Solar Splash Competition: MTSU's Solar Boat Team's Design Review with an Emphasis on Recent Capstone Projects

Dr. Saeed D. Foroudastan
Middle Tennessee State University

Abstract

The Experimental Vehicles Program (EVP) at Middle Tennessee State University (MTSU) has competed in a variety of vehicle competitions annually and has been participating in the Solar Splash Challenge since 2004. The competition is held in Springfield, Ohio every year in June, and usually takes about five days to complete. Once each team is registered, the judges conduct technical inspections of all onboard systems to ensure all vessels meet safety standards. The teams then compete on the water in multiple Slalom, Sprint, and Endurance heats. The results from these heats, the grades received for the technical report, and the interdisciplinary promotional video determine the overall winner. The competition is sponsored by prolific organizations such as UPS Battery Center, American Society of Mechanical Engineers (ASME) Solar Energy Division, and American Power Boat Association (APBA) [1].

The challenge requires students to build a solar-powered watercraft to compete in the qualifying, slalom, sprint, and finally endurance events. Each team is also responsible for constructing a technical report, which highlights innovative design aspects that the team added to the boat. Students learn to apply solar energy in a watercraft efficiently and gain hands-on experience with sustainable energy and energy management [2]. Each part is manufactured in MTSU laboratories and more than 80% of the boat is built by hand.

The solar boat project was created by the associate dean of Basic and Applied Sciences, Dr. Saeed Foroudastan. Most students who are in EVP use their hands-on experience to complete their Capstone course requirement and make an innovative design that can be contributed to the Solar boat. Team members who participate in the Solar Boat design and construction gain several advantages when entering the workforce due to their experience with engineering mechanics, teamwork, and interdisciplinary skills. The purpose of this paper is to explain how the technical design of vehicle competitions gives every member an advantage when entering the workforce, such as hands-on engineering experience, construction, fabrication, teamwork, and interdisciplinary skills.

Introduction

The EVP is not a dedicated course curriculum but is instead based on volunteers who participate solely to gain experience in designing, building, and manufacturing various vehicles. We submit various documents in each competition, giving students experience in writing, business, and finance [7]. The team is comprised of diverse students from majors including aerospace, mechatronics engineering, and biotechnology.

The Solar Splash competition has been held annually since 1994, with the overall goal of integrating sustainable power systems into vehicles and boats [1]. Since the team started competing, we have won over 35 awards and continue to improve our design. In 2022, we won the Outstanding Workmanship Award, Outstanding Hull Design Award, and Outstanding Drivetrain Design Award. We also won fourth place overall, and third place in the sprint configuration in the events. After analyzing the results of the 2022 Solar Splash, the team decided that the planning and steering capabilities of the boat needed to be upgraded to rank higher in the overall competition. There were several primary objectives this year including distributing weight to the back of the boat, shortening the drive train, upgrading the telemetry system, improving the steering, and remounting the solar array. To achieve these goals, the team collaborated on data collection, drive train modification, and solar panel array design with a combined effort towards efficiency and functionality in pursuit of victory. In the 2023 competition, our team placed fourth overall, third in the United States, third place for our video presentation, and lastly earned the Outstanding Solar System Design. Our team was successful at making the necessary changes to win the design awards we were striving for. The following sections will focus on the design changes implemented from 2022-2023, as well as various capstone projects that elevated the vehicle design while expanding members skillsets.

Solar Splash: About the Competition

The Solar Splash competition gives teams the ability to build teamwork, create system designs, and gain hands-on experience with sustainable alternatives to traditional watercraft power systems. Traditional watercraft power systems are inefficient for the environment, and this project creates an alternative that is less harmful. [3].

Before the competition starts, every team must submit a video presentation, and a technical report. The technical report is 90 points, and the video presentation is 40 points of your total score. Later during the competition, each team competes in a series of events that are added together to determine placement. The first event teams compete in is the qualifying, where the officials determine if your boat will be able to competently compete in the following events. The qualifying event is 100 points of the 1,000, and teams can then compete in all events after passing this event. The endurance race consists of 400 of the 1,000 points available, because the purpose of this race is to charge the lead-acid batteries with the solar panels throughout the event and the team with the most laps wins. The teams that can accelerate quickly and maintain battery voltage will have the most laps. Another aspect of the challenge is every team is allowed 100 pounds of lead-acid batteries in their boat, and for the duration of the competition teams must use the solar panels to charge the batteries. Most teams made sure their batteries were fully charged by the end of the day and started with charged batteries in the morning. The sprint event consists of 250 points, and the purpose of this event is to go as fast as possible. Finally, the slalom race is 100 points, and the fastest team to finish the course wins (the course is a figure-eight). The weight of the point system was considered by the team when creating design changes for the 2023 competition. This required team members to work together to discuss what skillsets we have available, and what each member can contribute to the competition to gain all possible points.

Solar System Design

This year the team elected to continue to use the four 120 W solar panels that used Sunpower's Maxeon Gen III cells. The panels weigh 4.5 pounds each and have a maximum voltage of 20 V along with the maximum amperage rating of 6 A. Sunpower's monocrystalline solar panels and cells are manufactured with built in redundancy, meaning that a loss in wattage or voltage will not be significant if part of the array is covered or shaded. These panels are readily available through retailers such as Amazon or directly from the manufacturer [3].

The team also decided to use a different solar panel array configuration, as this was the only award we did not receive in the 2022 design competition. Starting with a CAD rendering of the final array which can be seen in figure 1, our team used wooden beams and metal hardware to complete the design. The solar panel system is only used during the endurance event, meaning the aerodynamics of the array were not interfering with the sprint event [3]. The endurance event is a total of eight hours, and our design allows the driver to be always shaded in the event. In figure 2, the boat is shown at the endurance event with the completed solar panel array. Throughout the solar system design, team members gained valuable experience in the design process for any engineering project and the necessary teamwork to complete a project of this scale.

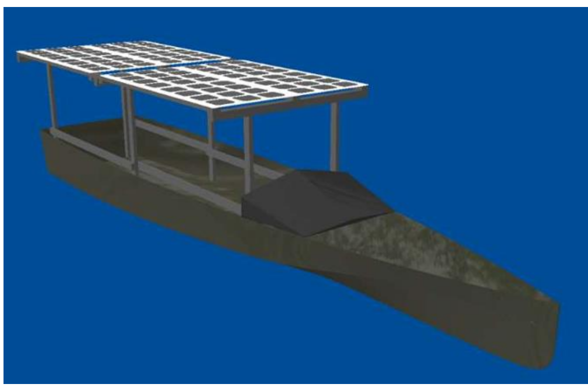


Fig. 1 (left). The 2023 solar panel array in a CAD rendering.

Fig. 2 (right). The endurance event at the 2023 Solar Splash with the team's final solar panel array.

Fig. 3. 2022 solar panel array.

Electrical Design

This year the team separated the electrical systems into two categories: the endurance and sprint events. The difference between the two configurations is the battery voltage and battery type. For the endurance race, the boat is powered by two 12 V Odyssey extreme 34M-PC1500 deep cycle marine batteries, which weigh a total of 49.5 pounds each. The Odyssey batteries have a reserve capacity of approximately 2.5 hours, and we elected to wire the batteries in series to create 24 V. The batteries are also wired to two 500 A fusses that splits the electrical power between our two Lynch motors independently. For the sprint configuration, we opted to use three 12 V Red Top Optima 75/25 batteries wired in series by 3/0 wire [3]. These batteries weigh approximately 100 pounds total and were selected based on energy density. Each motor’s electrical system is comprised of a 500 A fuse that is wired to a large red kill switch button.

We are also required to have a dead man's switch on the boat per Solar Splash rules, but the kill switches on the motors are different. As an extra safety redundancy, two red kill switches are mounted on top of the motor housing as a quick kill switch. These red buttons allow us to independently test each motor without the need to disconnect the opposing motor. It also allows us to disconnect all power to the electrical system to perform maintenance.

Another innovative design added onto the boat in 2022 is that all the electrical components and motors resemble a V8 engine block, which can be seen in figure 3 and 4. Several seniors wanted to get creative with their capstone projects, and this was the product of their research. To create this effect, the team designed a plexiglass case that would enclose the two Lynch motors and provide mounting points for the other components. The box was first created in a CAD rendering, and then sent to a plastic company to be machined by a CNC. The housing unit was made from a ¼" thick blue plexiglass sheet that was machined and later bent to create the desired shape. After the housing unit was completed, all the other components were carefully placed to resemble the V8 engine. The Alltrax motor controllers resembled valve covers, and a computer fan was mounted to the side of the unit to give the effect of a radiator fan. The high-raise intake system was mocked by using two red kill switches, and finally the solenoids and wiring resemble exhaust pipes coming out of the engine. The two Lynch motors are contained within the housing unit and can be seen through the plexiglass.

Because this project completely encloses the motors extensive research was conducted to verify the set-up was safe to run. In the event of a failure, the housing unit can still be taken off in a timely manner due to the securing units used [3]. The students who dedicated their capstone projects to this design made great progress in their own mechanical and electrical skills as well as project management, and each skill gained can be used in their future careers.

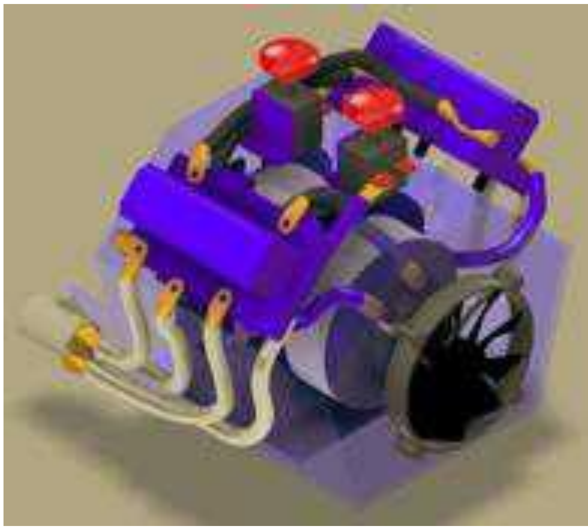
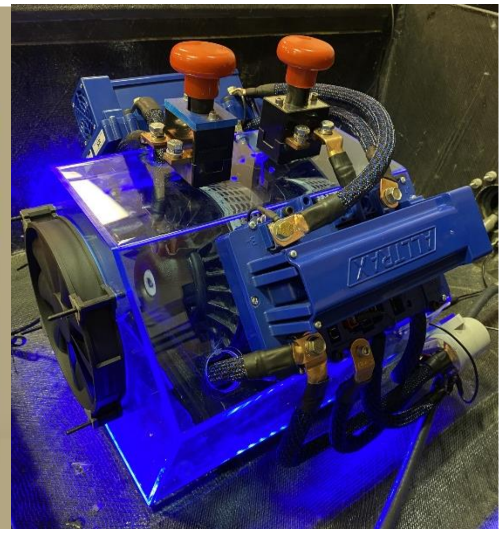

Fig. 4 (left). CAD rendering of the V8 motor case.

Fig. 5 (right). Finished version of V8 motor case.

Drivetrain System

In 2022, the team used an Arneson surface-piercing drivetrain because we were impressed by its performance on past models. The team started by reducing the 2016 Arneson drivetrain by 25% to reduce the overall weight. The tandem motors installed in the 2022 boat eliminated the need for a chain drive between the motors and allowed increased efficiency by implementing a direct drive system that utilizes a reduction box to allow for altering the output ratios of the motor shaft. The input shaft was machined in-house using a 3/4-inch aluminum rod and U-joints were used to connect the input shaft to the gear box incorporated into the motor housing. The socket housing was also scaled down to 5 1/2-inches and machined in house out of aluminum. Because of how much the boat sits up out of the water, or where the water line sits, a secondary transfer case was machined in house. This allows the center line of the drive train to be parallel to the lowest point on the transom, allowing for a fully submersible propeller rather than a surface piercing propeller. Using a laser cutter, we constructed all gaskets necessary to prevent water from entering the hull. Inside of the socket housing is the ball and socket joint constructed from ABS plastic which has enough structural integrity to effectively allow the propeller shaft to rotate left and right for steering, as well as up and down for trim. This was by far the most difficult part to machine or 3-D print but, by utilizing ABS plastic instead of the previous materials that included brass and aluminum, the construction became much easier and much more accurate since the outer diameter of the ball joint must match exactly to the inner diameter of the socket joint to prevent any binding and allow the shaft to pivot in all directions effortlessly. The ABS component as well as the drivetrain can be seen in figure 6.

After testing this design, the team elected to machine a metal fin that would attach onto the drivetrain to help with steering and turning (figure 7). After successfully creating all the design changes to the drivetrain system, students have expressed that they feel more prepared for their career and gained interdisciplinary skills as well as design process methods.

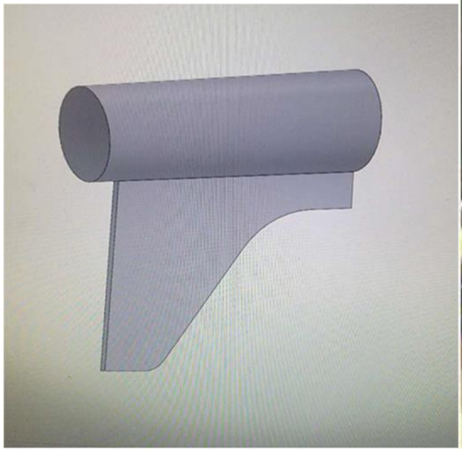
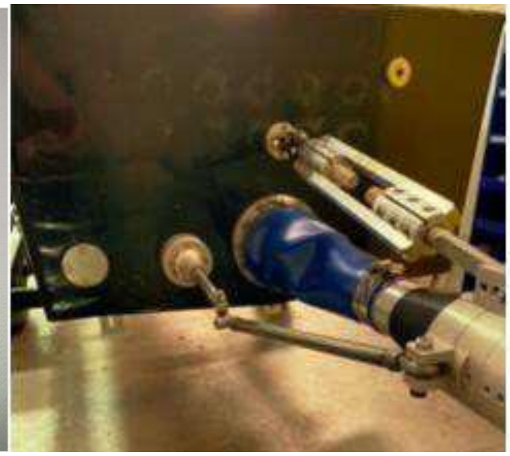

Fig. 6 (left). CAD rendering of the fin on the drivetrain.

Fig. 7 (right). Cable trim bar and 3-D printed drag reducers.

Project Management

If the team can successfully improve project management practices, then we can increase the efficiency and effectiveness of the team, leading to better results. This year, the team implemented a weekly meeting to make sure the top goals are met, and to get everyone on the same page. Efforts were made to diversify ranks by recruiting minority/women students and were successful in gaining more members with different backgrounds. The 2023 team was comprised of students with different majors like biotechnology, engineering management, mechatronics, aerospace, mathematics, computer science, and many more. This greatly improved our performance capacity and created different avenues of research. Each team member is selected for certain jobs based on their skillset, and the team captain is awarded to the person who has consistently shown dedication to finishing the design changes.

Budget for 2023

Table 1. Budget for the 2023 solar boat design.

Line Number	Item Specs	Price
1	Hull	1000.00
2	Drivetrain	400.00
3	Solar Cells	2000.00
4	Motor Controller	750.00
5	Batteries	1400.00
6	Lynch Motors	5000.00
7	Miscellaneous Electronics	300.00
8	Solar System Array	150.00
9	Total	11,000

The budget for the 2023 design changes was sponsored by Nissan and Lane Motor Museum, as well as our Engineering Technology Department at MTSU. Without their support, the team would not be able to integrate new and innovative technologies.

Capstone Projects

Every year students integrate the projects pertaining to EVP and their capstone projects. This allows students to complete a requirement of their degree while contributing to our projects and gain hands-on experience in the engineering field before venturing into a job opportunity. This year, we had several students use the solar boat project to create a capstone project, including a toroidal propellor, a software library to hack into our Tristar MPPT, and the V8 motor case that was mentioned in the electrical portion.

We had several toroidal propellor designs made in CAD, and each propeller was simulated in Open Prop to determine the best design. Based on the simulation results, the team elected to create a two-bladed propellor, because it was concluded the efficiency would increase 40-50%. Toroidal propellors create less drag than normal, and at our RPM for the motors the efficiency should increase approximately 62% [4]. The team also reached out to several local ceramic casting companies to be able to create the propellor, as this type of casting is not offered at the university. Precision Castings of Tennessee agreed to cast two toroidal propellors for the team, and let students interested in the process come in and watch. Unfortunately, the propellor was not manufactured in time to bring to the competition, but the research and networking that was put into the project will be beneficial to the team in future design changes.

Another project that a computer science major delved into was solving our Tristar MPPT software issues. Before the project, we were relying on proprietary software that came with our Tristar MPPT-45 solar controller. It was functional but required inefficient effort to log in at boot and had limited functionality into what it could exactly log. To solve this issue and further our software capabilities, we opted to construct a library which uses MODBUS to directly communicate with the solar controller over a serial connection. MODBUS is a communication protocol which works by having a master-slave relationship, in which the master requests something from the slave with packets corresponding to the desired action. For the construction of our library, we chose to leverage Python and the already existing library, Py Modbus, which does most of the heavy lifting for us regarding MODBUS. To start, we took the MODBUS data sheet and translated it into a Python API which allowed us to read specific values from the solar controller. Not only did we introduce reading values, but we can monitor the current faults and alarms and override certain charging regulators relating to the array and battery. The underlying method to consistently read values and monitor faults is to use multi-threading, in which we have a thread which consistently reads the entire memory of the solar controller and operations can be done on said memory under other threads.

After the API's design, the next goal was to create a logging framework which was expandable and easy to use. To do this, we incorporated callbacks by having Enums, which represented the variable we wanted to log; then it would translate to the correct function and be called to retrieve the current value. It would then write all the logged variables to a .csv file, which can be visualized with several data visualization frameworks.

In addition to accomplishing our initial goal, we also created a GUI for the boat which uses the library and allows us to see real-time data, control more of our boat, and it starts right at startup without navigating through endless menus [3].

Conclusion

The solar boat design gives members an opportunity to gain hands-on experience in their desired field while increasing their mechanical, fabrication, and documentation skills. The design changes input in 2023 were beneficial to the overall performance of the boat, an example being the solar panel array. We felt successful in creating an array that was never seen in the competition before and would greatly impact the driver while in the endurance race. Because our design was unique and shaded the driver during the 8-hour event, our array won a design award at the 2023 competition, and we plan to improve the design further for the 2024 competition. The team also elected to shorten the Arneson drivetrain to create a better planing capability, and created fins that attach to the drivetrain for an improved turning capacity. With our boat hull being so lightweight due to the materials used, we opted to shift the weight distribution to the back of the boat making an increase in the planing. With all the major design changes, the team was successful in increasing the efficiency of the planing, steering, turning, and overall performance of the solar boat.

Every year, the solar boat team at MTSU consistently improves the boat design by adding exciting technologies and reading developing, innovative research that can benefit the boat design. This year, our team did research regarding toroidal propellors on boats, and in aircrafts. We also created multiple versions of a toroidal propellor in CAD and picked the best design to fabricate. We hacked into our Tristar MPPT solar panel controller by utilizing a computer science major that can hack into programs. By hacking into the Tristar, we create the ability to control more voltage than the Tristar settings could manage and can charge 48 volts of batteries with our solar energy at a single time.

In 2022, students took part in creating a housing unit for the Lynch motors that resembled a V8 engine. Although this project mostly enhanced the creativity of the boat and not overall performance, the team was ecstatic to see the finished product, and it is a conversation starter at the Solar Splash competition.

The three capstone projects finished in 2022 and 2023 are just limited examples of research that senior level students can immerse themselves in to create an innovative and efficient design on the solar boat. The capstone projects contribute to the overall design and can help lower-level students gain the experience they need to carry out their own capstone project.

References

[1] Solar Splash Event. Web. Accessed 21 August 2023. www.solarsplash.com/introduction-and-information.

[2] Foroudastan, S & Nihill, C., "Experiential Learning Enhances the Knowledge of Future Engineers Through the Experimental Vehicles Program." Proceedings of the 2017 Conference for Industry and Education Collaboration, American Society for Engineering Education.

[3] Hardin, L. M., Wetter, D., Foroudastan, S., & Garretson, B. (n.d.). *Middle Tennessee State University Solar Splash Team- Experimental Vehicles program*. Technical Report 2023. Accessed 21 August 2023.

[4] Cornwell, S. (2023, February 9). *The toroidal propeller: The Pinwheel Innovation for Marine Engines*. Nautic Magazine. https://nauticmag.com/2023/02/06/the-toroidal-propeller-the-pinwheel-innovation-for-marine-engines/

[5] Foroudastan, S. Enhancing Undergraduate Performance through Peer-Led, Team-Learning (PL-TL). enhancing-undergraduate-performance-through-peer-led-team-learning-pltl.pdf

[6] Foroudastan, S. (n.d.). Solar Power and sustainability in developing countries. https://files.udc.edu/docs/cere/Solar%20Power%20and%20Sustainability%20in%20Developing%20Countries.pdf

[7] Foroudastan, S. & Cambell I. (n.d.). Student Projects: Hands-on Experience with Mechanical Engineering Technology. student-projects-hands-on-experience-with-mechanical-engineering-technology.pdf

Biography

SAEED FOROUDASTAN is the associate dean for the College of Basic and Applied Sciences at Middle Tennessee State University, which oversees 10 departments. He is also the current director for the Master of Science in Professional Science (MSPS) program and a professor of engineering technology at MTSU. Foroudastan's academic experience includes teaching at Tennessee Technological University and Middle Tennessee State University in the areas of civil engineering, mechanical engineering, mechatronics engineering, and engineering technology. Foroudastan is the faculty advisor, coordinator, and primary fundraiser for EVP teams entering national research project competitions such as the Formula SAE Collegiate Competition, the Baja SAE Race, the NASA Lunar Rover, and the Solar Boat Collegiate Competition.