Solar Splash Challenge Applies Hands-On Engineering Experience with Sustainable Energy and Energy Management

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Abstract

The Middle Tennessee State University Solar Boat Team challenges their skills by competing in the Solar Splash Challenge, a national educational event that takes place over the course of five days in June every year. This competition is sponsored by prolific organizations such as UPS Battery Center, ASME Solar Energy Division, and several high school and college level international participants. The challenge requires students to construct a solar powered boat to compete in several different categories including technical reports, visual displays, workmanship, sprint races and endurance events. Students learn to apply solar energy in a transportation efficient design and gain hands-on experience with sustainable energy and energy management. Each part is manufactured in the Middle Tennessee State University (MTSU) laboratories and more than 80% of the boat is built by hand.

The Solar Boat project originated in 2004 by the MTSU Associate Dean of Basic and Applied Sciences, Dr. Saeed Foroudastan. Most students use this project to complete their Capstone course requirement, a necessity to graduate. Seniors help undergraduate level students succeed in the competition by helping them learn about 3D design technology. 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.

1. Introduction

This exciting, teamwork -oriented summer challenge has been an educational event since 1994 [1]. The Solar Boat participants at MTSU have received over thirty awards, such as 1st Place Outstanding Workmanship (2019), 1st Place Outstanding Drive Award (2019), Design Achievement Award (2012), Teamwork Award (2011) and the Outstanding Drivetrain Design Award (2006) [2]. The Solar Boat constructed by 2019 team is powered by the use of photovoltaic panels and batteries. The 2019 Solar Boat design uses custom-made solar arrays using Sunniva Technologies' Maxeon Gen III solar cells. In the past, the MTSU Solar Boat team has had a good amount of success when applying two 240 Watt Panasonic HIT solar panels, pre-built widely manufactured solar panels. In 2019, the team resolved to build their own solar panels constructed inside the MTSU laboratory. The MTSU program secretary ordered 150 individual Maxeon Gen III Le3 Solar cells and 500 Maxeon interconnecting tabs required to solder the cells together. These are made by Sunniva Technologies. Maxeon Gen III Le3 cells each output exactly 0.634 Volts at 6.06 Amp, providing the total amount of power output of 3.84

Watts Power per cell. In total, 138 cells would be required in order to achieve a total wattage of 529.92 Wp to draw the maximum allowable power by Solar Splash rule number 8.4. Unfortunately, due to damage during shipping paired with time constraints, the team was restricted to applying only 125 cells, supplying the solar cell with a total energy capacity of 480 Wp. After acquiring the materials needed, the MTSU Solar Boat team members tested the cells by rewiring them into a TriStar MPPT-45 charge controller. The tests concluded the total wattage had not changed from the pre-manufactured Panasonic panels but showed the array had indeed increased in efficiency. The 280 W Panasonic panels that were previously used in the competition had a peak efficiency of approximately 19%. The Maxeon solar panels will achieve a peak efficiency of 24.8%, adding a 5.8% increase. A primary decision among the MTSU team was to employ the Maxeon cells because they are built to provide efficient solar power even if the array is partly covered under shade of clouds or trees. For the benefit of the team, the loss in wattage or voltage will not be a significant amount. The aim for the Solar Boat team is to show originality upgrades and earn awards for Electrical, Innovative and Workmanship design and demonstrate improvement in overall team performance.

Fig. 1. Solar panel array for 2021 Solar Splash Competition.

2. Solar Splash Competition

Many students agree that constructing a fully functional, energy-efficient motor challenges their engineering and classwork knowledge and workmanship skills. The Solar Boat students first provide fundamental examples for 3D hull models using Inventor 2020. The Solar Boat project was founded due to the initiation of the Solar Splash Competition hosted by the Institute of Electrical and Electronics Engineer Power Electronic Society, an international, scholarly competition promoting solar/electric powered boats [1]. The Solar Boat team has participated in the Solar Splash Competition since its initial challenge in 2004. The Solar Boat allows students the time and effort to advance their knowledge about utilizing solar energy as an alternative energy source. Members work together throughout the course of the project to brainstorm, research, design, and test the creative solar design project. Many of these team members are university seniors who use the Solar Boat program to their advantage by completing it as their capstone project [3]. For the sake of the student upon graduation, this project helps graduates to

gain hands- on engineering experience and can benefit their credentials when entering into the engineering workforce.

The many team members of the MTSU Solar Boat program have faced individual and team-related challenges during the process of completing the solar boat, but in learning efficient problem-solving techniques, they have come up with a myriad of creative solutions. Throughout the time participating in the Solar Splash competition, the teams have come up with many creative shortcuts for implementing a new design. In more recent years, MTSU Solar Boat teams have incorporated an innovative drivetrain system. The drivetrain system helps to support steering and provides adjustable trim. Another addition is the hull, which was constructed completely of basalt biaxial woven fiber paired with a special core material known as Polyethylene Terapthalate (PET). The material used was cost-effective and lightweight, allowing the team to construct a structurally rigid hull that averaged seventy pounds. The new team members constantly improve on the year's previous design. This year's team was motivated to reducing the aerodynamic drag of the boat. The telemetry system is another option the team plans to improve on. The telemetry system is initiated by a 2-mile range WI-FI system to provide the team onshore monitoring of system voltage, current draw, throttle position, speed, distance traveled, and GPS position.

The MTSU Solar Boat team members are determined to find new, innovative designs every year. The team members and faulty staff have been graciously awarded with several design-specific awards. Some of these design awards include: Design Achievement Award, Outstanding Workmanship Award, placing in the top 10 overall, Sprint Award, Placed First in Solar Slalom, Visual Presentation Award, Sportsmanship Award, Outstanding Electrical System Design Award, placed third and fourth in Best Technical Report and Technical Display, Outstanding Drive Train Design, and Outstanding Hull Design Award [6]. The MTSU Solar Boat project has won over 30 awards, which give a great sense of pride for the program members. These students continue to work hard and dedicate many hours to this project [6].

3. Materials Chosen

1. Hull: The Middle Tennessee State University Solar Boat students have chosen to design and construct the hull by using Autodesk CFD to analyze the fluid dynamics, and the hull with the least amount of drag was selected. To test the hull's flotation, the team takes the unmodified hull to a local swimming pool in their hometown. Team members enter the craft and attempt to capsize the hull and make it sink. If the craft does not capsize, the students know they have made a good product. The next phase of the hull testing requires students to sit on top of the boat when it has capsized in another attempt to sink it. The design and fabrication of the hull was done by the student, but a consultant provided the material and guidance to help the student [4].

2. Drive and steering: The drive train and steering system have proven to be undoubtedly necessary throughout the years [8]. The steering system provides a clear and direct turning capability with only a few turns of the steering wheel. The drive train is powerful and reliable as well. The boat powers forward by twisting of the throttle knob manually.

3. Telemetry: The telemetry system is very compact and simple. The motor controllers were chosen for their ability to connect to the USB server and then to the wireless antenna. From there, the team can receive the status of our motor controllers from the onshore control box.

4. Batteries: Batteries are required based on the rules. For the sprint mode, the teams chose three automotive batteries to provide a satisfactory power trip with 36 volts. For the endurance the team decided to use two heavy-duty marine deep-cycle batteries to provide maximum power for an extended period.

5. Solar Panels: The panels that were chosen are commercially available. After an extensive amount of research and comparison, panels are chosen and have the best efficiency. Additionally, they are easy to install onto the hull.

4. Design

1. Create various 3D hull models using Autodesk Inventor 2020
2. To test each model, the students use a simulation software, Autodesk CFD (Computational Fluid Dynamics). This program tests how the hull models will perform and will determine the drag of each design.
3. The design with the lowest drag is chosen as the final model.
4. The final model is then sent to DayCab Company in Rockwood, TN. This company has a large-scale CNC so they can take the 3d model and turn it into a life-sized, physical object made from foam [4].
5. The boat must be designed in two halves (front and back) as it is longer than the CNC machine
6. After boat hull halves are machined from foam, they are then transported to Composite Solutions, in Woodbury, TN. Composite Solutions allows the students to work at their facility so they can have plenty of space to construct [7].
7. The two foam halves are then glued together using various composites
8. This is referred to as a plug as it will be the plug that makes the mold foam.
9. The surface of the foam plug was deemed to be too delicate, so the students decided to cover the entire surface with a thin layer of fiberglass.
10. After fiber glassing, the surface of the plug was not smooth enough for sustainability. A smooth plug will allow the mold to be removed will be easier.
11. In order to make the rough surface smoother, the team covers the entire surface of the fiberglass with a grey sanded primer.
12. This will allow the boat to be sanded to the plug for desired smoothness.
13. This is done using various grit sandpapers. Once the boat is perfectly smooth, then the process begins using the plug to make a mold.
14. This is done by pouring a molding gel coat over the top of the plug along with various layers of fiberglass.
15. After the gel coat dries, the plug is removed from the gel coat and is left with a boat mold.
16. Begin the processing of vacuum forming a boat from the mold.
17. This is done by first placing numerous layers of fiberglass inside the mold.
18. The mold is then covered with a vacuum bag.

19. Air is sucked from the vacuum bag while fiberglass resin is injected in.
20. The vacuum bag will compress all the resin across the surface of the mold.
21. Once dried a completion of a boat hull with a consistent thickness is created.
22. After the boat hull is made it is then transported back to the Solar Boat lab at MTSU.
23. The students begin installing the various electrical components into the boat. This includes:
24. Installing the electric motors
25. Wiring the dash panels
26. Installing the batteries
27. Attaching the drivetrain and propeller
28. After all the electronic and mechanical components are attached, the students then move on to testing.

Figs. 2 and 3. Step 4: The final model is then sent to DayCab Company in Rockwood, TN. This company has a large-scale CNC so they can take the 3d model and turn it into a life-sized, physical object made from foam. Step 7: The two foam halves are then glued together.

5. Materials Testing

The initial test requires the completed boat to be taken outside on a clear day. The solar panels are mounted in the proper position and are attached to the boats electrical charging system which is set on endurance mode. The batteries must be displayed below full charge. The objective is to test the connectivity and functionality of the solar power input and charging capability. When outside, the goal is to observe the digital readout of the solar power input on the helm for any shift in solar power. The following test is an endurance run at the local lake. The idea is to simulate an endurance race similar to that in the competition to see if the boat is capable to race. The duration of this test typically lasts two hours, equivalent to the competition. The skipper stays in communication with the onshore personnel using a portable radio. The path of the boat is estimated to be one-quarter of a mile. Data on the boat performance is taken by the skipper and logged by the onshore crew. Testing is performed on Percy Priest Lake. The experiment will test the boat's top speed as well as how long it can operate before running out of battery. After testing the boat is brought back to the shop to change anything that is needed to be changed. The tests are repeated in the testing and redesigning until the results provide a successful synopsis. The vehicle is painted, and the decals are added to make it competition ready [5].

6. Results

In the last two years, the team members nominated to use an outboard style, chain-driven drivetrain that was steered by a simple hydraulic steering cable which worked but had a few detrimental design flaws. The first flaw we recognized was after the team acquired a pre-owned mercury 9.5 hp outboard that was rusted, and in effect did not spin effortlessly. Even after the team chose to clean up the outboard enough to get the outboard to spin voluntarily, there was still some hesitation to use it. The second flaw was the chain position. After the chain-driven outboard and electric motors were mounted directly above the outboard, it made it necessary for our chain to be positioned horizontally, which resulted in excessive noise and power reduction. The team consulted each other with these downfalls and the team began research on drivetrains that would produce optimal results at low-power inputs. The research concluded that Arneson style drives, also called surface piercing drives, are on average 30-40% more effective due to their reduction in underwater drag compared to the previously used outboard style. The MTSU Solar Boat team collaborated to give this modern drive style another chance in the redesign of the 2020 solar-boat design.

This year's custom-made Arneson drive is a direct drive system that utilizes a ball and hip joint that is attached to the transom of the boat at the lowest possible position. A shaft with thrust bearings that houses the drive shaft is extended about three feet from this joint with a surface piercing propeller at the end. This system allows us to position the drivetrain at various trim positions to test both fully submerged props and surface piercing props.
The communication system is extremely important to the overall success of our program this year. Like most other systems, we can remotely communicate with the boat and driver to record and monitor readings for throttle percentage, battery voltage and amperage draw, motor performance, solar panel output, and motor controllers. Our Wi-Fi enabled system uses an onboard Ubiquiti PicoStation M2HP – Wireless Access Point – Airmax – 802.11 B/G/N and a TRENDnet 8dBi Outdoor Omni Directional Antenna TEW-AO08O to transmit live feed of motor and battery amps and voltage draw to another identical on-shore PicoStation where it is monitored on a Asus Republic of Gamers laptop computer, then relayed through walkie-talkies to the boat captain.

What makes this system unique is that not only can we monitor the readings necessary to ensure optimum performance, but we can also remotely adjust the voltage and current going to the motor and modify the throttle curve thereby maximizing our performance in the endurance competition. In addition, this allows the boat captain to focus more on the course direction and the other boat drivers thereby reducing the likelihood for a boat accident. The team participated in the 2019 Solar Splash competition and achieved first-place in the Outstanding Workmanship Award and Outstanding Drive Train Award.

Budget

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	250.00
8	**Total**	**10,800.00**

Most of the funding for the Solar Boat project comes from the MTSU Student Government Association which allocates funds for many student projects. Additional funding comes from grants and donations that are secured by the faculty advisor Dr. Saeed Foroudastan.

7. Industry Partners

The Solar Boat is fabricated within Middle Tennessee State University (MTSU) laboratories and additional locations that provide sufficient space when constructing the hull due to its large size. This provides students with a working knowledge of control and power systems, instrumentation systems, modern 3D modeling and testing protocols, and mechanical systems [2]. When parts of the vehicles cannot be fabricated within MTSU laboratories the students seek outside help. This provides the university and its students the opportunity to create lasting partnerships with local leading industrial companies such as Day Cab Company, Murfreesboro Electric, and Advanced Plastics.

The Solar Boat team attempts to purchases as much of their vehicle components from local businesses to support the community. These businesses include Murfreesboro Outdoor and Motion Industries who both provide parts and gears. Partnerships between the university and local businesses such as Murfreesboro Electric, Advanced Plastics, Fastenal, Tennessee Valley Authority, Stratos Boats, Siemens, Performance Electronics, Davis Science Group, AllVan, Pro Charging Systems, Tennessee Board of Regents, Precision Metal Forming Association strengthens sustainable partnerships and benefits the local economy as well.

These partnerships are exceedingly advantageous to students involved in the Solar Boat project. These companies not only provide materials for the students but will also act as a mentor for the project and the students. The students learn the achievements involved in initiating and completing an engineering project. In addition, the competitors gain interpersonal and professional skills that provide lasting connections in the engineering business sector [3]. Local business professionals that provide mentorship help provide direction to the students during the design and construction phase of the project. Since graduation, Solar Boat competitors have benefited from these business relationships. These students often obtain highly desired employment with these partnerships and receive profound recommendations from the industry

professionals. These professionals have a familiarity of the student's hands-on experience, professional skills and knowledge with sustainable energy and engineering management [2].

8. Teamwork

The entire team effort behind building our new solar powered competition boat was a collaboration between new and old team members. Aside from the roles of Captain and Co-captains, there were only a few specific roles for the team members. A few specialized tasks were granted to certain team members who possessed certain skills or resources required for them.

Fig. 4. Testing the solar boat.

10. Student Advantages and Capstone

The Solar Boat competition provides an educational, beneficial platform for MTSU undergraduate students who are interested to execute essential classroom knowledge and apply hands-on research following graduation. Annually, approximately 150 students from the MTSU College of Basic and Applied Sciences (CBAS) work together to form peer-led project teams. Each boat serves as a multi-step process which allows a team of students to expand upon MTSU research by using their knowledge from the classroom to complete the cost analysis, design conception, fabrication, and test novel vehicle designs with the ultimate goal of competing on the national and international level.

The Solar Splash competition is comprised of various events providing unique challenges that test each part of the vehicle’s construction and performance. These competitions allow MTSU students the opportunity to compete against top engineering schools from around the world. The Solar Boat project is an integral experiment in the professional development of Middle Tennessee State University (MTSU) students. These essential experimental vehicles projects provide a friendly environment in which S.T.E.M students to exercise their classroom knowledge in a real-world setting and learn essential leadership and team collaboration skills. The students are given the opportunity to build their own creative ideas in collaboration with their peers; a rare occasion in typical college curriculum. The creation of their ideas advancing into physical manifestation helps to inspire confidence in their abilities for the future and establish a better

understanding of their classroom engineering concepts, and other S.T.E.M concentrations as well.

9. Conclusion

The MTSU Solar Boat design team considers this project as an overall success due to the extensiveness of the redesign in the 2020 construction and the time and effort that the participants volunteered in their available time. In retrospect, the hull redesign achieved the greatest impact on the overall boat performance. The additional substitute of the Arneson surface piercing drive has effectively caused the boat to reach greater speeds in the sprint event. Some examined weaknesses with this year's design resulted from the underestimating how long it would take to build schedule, this unfortunately impacted the amount of time to test its p performance. Second, the design of the hull proved harder than the team expected, causing delays in the build schedule.

There are a couple lessons to be learned from this year's design. First, allow sufficient time for items such as a complete redesign and second, ensure sufficient resources are available to tackle this large of an effort. In conclusion, the objectives of the team have been met in that performance has been significantly improved and the final build quality is one the team is very proud of. The MTSU Solar boat team would like to acknowledge and thank the efforts of Day Cab Company, Murfreesboro Outdoor and Motion Industry, Fastenal, Stratos Boats, Siemens, Performance Electronics, Davis Science Group, AllVan, Pro Charging Systems, Tennessee Board of Regents, Precision Metal Forming Association, and Advanced Plastics for their contribution in building the Solar Boat, and the sponsorships provided by Tennessee Valley Authority (TVA) and Murfreesboro Electric.

In 2019, the MTSU Solar Boat Team participated in all the events and the members were enthusiastic about their achieved results. In 2020, the Solar Splash Challenge was canceled due to the COVID-19 pandemic, but the team has used this time to implement all the previously mentioned improvements and the boat and will be attending next year's competition to demonstrate the finished result.

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Biography

SAEED FOROUDASTAN is the associate dean for the College of Basic and Applied Sciences (CBAS). The CBAS oversees 10 departments at Middle Tennessee State University. He is also the current director for the Master of Science in Professional Science program and a professor of engineering technology at MTSU. Foroudastan received his BS in civil engineering, his MS in civil engineering, and his PhD in mechanical engineering from Tennessee Technological University. Additionally, he has six years of industrial experience as a senior engineer and 25 years of academic experience as a professor, associate professor, and assistant professor. 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. He has actively advised undergraduate and graduate students, alumni, and minority students in academics and career guidance. Foroudastan has also served as faculty advisor for SAE, Mechanical Engineering Technology, Pre-engineering, ASME, Experimental Vehicles Program, and Tau Alpha Pi Honors Society. In addition to Foroudastan’s teaching experience, he also has performed extensive research and published numerous technical papers. He has secured more than $2 million in the form of both internal and external grants and research funding. 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 SolarBike Rayce, the NASA Lunar Rover, and the Solar Boat Collegiate Competition. For his concern for and dedication to his students, Foroudastan received MTSU awards such as the 2002-03 Outstanding Teaching Award, the 2005-06 Outstanding Public Service Award, and the 2007, 2018, and 2019 Faculty Advisor of the Year Award. He received the Excellence in Engineering Education Award and Faculty Advisor Award from the Society of Automotive Engineers (SAE). He was also nominated for the MTSU 2005 and 2009-11 Outstanding Research Award. He received two Academic Excellence awards from the Tennessee Board of Region in 2010-11. Foroudastan has also won many College of Basic and Applied Science awards. In addition to this, Foroudastan also reviews papers for journals and conference proceedings of ASEE, ASEE-SE, and ASME, and he has been a session moderator for several professional conferences.