV / 1080 BFX	108
AT10 MOV / 1150 BFX	115
AT10 MOV / 1240 BFX	124
AT10 MOV / 1400 BFX	140
AT10 MOV / 1500 BFX	150
AT10 MOV / 1600 BFX	160
AT10 MOV / 1700 BFX	170
AT10 MOV / 1800 BFX	180
AT10 MOV / 1900 BFX	190

AT10**move** Pitch/Length Version	Number of Teeth
AT10 MOV / 2000 BFX	200
AT10 MOV / 2120 BFX	212
AT10 MOV / 2240 BFX	224
AT10 MOV / 2360 BFX	236
AT10 MOV / 2500 BFX	250
AT10 MOV / 2650 BFX	265
AT10 MOV / 2800 BFX	280
AT10 MOV / 3000 BFX	300
AT10 MOV / 3150 BFX	315
AT10 MOV / 3350 BFX	335
AT10 MOV / 3550 BFX	355
AT10 MOV / 3750 BFX	375
AT10 MOV / 4000 BFX	400

AT10**move** Pitch/Length Version	Number of Teeth
AT10 MOV / 4250 BFX	425
AT10 MOV / 4500 BFX	450
AT10 MOV / 4750 BFX	475
AT10 MOV / 5000 BFX	500
AT10 MOV / 5300 BFX	530
AT10 MOV / 5600 BFX	560
AT10 MOV / 6000 BFX	600
AT10 MOV / 6300 BFX	630
AT10 MOV / 6700 BFX	670
AT10 MOV / 7100 BFX	710
AT10 MOV / 7500 BFX	750
AT10 MOV / 8000 BFX	800
AT10 MOV / 9000 BFX	900

move-series®

Fig. M.1- BRECOflex AT10 MOV belt specification sheet

move-series®

AT10 Pitch Truly Endless "BFX"

AT10**move** Belt "BFX" Specifications

Construction	Tension-member	Dimension	Belt Width (mm) 25	32	50	75	100
Truly Endless "BFX"	AT10-*move* Tension Member	F_{zul}[N]	6,750	8,625	13,470	20,200	26,940
	Belt Mass	[kg/m/cm]	0.173	0.222	0.347	0.520	0.693

AT10**move** - BFX Tooth Shear Strength (specific belt tooth load bearing)

AT10move RPM 0-1900				AT10move RPM 2000-10000			
R.P.M. n [min]	F_{USPEC} [N/cm]	M_{SPEC} [Ncm/cm]	P_{SPEC} [W/cm]	R.P.M. n [min]	F_{USPEC} [N/cm]	M_{SPEC} [Ncm/cm]	P_{SPEC} [W/cm]
0	113.2	18.02	0.000	2000	62.1	9.89	20.698
20	111.5	17.76	0.371	2200	60.1	9.55	22.022
40	110.0	17.51	0.733	2400	58.2	9.26	23.254
60	108.6	17.26	1.086	2600	56.4	8.98	24.424
80	107.2	17.05	1.429	2800	54.7	8.72	25.533
100	105.8	16.85	1.763	3000	53.1	8.47	26.596
200	100.1	15.94	3.342	3200	51.7	8.24	27.597
300	95.6	15.22	4.774	3400	50.4	8.01	28.536
400	91.6	14.60	6.114	3600	49.1	7.81	29.429
500	88.4	14.06	7.361	3800	47.9	7.61	30.292
600	85.5	13.60	8.547	4000	46.7	7.42	31.108
700	82.7	13.17	9.656	4500	43.9	6.99	32.956
800	80.4	12.80	10.718	5000	41.4	6.61	34.650
900	78.2	12.44	11.735	5500	39.3	6.25	36.036
1000	76.2	12.14	12.705	6000	37.3	5.93	37.268
1100	74.4	11.84	13.644	6500	35.4	5.62	38.346
1200	72.7	11.57	14.538	7000	33.6	5.34	39.270
1300	71.1	11.32	15.400	7500	32.0	5.08	40.040
1400	69.6	11.07	16.232	8000	30.4	4.85	40.656
1500	68.2	10.84	17.048	8500	29.0	4.62	41.118
1600	66.8	10.64	17.818	9000	27.6	4.40	41.426
1700	65.6	10.44	18.572	9500	26.4	4.19	41.734
1800	64.4	10.24	19.312	10000	25.1	4.00	41.888
1900	63.1	10.06	20.020				

Ordering Example: **move**-series® Timing Belt

[WIDTH] [PITCH] / [LENGTH] [CONSTRUCTION]

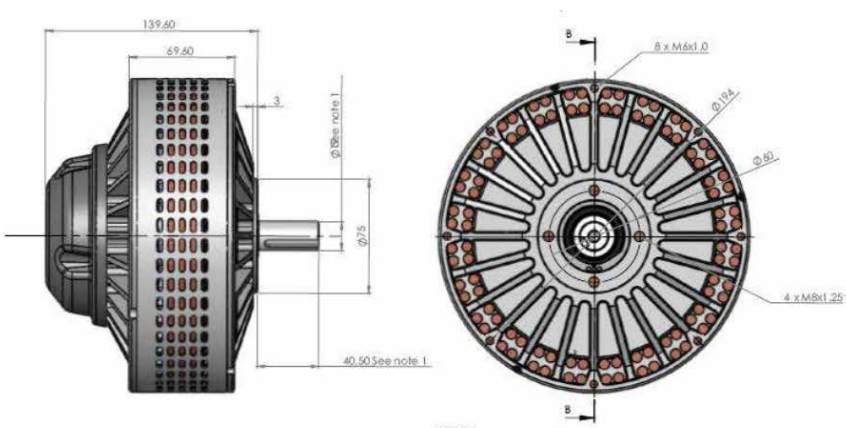
50 AT10 MOV / 3750 BFX

Fig. M.2- BRECOflex AT10 MOV belt specification sheet

Appendix N: Motor Specifications

Technical Data

Motor	No Load Current	Torque Constant	Speed Constant	Armature Resistance DC	Armature Inductance @ 15kHz	Armature Inertia	Peak Power	Peak Efficiency	Peak Current	Rated Power	Rated Speed	Rated Voltage	Rated Current	Rated Torque
	A	Nm/A	Rpm/V	mΩ	µH	Kgm^2	kW	%	A	kW	Rpm	V	A	Nm
95	6	0.113	81	21.5	22	0.0238	18	92	400	10	3888	48	250	28
126	10	0.0737	105	175	6	0.0234	7.59	83	400	5.06	2520	24	270	19.2
127	5	0.15	54	22.5	23	0.0236	16.08	89	400	8.55	2592	48	215	31.5
D95B	6	0.14	76	20.5	11	0.0238	28.50	92	400	15.00	6000	72	210	30
D126	5	0.0748	100	138	5	0.0234	11.14	81	400	6.91	3600	36	250	18.3
D127	4	0.17	50	17.5	13	0.0236	25.38	92	400	12.56	3600	72	200	33.3
D135	3.5	0.185	45	16.75	16	0.0236	29.04	93	400	14.39	3780	84	200	36.4
D135 RAG	7.36	0.207	42	16.95	16	0.0238	34.32	93	400	16.84	4032	96	200	39.9
D135 RAGS	7.45	0.21	40	16.95	16	0.0238	36.00	93	400	18.00	4400	110	200	42.0



NOTES:
1). Dimensions are for the standard drive shaft only - Refer to drive shaft drawing for optional shaft configurations

LMC GENERATING MOVEMENT EFFICIENTLY

LCM Limited, Lynch Motor Company Ltd, Unit 27,
Flightway Business Park, Dunkeswell, Honiton, Devon EX14 4RJ
Tel: +44 (0) 1404 892940 **Fax:** +44 (0) 1404 891990
email: sales@lmcltd.net **www.lmcltd.net**

ACS REGISTRARS ISO 14001
ACS REGISTRARS ISO 9001

Fig. N.1- Lynch LEM 200 data sheet

LMC GENERATING MOVEMENT EFFICIENTLY

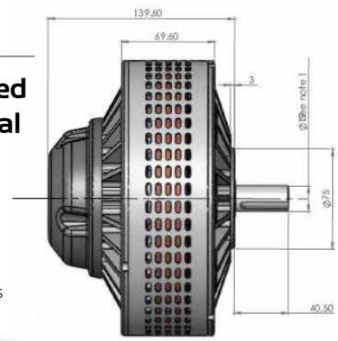
MOTORS LEM-200

Overview

The LEM-200 is an axial gap DC brushed motor suitable for traction and industrial applications.

Example applications include grass cutters, Go-Karts, motorcycles, golf carts, scissor lifts, lightweight vehicles, boats and generators.

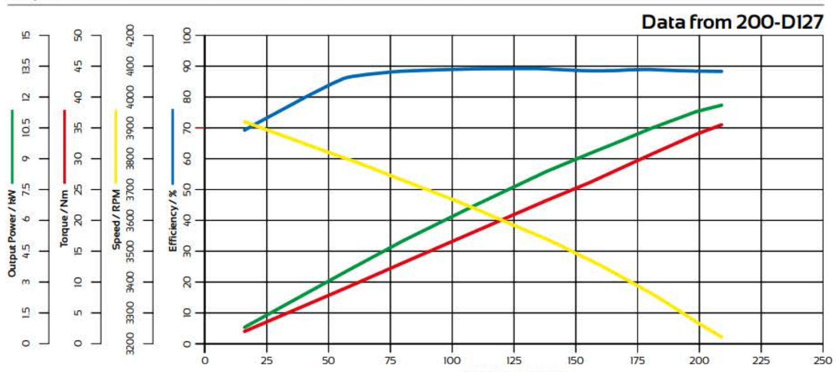
The LEM-200 is available in 95, 126, 127 and 135 strip armatures with magnet grade selection dependant on application.



Features

- **High efficiency (up to 93%)**
- **Lightweight design (11kg)**
- **Simple electronic control**
- **Long brush Life**
- **Interchangeable Shaft**
- **Rugged Construction**
- **CE Marked**
- **Ip20 rating**
- **Available from 12 to 110v**
- **Speed proportional to voltage**

Typical Technical Data Curve



Important

Any model of the LEM-200 can be made up into the 2X2 version. This is 2 motors married together on a single shaft see 2X2 installation drawing for details on our website. This can also be supplied in a V-Twin layout which gives the same performance.

Fig. N.2- Lynch LEM 200 data sheet

Appendix O: Data Acquisition Post-Processing

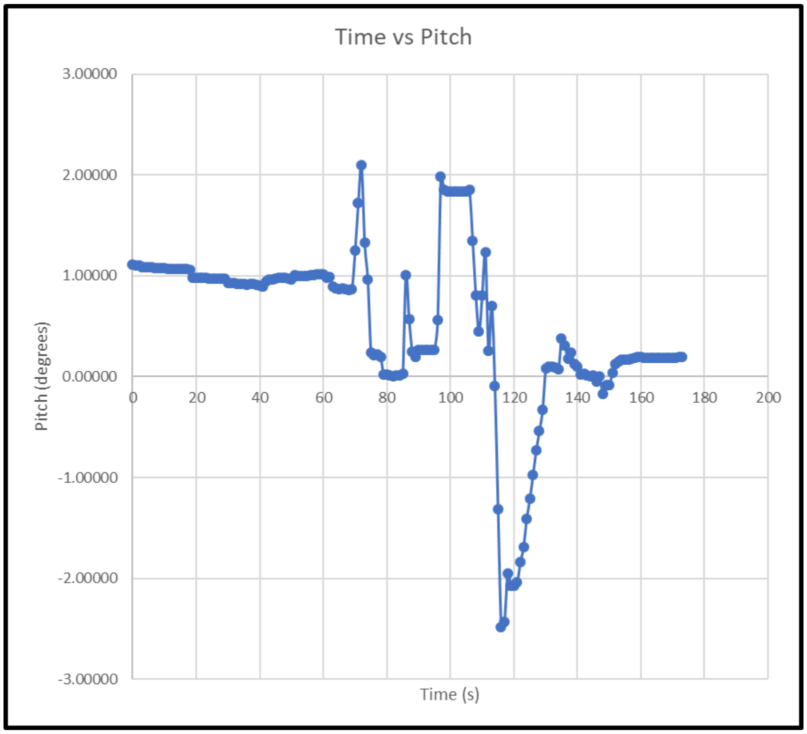


Fig. O.1- Initial water test, sprint event, measured pitch according to time

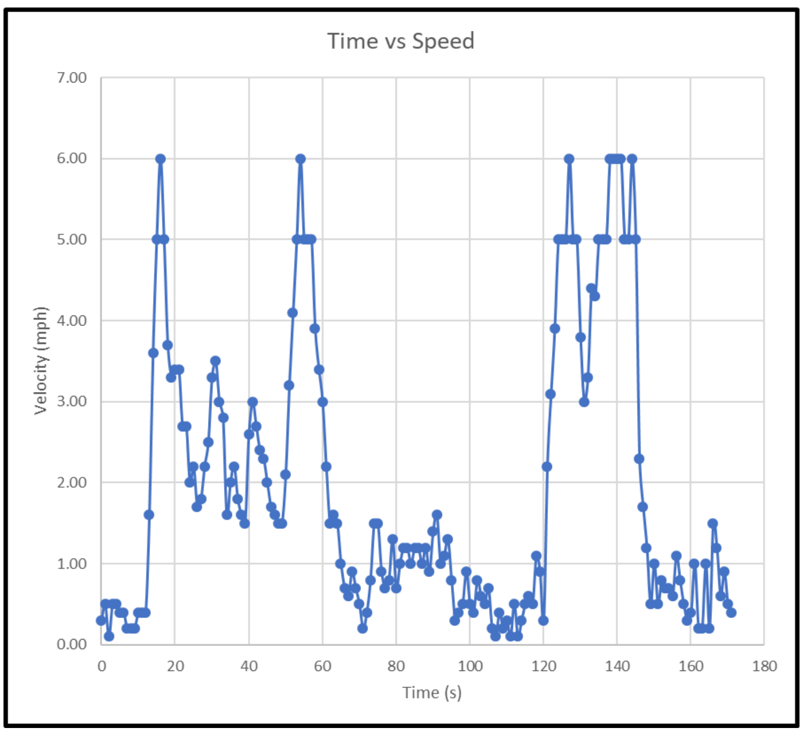


Fig. O.2- Initial water test, sprint event, speed according to time

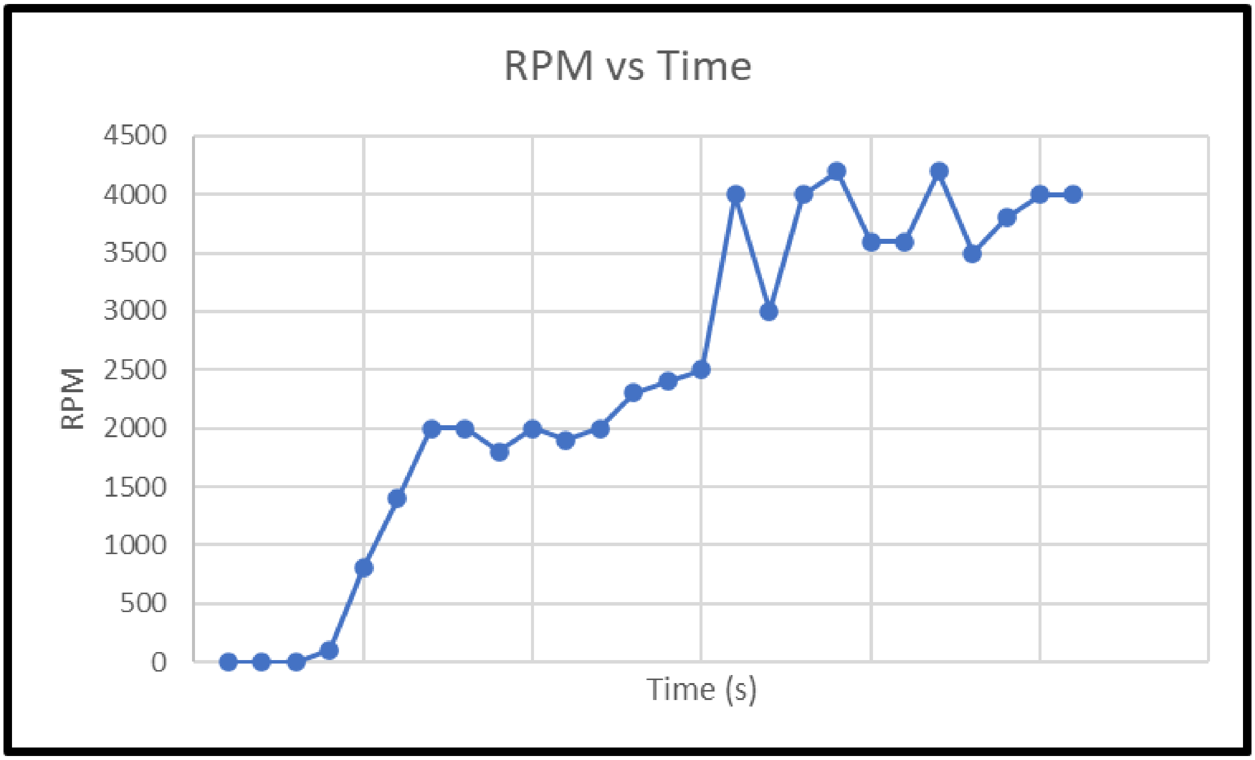


Fig. O.3- Dry test, sprint event, RPM according to time

InterSense® InertiaCube4™

The 4th generation InertiaCube4 is the industry's leading 3-Degrees of Freedom (DOF) MEMS-based inertial technology, utilizing advanced Kalman filtering algorithms to produce a full 360° sourceless orientation tracking sensor. The sensor's portable package with high-end performance and accuracy is ideal for a range of applications, including simulation & training, virtual & augmented reality, motion capture, robotics and human movement analysis.

Technical Specifications

Key Features

- Sourceless 3DOF Tracking with Full 360° Range
- Accuracy of 1° Yaw, 0.25° Pitch & Roll
- 200 Hz Update Rate 1000 Hz available for USB
- 2000° Maximum Angular Rate
- Adjustable Output Filters and Rotational Sensitivity
- In-situ and Environmental Compass Calibration Tools for Static Magnetic Field Compensation
- USB and RS-232 Versions Available
- AHRS Output

General Specifications:

Degrees of Freedom: 3 (yaw, pitch and roll)

Angular Range: Full 360° — all axes

Maximum Angular Rate: 2000° per second*

Minimum Angular Rate: 0° per second*

Accuracy (RMS): 1° in yaw, 0.25° in pitch and roll at 25°C*

Angular Resolution: 0.01° RMS*

Max Update Rate: 200 Hz, 1000 Hz available for USB (contact Thales)

Minimum Latency: 2 ms for RS-232 (PC host and OS dependent)

Prediction: up to 50 milliseconds

Interfaces: USB or RS-232

RS-232 Rate: 115200 baud

Size: 36.6 mm x 27.7 mm x 13.8 mm

Weight: 11 grams

Cable Length: USB 6 feet (2 m), RS-232 15 feet (4.572 m)

Power: 6 VDC, 40 mA

Operating Temp. Range: 0° to 50° C

O/S Compatibility: Windows, Linux, and Mac OS X

Software Features

Compass Calibration Tool compensates for the effects of static magnetic field distortions

Magnetic Environment Calibration Tool prevents performance degradation by dynamic detection of magnetic disturbances

U.S. Patents

5,645,077; 5,807,284; 6,162,191; 6,176,837; 6,314,055; 6,361,507; 6,409,687; 6,474,159; 6,681,629; 6,757,068; 6,786,877; 6,922,632; and 7,000,469

*Measurement with perceptual enhancement set to '0' (at +25° C)
Specifications are subject to change without notice.

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ISO 9001 · AS 9100

2604:062020:V2

Thales has a policy of continuous development and improvement and consequently the equipment may vary from the description and specification in this document. This document may not be considered as a contract specification. Graphics do not indicate use or endorsement of the featured equipment or service.

Fig. O.4- Inertial measurement unit (IMU) data sheet

General

DIMENSION	2.9" x 5.7" x 1.4" (7.48 x 14.42 x 3.64 cm)
TOUCHSCREEN	✔
DISPLAY SIZE	2"W x 3.5"H (5.06 x 8.93 cm); 4" diag (10.2 cm)
DISPLAY RESOLUTION	272 x 480 pixels
DISPLAY TYPE	bright, transflective 65K color TFT, dual-orientation touchscreen; sunlight readable
WEIGHT	10.2 oz (289 g) with included lithium-ion battery pack; 11.7 oz (333 g) with 3 AA batteries (not included)
WATERPROOF	IPX7
BATTERY TYPE	rechargeable lithium-ion (included) or 3 AA batteries (not included); NiMH or Lithium recommended
BATTERY LIFE	up to 16 hours (lithium-ion) up to 22 hours (AA batteries)
INTERFACE	high speed mini USB and NMEA 0138 compatible
MEMORY/HISTORY	3 GB

Maps & Memory

ABILITY TO ADD MAPS	✔
BASEMAP	✔
AUTOMATIC ROUTING (TURN BY TURN ROUTING ON ROADS) FOR OUTDOOR ACTIVITIES	Yes (with optional mapping for detailed roads)
MAP SEGMENTS	4000
INCLUDES DETAILED HYDROGRAPHIC FEATURES (COASTLINES, LAKE/RIVER SHORELINES, WETLANDS AND PERENNIAL AND SEASONAL STREAMS)	no (additional mapping needed)
INCLUDES SEARCHABLE POINTS OF INTERESTS (PARKS, CAMPGROUNDS, SCENIC LOOKOUTS AND PICNIC SITES)	no (additional mapping needed)
DISPLAYS NATIONAL, STATE AND LOCAL PARKS, FORESTS, AND WILDERNESS AREAS	no (additional mapping needed)
EXTERNAL MEMORY STORAGE	yes (32 GB max microSD™ card)
WAYPOINTS/FAVORITES/LOCATIONS	4000
TRACKS	200
NAVIGATION TRACK LOG	10000 points, 200 saved tracks
NAVIGATION ROUTES	200, 250 points per route; 50 points auto routing

Fig. O.5- Garmin Montana 600 specs

Appendix P: Project Management Materials

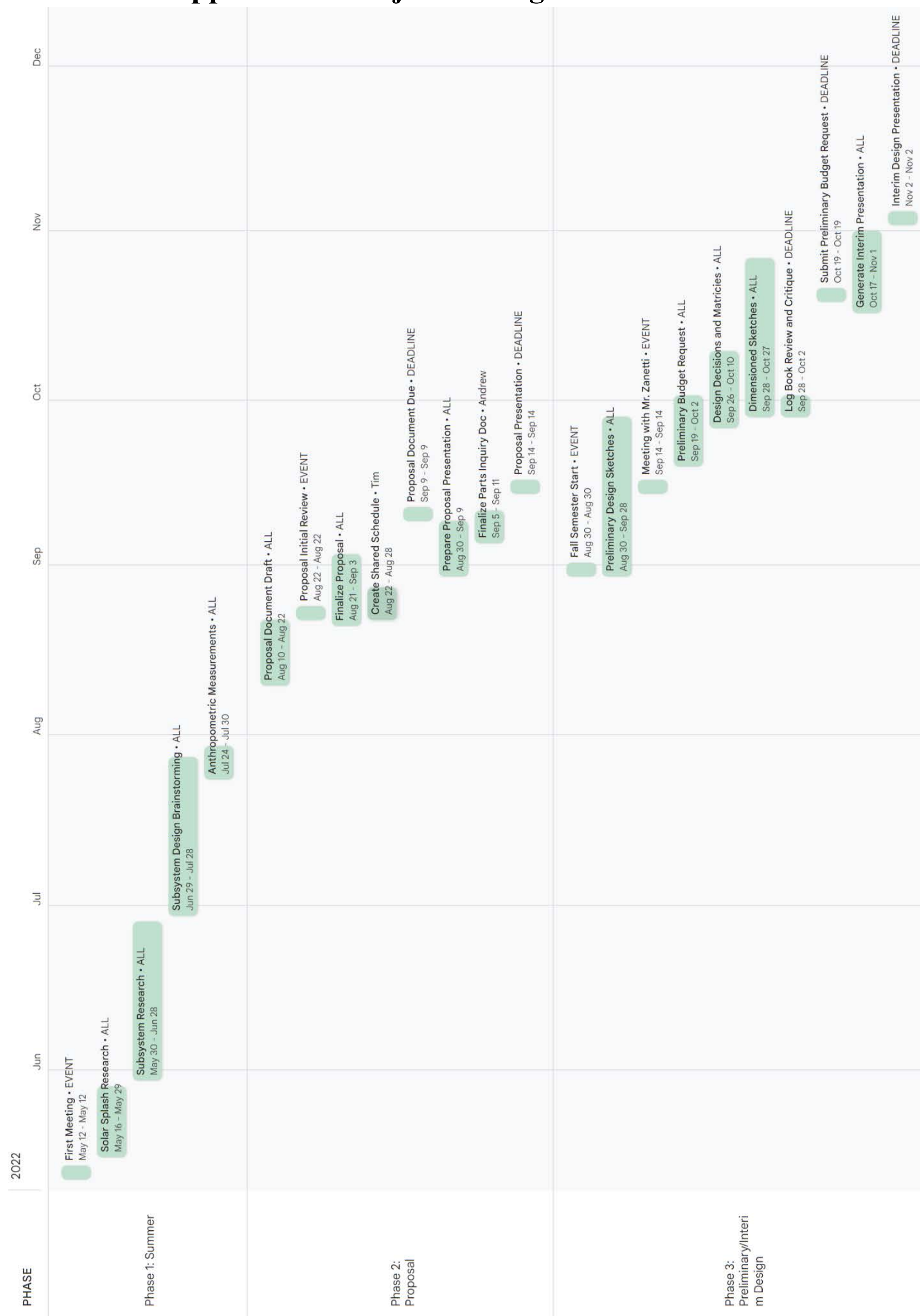

Fig. P.1- Gantt chart for Phase 1 through Phase 3

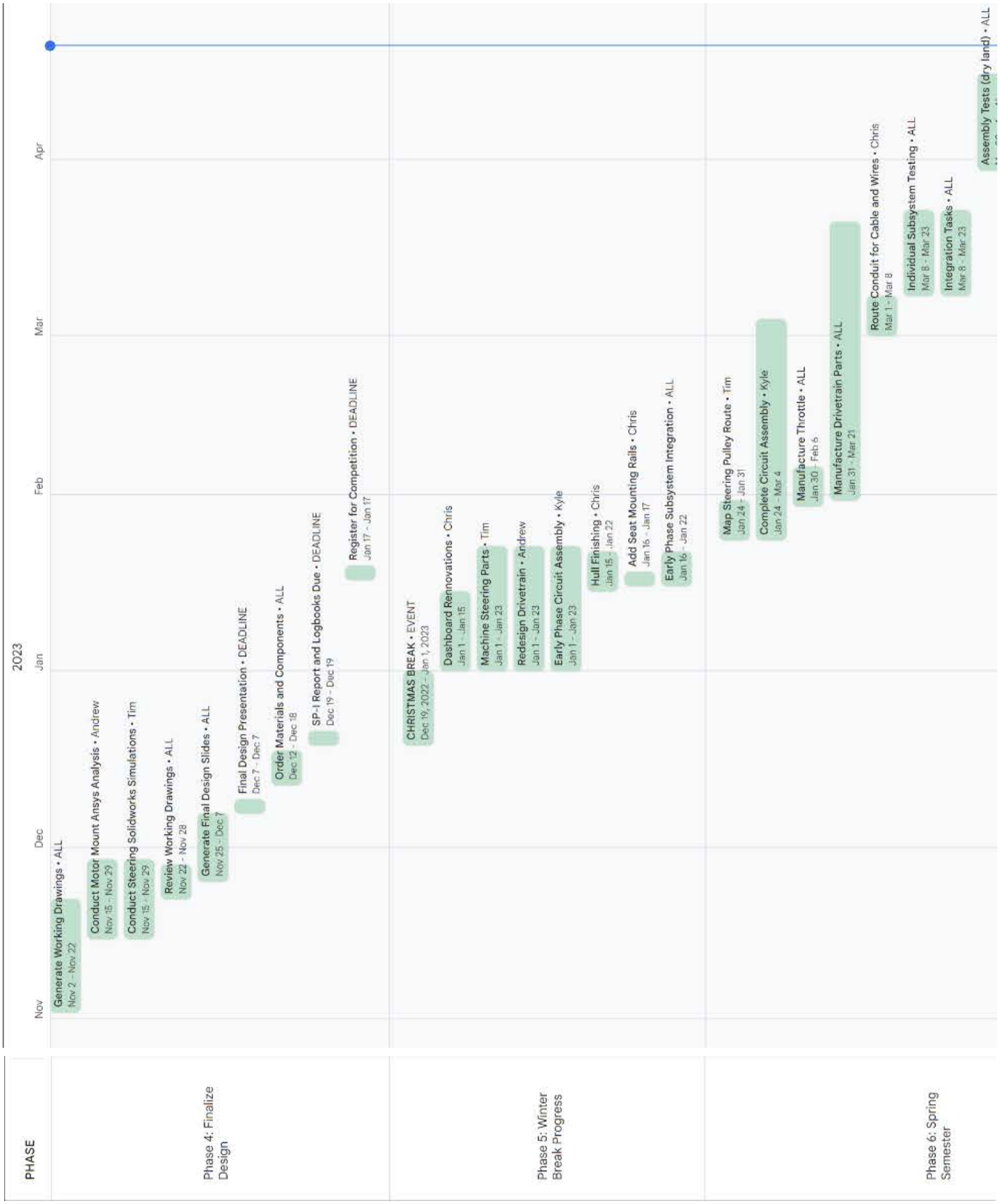

Fig. P.2- Gantt chart Phase 4 through Phase 6

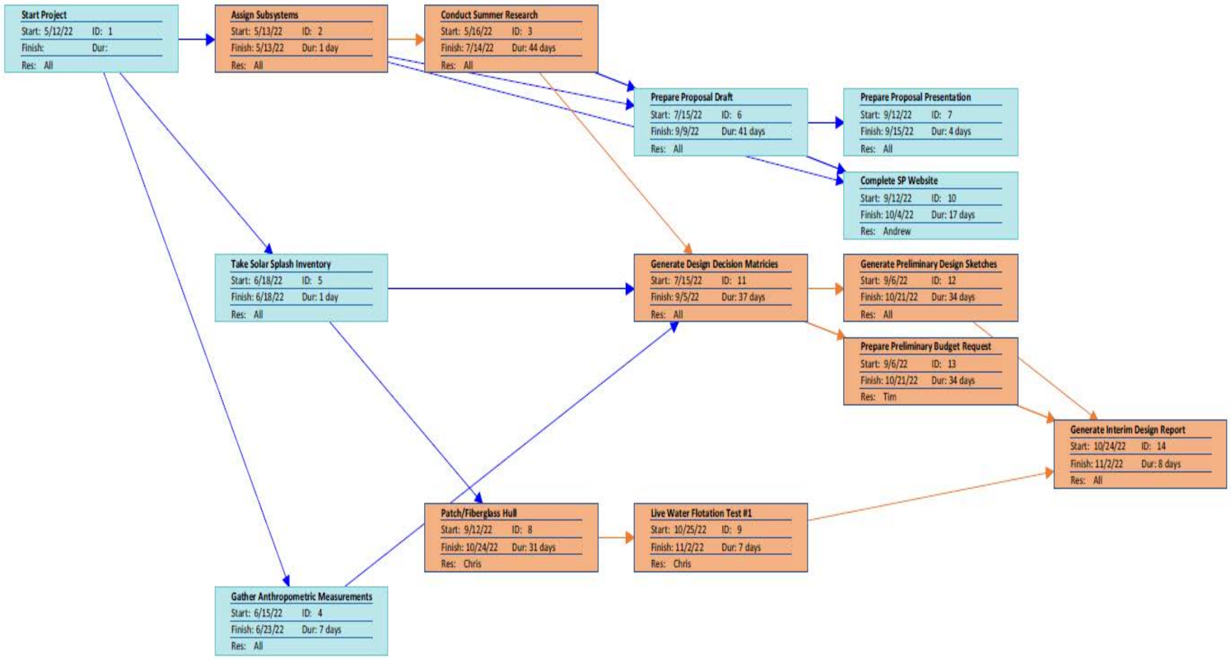

Fig. P.3- Critical path network for Phase 1 and Phase 2

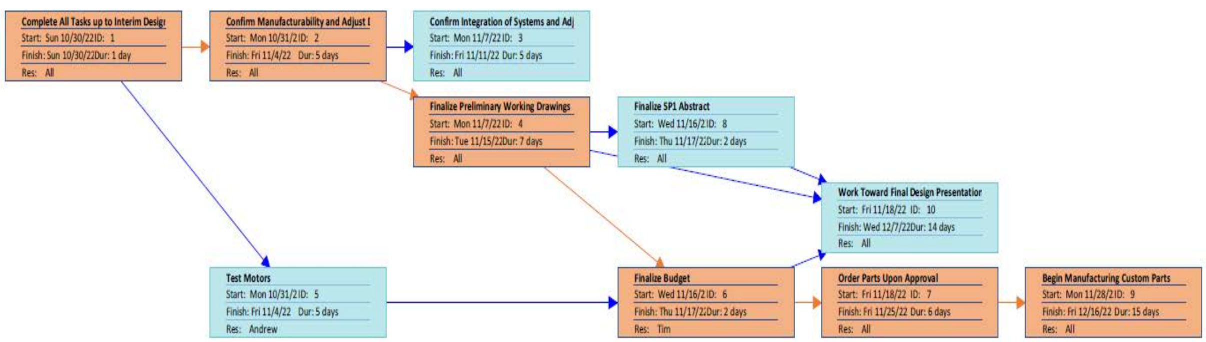

Fig. P.4- Critical path network for Phase 3 and Phase 4

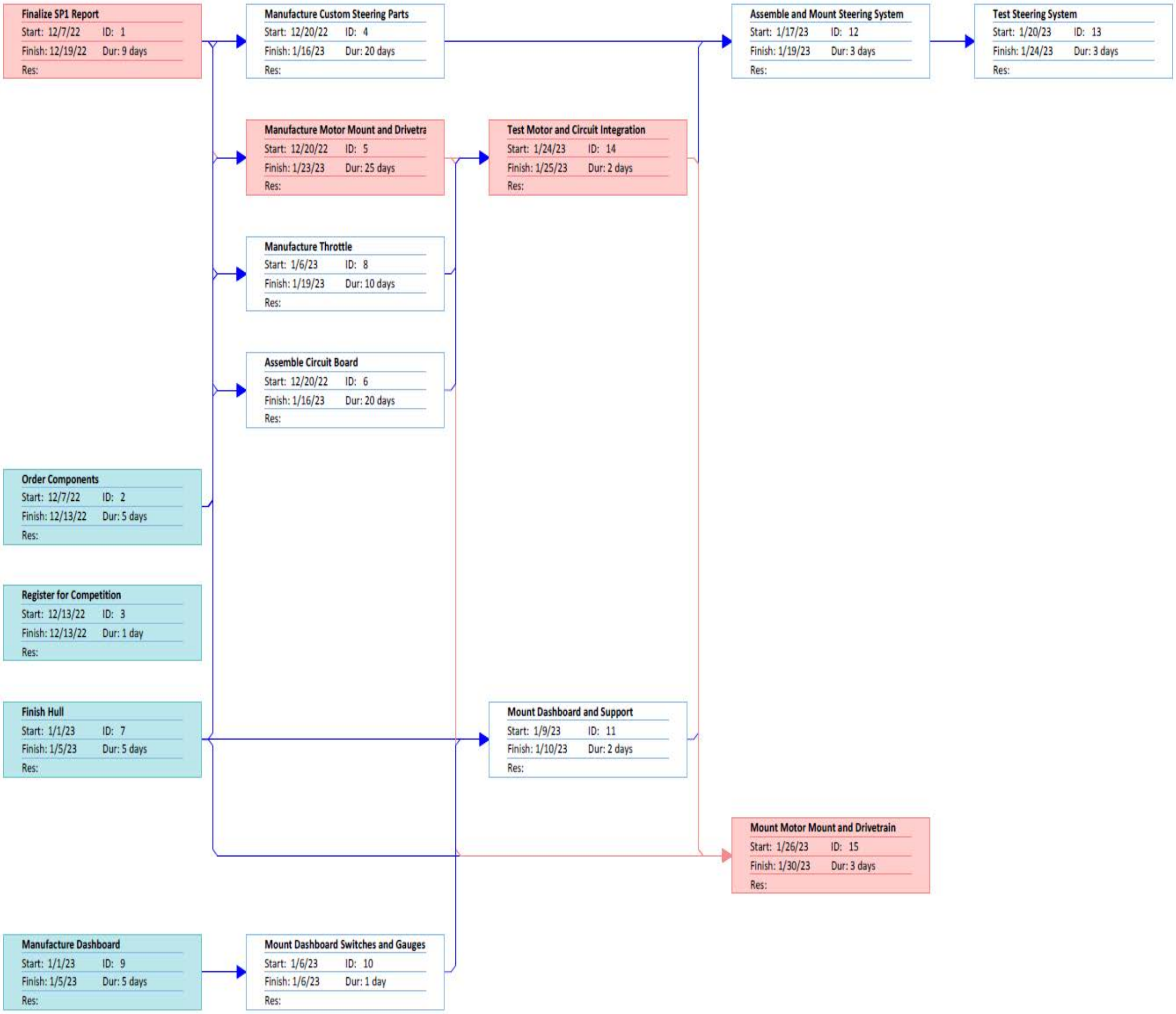

Fig. P.5- Critical path network for Phase 5