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Experimental Vehicles Program Improves Student Performance Through Energy Conversion and Conservation with Hands-On Learning

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Abstract

The Experimental Vehicles Program (EVP) at Middle Tennessee State University is an undergraduate research program consisting of four experimental vehicle projects: the Solar Boat, the NASA Human Lunar Rover, the Formula Hybrid SAE, and the SAE Baja. The EVP was implemented to help students develop their professional skills and use their classroom knowledge of Energy Conversion and Conservation to promote hands-on learning. The members work on projects that could look very similar to what they might work on in their respective careers. Each of the four teams work to research, design, and build their vehicles to prepare for their respective competitions. All four of the completed projects participate in national competitions, this paper will focus mainly on the Solar Boat project and the NASA Human Lunar Rover project. These projects have been extremely successful, winning many awards at the competitions. Since each event is highly competitive, the students must work diligently to design a better vehicle and have the opportunity to use top-of -the -line technology to do so. The program provides a safe environment where students are encouraged to test their ideas, and work together to improve them. First, this allows students to build life skills such as teamwork, creativity, and communication. Second, students are also able to work with faculty mentors and industry partners for guidance and advice. Many times, these relationships turn into career connections. Most of these students have a great chance of securing an excellent job once they graduate. Those connections paired with all the skills the students learn on the way provide big advantages when students are ready to enter the workforce. Every year, about seventy students participate in the EVP and are given the opportunity to further their knowledge through hands-on learning.

Introduction

The world is constantly evolving and bringing new challenges. These new challenges require engineers with great experience. Therefore, the Experimental Vehicles Program (EVP) was formed at Middle Tennessee State University. The EVP program allows students to get hands-on engineering experience, along with building their research and development skills. Building experimental vehicles provides many opportunities for students to develop their creativity, work as a team, and create parts with groundbreaking technology.

Each year, the EVP students create new, increasingly efficient vehicles for each project. These unique research projects provide great benefit for the professional development of engineering technology. Students gain a direct application of hands-on learning in the workshop, which is different than the traditional learning style in a classroom. In addition, these projects help students learn to think inventively, communicate professionally, manage projects efficiently, and work cooperatively in a team environment [1].

Solar Boat

One of the projects offered by the EVP is the Solar Boat. The Solar Boat project was founded following the inception of the Institute of Electrical and Electronics Engineer Power Electronics Society's Solar Splash Competition, and international collegiate competition showcasing solar/electric boating [2]. The EVP has participated in the five-day Solar Splash Competition since its inception. Students who work on The Solar Boat are inclined to think about current topics, such as use of solar energy as an alternative energy source. While the team must follow a strict set of guidelines to be able to compete in the Solar Splash, they still have a large amount of creative freedom. Team members collaborate throughout the course of the project to brainstorm, research, design, test, and adjust their boat. It requires commitment and determination from everyone involved.

Figure 1: Solar Boat dash

The team faces a variety of challenges during the process of completing their boat. Throughout the time of the EVP participating in the Solar Splash, the different teams have come up with multiple creative repairs. One of the recent teams incorporated an innovated drivetrain system. It helps with steering and provides adjustable trim. The aforementioned team also constructed the hull completely of carbon fiber paired with a special core material known as Lantor® Soric XF3. This material was inexpensive and light weight, allowing the team to construct a structurally rigid hull that was approximately just ninety pounds. There were multiple improvements to last year's design, the team straightened out the skew that pulled the boat to the left, the telemetry system was improved, and the aerodynamic drag of the boat was reduced. The telemetry system is implemented by a long-range WI-FI system that has a maximum range of two miles to provide the team onshore monitoring of system voltage, current draw, throttle position, speed, distance traveled, and GPS position.

The modifications and innovations discussed above are just some of what the team has done over the years. Each year, the boat improves, and the team shows the new model in competition. The teams continually place in the top of the competition and win multiple design specific awards. Some of these awards include: Design Achievement Award, Outstanding Workmanship Award, 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. Most of these awards have been won multiple times by the Middle Tennessee State University Solar Splash team.

Figure 2: Solar Boat on the water

Solar System Design

In the past, Middle Tennessee State University has seen great success by employing two 240 Watt Panasonic HIT solar panels. This year the MTSU team decided to implement our own custom solar arrays. 150 individual Maxeon Gen III Le3 Solar cells were purchased through Sunniva Technologies along with 500 Maxeon interconnecting tabs for soldering cells together. Maxeon Gen III Le3 cells each output 0.634 Volts at 6.06 Amp, giving us a power output of 3.84 Watts Power per cell. 138 cells are needed in order to achieve a total wattage of 529.92 Wp. By doing this, we draw the maximum allowable power by Solar Splash rule 8.4. However, due to damage during shipping paired with time constraints, we were only able to successfully implement 125 cells, providing us with a total of 480 Wp. These cells were then wired into a TriStar MPPT-45 charge controller in order to monitor and control charging. Although the wattage has not changed from the pre-manufactured Panasonic panels, the array will achieve an increase in efficiency. The panels that were previously used, the 280 W Panasonic panels, had a peak efficiency of approximately 19%. This year's Maxeon solar panels can achieve a peak efficiency of 24.8%, providing us with a 5.8% increase. Furthermore, Maxeon cells are manufactured with built in redundancies. This means that a loss in wattage or voltage will not be significant if part of the array is covered or shaded which was the main reasoning behind why the team selected these particular cells.

In order to begin our solar array design, some assumptions must be made. We are aware the solar array must be able to charge three 12 Volt Optima 8025-160 Sealed Lead Acid Batteries, equaling a total voltage of 32 V for sprint as well as two Trojan deep cycle 12V batteries, equaling a total voltage of 24 V for endurance. In order to do this most efficiently, the solar array must deliver a voltage that is 6 V more than the battery pack voltage to the charge controller. This means that the combined voltage the cells must deliver to the controller is 42 V, based off the highest pack voltage (sprint). This requires that at least 67 cells be wired in series in order to achieve this voltage. From here, we began our solar design. Our design consisted of 69 cells wired in series. Those were wired to another pack of 69 cells in parallel with the first. In total, this would deliver 43.75 V and 12.12 A, or 530.25 W with each parallel group providing half the power. This design was simple to wire but had one major flaw. If one of the cells or interconnecting tabs between the cells were to break, there would be an immediate loss of approximately half the power. In order to combat this, each pack of cells was wired in parallel at each individual cell junction. The key advantage of this design, due to the parallel links at each cell junction, is that one broken single broken cell cannot disrupt the circuit. However, due to the damage of some cells we were only able to achieve 124 total panels, totaling 39.625 V and 12.11 A, or 480W. The back section consisting of 80 panels is shown in *Figure 3*.

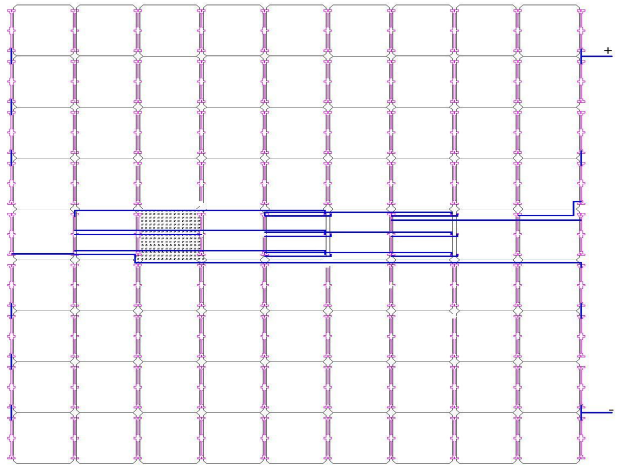

Figure 3: Detailed drawing of all cell connections

The second major consideration was that the solar system design needed to fit within the small surface area of our top deck. Pre-manufactured Panasonic panels were mounted using Ram ball mounts at various structural points around the boat. This required very little contact with the top deck of the hull. With this year's integration of custom solar arrays, the team had two potential designs for how to attach the solar panels to the hull. The first idea was to create a custom frame around each pack of cells and use the typical ram mounts. However, the original Panasonic panels weighed 33 lbs. a piece, totaling 66 lbs. for the full system. This idea was not implemented due to the concern of the extra weight added to the frame. This led the team to our current design. The team permanently mounted the cells directly to the top deck and made the top deck removable. This would allow us to mount the panels easily with minimal weight while allowing us to replace them if necessary. The solar cells were attached in two parts: the bow section consisting of 45 cells and the stern section consisting of 80. First, the cells were wired and tested using 500 W halogen lamps. The arrays produced the proper voltage and current. Second, each cell was adhered to an ABS sheeting provided by Advanced Plastics using a non-conductive, Loctite polyether adhesive sealant. Advanced Plastics also provided a thin layer of plexiglass which was added on top of the cells to prevent damage. These ABS sheets were finally secured to the top deck of the hull using the same caulk. *Figure 4* below shows the final mounting of the stern section.

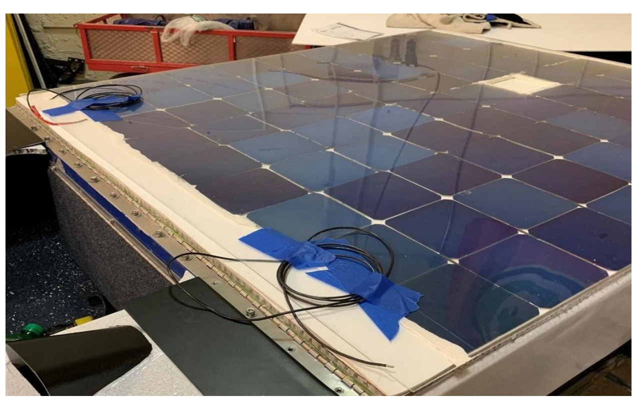

Figure 4: Stern solar array after final mounting

NASA Lunar Rover

The Lunar Rover is a popular project the EVP offers. The Rover receives specific guidelines from NASA for the Great NASA Lunar Rover Race. The team participates in each year. Some of the criteria is included is as follows: it must be able to operate through different terrains of the half-mile course. It must be operated by one female and one male. It must be carried to and be assembled at the starting line, and more. The team brainstorms together in the lab before deciding on the design. The lab has multiple materials and tools the team can test.

Figure 5: NASA Lunar Rover in action

In recent years, the Lunar Rover team has improved on the steering system, changing it from its original design of a radial system to closely resemble a rack and pinion system. The team decided to try this after tests showed the radial system to be unsatisfactory. The use of left and right-hand controls proved to be more efficient than that of a traditional steering wheel. The steering system and wheels were designed so that the wheels stay at ninety degrees through the rough terrain. Also, the students have constructed a suspension system for the riders so that they can easily ride right over the rough terrain. The propulsion system was modified as well. It consists of two complete systems, requiring an increased level of communication between drivers, but has a built-in redundancy and can continue operating even if one system fails. A telemetry system has also been developed and improved, allowing the team to track the rover while it is operating through the course.

Figure 6: Students on NASA Lunar Rover

Wheels

When designing wheels, the Middle Tennessee Rover team has typically utilized a 28” to 30” diameter constraint, and this wheel size has been successful. Last year’s wheel design used a diameter of 28”, drastically reducing weight. Unfortunately, while a weight reduction was experienced, this size change also impeded the performance of the vehicle. Our current design opts for a wheel with a larger diameter, increasing the size on our design to a 32” outer diameter. This size was based on three constraints: the 15” clearance between the frame and the ground required by the rules, the print bed size available for the NinjaFlex-capable printer (47” x 47” x 16.5”), and the 24” outside diameter of the 1” thick ultra-high molecular weight (UHMW) polyethylene rims.

The rims are made of black UHMW polyethylene because of its availability as well as the previous success experienced by the UHMW polyethylene rims used by the Rover team in 2018. This material determination made it possible to perform a FEA available with Autodesk

Inventor's static analysis feature. Once the simulation proved the validity of the rim geometry and use of this specific material, the rims were machined from sheets of UHMW. The design allows the rims to slide into a 3D printed tire with the appropriate pattern, allowing it to rotate and lock into attaching sections.

Our tire design includes a honeycomb pattern to allow for both strength and flexibility. Due to unacceptable stress analysis results, angled bars were included for necessary reinforcement. The tires are printed from thermoplastic polyurethane (TPU) because of its elasticity and resistance to abrasion. While the team was impressed by the performance of the honeycomb design in the wheel design from the 2018 competition, a material change was necessary, because the tire did not perform as well, as expected. The tire, which was printed from *Onyx*, a composite consisting of carbon fiber powder in a nylon-101 matrix was too rigid for our purposes. TPU resolved this issue by adding the necessary flexibility and shock absorbency.

Tread was an important consideration, because the teams' previous solution was ineffective. During the 2018 competition, the team utilized a diamond-plate styled rubber stair tread that attached to the smooth outer surface of the tire by a thin layer of adhesive. Unfortunately, this adhesive failed, forcing the team to reinforce the tread with rivets. The need for adhesives to secure the tread was eliminated by the current design because the tread was not a separate part anymore. Now the tread is printed as part of the tire. The new printing method, known as direct pellet extrusion, allowed for shorter print time. As a result, the team integrated the tread into the design, preventing the need for extra reinforcement or methods of attachment. Simulations were conducted on the entire wheel assembly with a distributed load of 450 lbs. and yielded maximum Von Mises stresses of 0.764 ksi as shown in Figure 7.

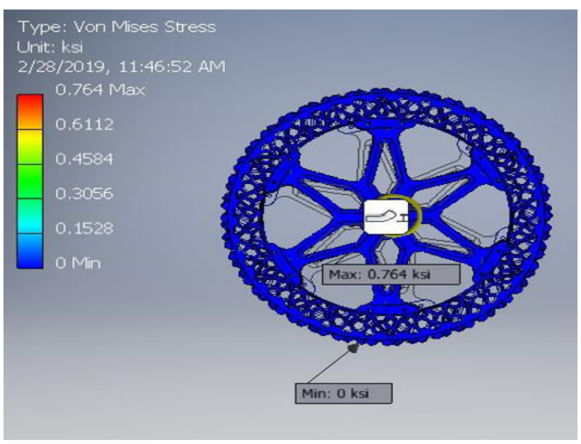

Figure 7: Von Mises Stress simulation

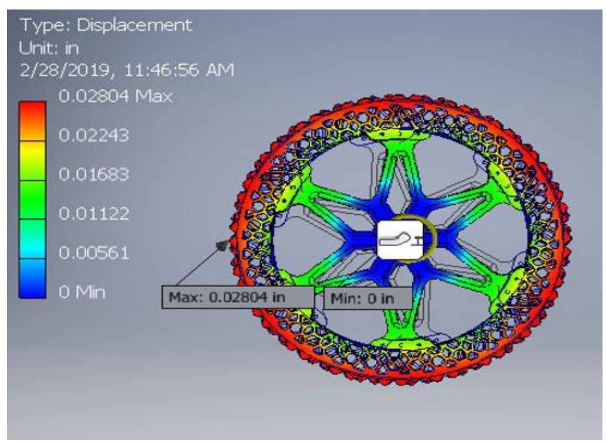

Figure 8: Displacement simulation

The wheels are an important feature that the Lunar Rover team pays specific attention to each year in their design. From 2010-2015, the team constructed the wheels completely in house with some very impressive designs. Starting in 2016, NASA changed the qualifications to require airless tires. The primary idea behind the wheel's design was inspired by a solid-body cross flexure, also known as a cross spring pivot mechanism. The design features arced rails on opposite sides of the solid body tire that allows the tire to compress but not be permanently deformed the spring action. The team chose Ultra High Molecular Weigh Polyethylene (UHMV) as the tire material and used recessed bumpers made from SBR abrasion-resistant rubber for tread. The rigid rim of the wheel was designed to be machined from a solid piece of 7075-T7 aluminum billet and were made to be much more weight efficient than the previous designs. The Rover Challenge Team has been awarded with the Best Wheel Design Award, Telemetry System Design Award, the NASA Systems Safety Award, and the Drive Train Technology Challenge Award. Winning more awards than any other school, the EVP teams have on average placed in the top five overall in the United States and internationally.

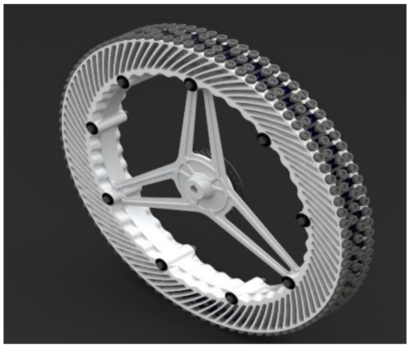

Figure 9: New airless tire design

Retention and Graduation

The Experimental Vehicles Program was created to give undergraduate students a hands-on project to help supplement what they gain from their classroom experience in STEM areas of concentration. Once the students are in the program, they are mentored by upperclassmen, faculty advisors, and local industry partners. Throughout the process of researching, designing, and building whichever project they work on, the students are gaining experience that is applicable to their future careers and learning problem solving skills while strengthening their ability to work on a team. These things they gain from the EVP are so valuable. The EVP has been proven to help the students' grades increase the likelihood of the students remaining in the STEM majors. Not only do EVP students benefit from the projects they work on, but students from multiple STEM backgrounds are able to go see what the EVP students are inventing and how it relates to real designs used in the field. Undergraduate students are allowed to take a capstone course in their last year of study where they can assist with the projects and gain experience with design, research, and development. By participating in the EVP students are able apply their knowledge gained in the classroom to real world engineering situations.

Exit Survey and 5 Year Program Review Questions	EVP Alumni Responses
Did the technical skills learned help prepare you for work in the industry?	100%
Do you feel like the interpersonal/teamwork skills learned prepared you for the workplace?	87%
Was the EVP a talking point in your interview process to be hired? If so, do you feel like being a part of the EVP helped you in acquiring your job?	100%

Table 1: Engineering Exit Survey [3]

Another major advantage that helps the students who participate is the group atmosphere. For most students, learning in a small group is easier than trying to learn individually. These teams of 10-15 students can learn in an environment where mistakes are learning experiences. It provides students a safe place to learn while not feeling intimidated, which increases the likelihood of students staying in the S.T.E.M majors. The teams consist of engineering technology students and non-engineering students. This diversity within the team allows for members to share their knowledge with each other and provide other members with opportunities to learn more about research and hands on development.

Table 1 shows the great results the EVP provides for members who participate. All past EVP graduate students received a survey consisting of 15 questions, three of which are listed in Table 1. From the survey, 95% of members said that the program helped them to stay in school, graduate, and obtain a job with higher pay than a student who did not participate in the EVP. All of students who have worked on the EVP projects said they would recommend this program to other students. In addition to what is listed in the table, out of the members who participate in the EVP projects, 95% receive highly desired jobs upon graduation both at the national and international level.

Students from all universities, national and international, participate in the Solar Splash and Lunar Rover competitions. One advantage that EVP members have is that the Middle Tennessee State University faculty allows the students design, build, and make their own parts for the vehicles. By manufacturing the vehicles on their own, students are better equipped to know if something needs to be fixed during the competition and how to repair it quickly. The experience members receive from working in teams without the constant help of a faculty member provides students with a chance to adapt to challenges they may face in their careers after graduation.

EVP students are responsible for conducting extensive research and development to come up with a purchasing plan for what they need to complete the project and are required to submit cost and design reports to their advisors. Then Middle Tennessee State University faculty advisors require students to design, develop, and manufacture approximately 70% of their materials in the machine shop. To develop their professional communication skills, students apply for every award in their competition, which has led them to win an award every year.

Each year faculty advisors submit grants to obtain money from companies in the industry who support the students in the program. Our faculty advisor has been able to raise approximately $60,000 each year for the EVP. Those in the industry that help fund the program help to mentor students on their designs, research, development, and professional communication. The volunteers can see the impact the EVP has on the students and how much they achieve through hands-on experience. By working together, the se industries are happy to hire the students in the EVP because they witness firsthand how dedicated these members are to their field of study.

Conclusion

The Experimental Vehicles Program at Middle Tennessee State University has been extremely successful since its inception in 2004. Members work in small teams on of the four projects offered, allowing each of their voices to be heard and their engineering talents recognized. The EVP has increased the students' enthusiasm for the S.T.E.M disciplines as well as their engineering knowledge. The students are provided with incredible engineering labs where they can work together to research, design, and perfect their vehicles. Throughout the process they gain skills such as project management, decision-making, leadership, critical analysis, problem solving, and communication. Students learn the value of competition to motivate them to participate at the national and international level.

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