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The NASA Rover Challenge: Revolutionizing Student Learning through Hands-on Design and Implementing 3-D Technology

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Abstract

Middle Tennessee State University's (MTSU) Rover project was implemented for both domestic and international students to design and build a Rover that can compete in the NASA Human Exploration Challenge, a competition for students that occurs annually in Huntsville, Alabama at the National Aeronautics and Space Administration facility. To date, MTSU has received the second largest number of awards to be awarded to a university. The Experimental Vehicles Program (EVP) aims to foster interest in undergraduate students in the Engineering program and enthuse team members with rigorous competition by working together to compose various experimental vehicles with the guidance of faculty mentors. Additionally, partnerships from both national and international industry backgrounds have the choice to assist students in creating the Rover. In the beginning, the program was formed to give students majoring in Engineering Technology at MTSU a direct application for the skills and knowledge they have learned during their undergraduate classes. Today, the program welcomes international students from various science, technology, engineering and mathematics (S.T.E.M) education backgrounds.

Background

EVP has 15-20 international members currently active in the program. The members work with American students and learn about each other's customs. Through building the rover, international and domestic students work together to learn how to bridge potential language barriers. In the EVP program, students from various backgrounds experiment with exciting new technologies to enhance their engineering knowledge outside of the classroom. These mechanics include control and power systems, instrumentation systems, modern modeling testing protocols, and mechanical systems. When certain parts of the vehicles cannot be constructed within MTSU laboratories, students pursue assistance from the public. Through this process, the Lunar Rover team members build partnerships with leading industrial companies and create long-lasting relationships with some of the industry's most influential representatives [6].

The MTSU Rover team intentionally invests in vehicle components from local businesses. Two of these local businesses are the Murfreesboro Outdoor Bicycle Shop and Motion Industries, who have provided a multitude of parts and gears for various projects. A few other well-known local associations include: 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, NASA Space Grant, and Lane Motors Museum, all of whom contribute to the economy at large.

In addition to their experience with the Rover team, the mentors may choose to help EVP members to gain highly versatile and qualified skill sets. The international students learn about the time and effort involved in finishing an entire engineering project and how to cultivate the professional skills that are needed to make lasting connections after graduating college.

The program cultivates a sense of belonging to international members who may not have their families close to home for support. The program has been deemed highly beneficial for international students due to the fact that it enhances the network for individuals to discover new employment opportunities. After graduation, program graduates can potentially benefit from these relationships by obtaining a highly desired employment position or by receiving an outstanding recommendation from various industry CEO's who have a first-hand demonstration of the student's real-world experience and professional demeanor.

Introduction

Middle Tennessee State University's Human Exploration Rovers have steadily improved, resulting in multiple top seven placements out of approximately one-hundred teams competing in the national NASA Human Exploration Rover competition, peaking with two 3rd place overall finishes in 2013 and 2015.

The primary objective of this year's design was to improve the 2019 model by upgrading key components and to improve the known disadvantages. A model of the rover was drawn in Autodesk Inventor by MTSU students and ran through a finite element analysis (FEA) stress simulation to determine distribution of stresses across various vehicle components.

The students use Autodesk Inventor and Simplify3D to design and perfect the creation of airless wheels. From there, the members convert their designs into the appropriate format for 3D printing made possible by Simplify 3D. Simplify 3D is made accessible so MTSU students through their own personal license. Autodesk Inventor was made available for Rover team members with their own educational licenses.

NASA Human Exploration Rover Challenge

Annually, the NASA Human Exploration Rover Challenge showcases students' abilities to tackle an engineering design challenge and compete for awards such as grants, accolades, and trophies. In the past, teams were challenged to create a Rover with recycled material, and recycled wheels used from other vehicles. Today, the specifications for the wheel technology requires "airless" tires. MTSU's Rover teams have designed and manufactured 3D printed wheels that are capable of traversing on simulated extraterrestrial terrain. The simulated terrain contains 5-15-inch boulders, a 6-inch-deep gravel bed, and erosion grooves and crevasses that vary in depths and widths [1]. The standard for each competition includes both a male and female driver. During the 1/2-mile terrain competition, teams earn points based on stages successfully passed, within an 8-minute time limit. Points are also earned through pre and post challenges that depend on the assembly of the vehicle, and the design of the rover. To add more complexity to the race, and encourage students to think critically, they are required to carry the un-assembled vehicle to the starting line and are evaluated on assembly time. The competitors also get two attempts at the course with the final time consisting of the assembly time and the fastest time of both runs. MTSU has won several awards throughout the years, such as Safety Award (2018), Best Engineering Design (2014), and Most Unique Design (2008). The NASA Human Exploration Rover Challenge is linked with the Artemis mission that hopes to return and explore the Moon

by 2024 [1]. The competition encourages students to design, build, and test their Rovers in hopes to develop the next generation of engineers and scientists.

Figure 1: NASA Lunar Rover in action at the NASA Human Exploration Rover Challenge, 2019

Design

The Rover is designed to simulate the NASA Lunar Rover. Each vehicle is designed to be human powered by two students, one male and one female during the competition. Each year MTSU students participate in the “NASA Human Exploration Rover Challenge” a half-mile simulated lunar terrain course that includes "craters", rocks, "lava" ridges, inclines, and "lunar" soil. The students are aware of the challenges they face during the competition, so they design the Rover to withstand the deterioration the vehicle could undergo. The design and construction of the Rover is completed in three different laboratories located on the MTSU campus in the Voorhies

Engineering Technology building. More than 80% of the parts are designed and manufactured by the students alone. This hands-on method is a great advantage for students to learn from their mistakes and be equipped if any failures occur. For instance, when a part is damaged, and needs to be fixed during the competition, the students can quickly repair that part because of their familiarity and understanding of how each part is designed and built. In the past, the use of aluminum proved to be too difficult to employ in fabrication because of the difficulty in TIG welding. The use of 3D printed joints created Rover failures because they proved to be too weak to hold the frame together. Despite the challenges throughout the years, the students used precise documentation for future students entering the Rover Project. Considering the lessons learned, for this competition, the students desire to use 3D printing technology and 4130 chromoly tubing provided great success in this year's Rover design and fabrication [2].

The Rover team designed the main frame with a 1" outer diameter 4130 Chromoly tubing and a wall thickness ranging from .035"-.065". The .035" wall thickness tubing is used in the straight members of the frame that do not require bending; this helped with the material to slightly reduced the overall frame weight. The .065" wall thickness tubing was used where frame members required bending to achieve the desired angles and frame geometry. The control arms were fabricated using ¾" outside diameter Chromoly tubing with a wall thickness of .065". This made more a sleeker profile for the control arms while maintaining the needed stiffness over the 15" members without lattice support. All the design work for this rover was completed in Autodesk AutoCAD and Autodesk Inventor. The students model the entirety of our rover using these software packages before beginning fabrication to ensure that the design would work as they had intended. This also helped the students to see possible errors in the design and give them an accurate estimate for material costs when purchasing and budgeting [2]

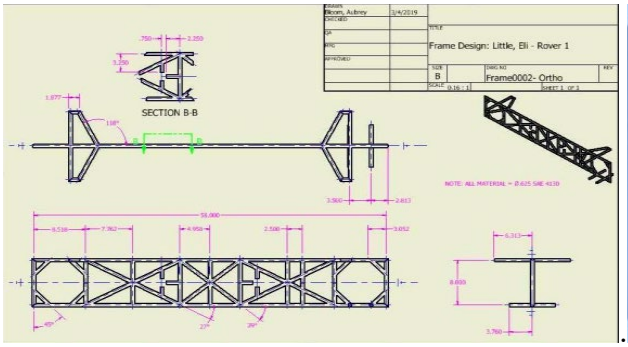


Figure 2: Dimensional CAD drawing of the frame in Autodesk Inventor

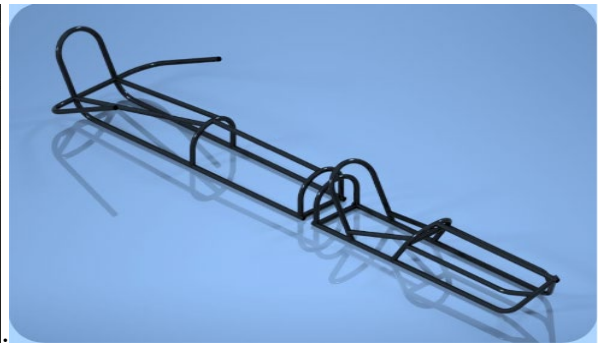


Figure 3: Autodesk Inventor 3D Rendering

Materials Testing

For the Rover team to make the most knowledgeable decision on various material choices for 3D printing our 2019 model, the Rover team tested five materials and compared them to our frequently used PLA filament. The student's ran a series of testing for each individual material. This complex test involved printing a test sample group of specimens in two orientations and at

three separate temperatures proportionate to the material's average printing temperature range. This testing allowed to test the tensile strength of the materials at various temperatures to find the settings that delivered the most acceptable results. They were also able to test the interlayer adhesion of each material at these given temperatures as well. Throughout the testing, the teams kept all slicer settings identical for all materials to avoid any bias for any material.

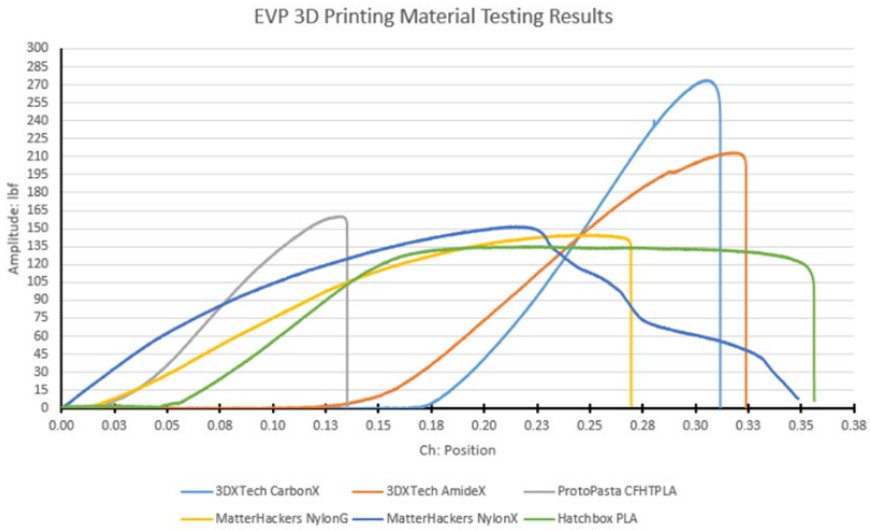
For our testing we used HatchBox PLA as our control material. And tested the following materials:

1.Proto-pasta CFHTPLA (Carbon fiber reinforced high temperature poly lactic acid)

2.MatterHackers NylonX (carbon fiber reinforced nylon)
3.MatterHackers NylonG (glass fiber reinforced nylon)
4.3DXTech CarbonX (carbon fiber reinforced nylon)

5.3DXtech AmideX (glass fiber reinforced nylon)

Figure 4: Results of Multiple Material Testing



Explanation of Results

As testing progressed, the team noticed a trend. The more the print temperature increased, the interlayer adhesion proportionally increased for all materials. There was an inverse relationship between interlayer adhesion and tensile strength. The team understood that this would be the best material to print the final parts with a near perfect balanced level of adhesion and tensile strength.

Explanation of Materials Chosen

The material the team chose for 2019's Rover completion tires is MatterHackers NylonG, which is a glass-fiber- reinforced -nylon. In the materials testing conducted, NylonG had the highest impact resistance and an impressive amount of tensile strength. These reasons made it the best choice for the pneumonic tire because it can absorb consistent, hard-hitting impacts and still keep its original composure after elastic deformation.

The team decided to employ a new material for the spoke segments. This material is currently manufactured by 3DXTech Company. The base material for this filament is a semi-aromatic polyamide copolymer, referred to in conversation as nylon. Due to the higher temperature required to print with nylon filaments, they exhibited excellent interlayer adhesion. The conjunction of these filaments with high-modulus carbon fiber increases both tensile strength and stiffness of the final materialized parts.

The MTSU Rover team chose the MatterHackers Build Series TPU for the tread. This material granted the team two key advantages: abrasion resistance to increase the durability of design and being elastic enough that the contact patch and traction is proportionally linked to vehicle load. Our six tread sections are three inches wide and 13.22 inches long featuring an alternating trapezoidal studded pattern that allows for greater traction on terrain such as dirt and gravel, while the large contact patch allows for flotation on terrain such as sand and mud.

Budget

The cost to build the 2019 rover design was exactly $8,430. The funds were provided by assistance from the NASA Space Grant and MTSU's Student Government Association. Only two changes were updated in this year's rover, the suspension was updated which involved replacing the air shocks with coil-overs, and drivetrain was updated with a new differential.) were made in-house for the 2020 rover. This was created minimal additional budgeting, so the budget remains relatively unchanged and is detailed in this report. This team's Rover wheel design and was provided by several generous sponsors, including: Lane Motor museum, Fastenal, Tennessee Valley Authority, and Middle Tennessee State University's Student Government Association [3].

Frame.....$1,250

Chromoly Tubing (0.625" OD x 0.125" Wall) $1,000

Extra Welding Supplies $250

Suspension.....$595

Shocks $595

Drivetrain.....$985

Tandem Crank Set..... $400

Crank Bottom Bracket Shells $50

Sprockets..... $100

Pedal Assemblies $200

Utah Trikes Differential..... $235

Wheels.....$4,500

Thermoplastic Polyurethane Pellets .....$3,800 UHMW Polyethylene Sheets ..... $600 Fasteners (Bolts, Nuts, Etc.) $100

Steering $500

Rack and Pinion Steering..... $500

Seating and Restraints $600

Seat Belts..... $100

Seats $500

TOTAL $8,430

Teamwork

Teamwork is essential for the success of the Rover; it requires time commitment along with physical and mental endurance. The 2020 Rover and wheel design teams were led by Elijah Little and Ali Zand. Through the 11-month process of designing, prototyping, testing, and the fabrication of the Rover, both young men led their teams by example. They encouraged all participants to work in a collaborative effort to fulfil the common goal of creating a Rover that has the potential to win first place in the NASA Human Exploration Rover Challenge.
Each member of the team puts in a maximum of 20 hours weekly, but over the course of the 11 months, an average of 300 hours goes into the development of the Rover. Spending weeks on end with each other strengthens the comradery of the teams. Dr. (xxxxxxxxxxxxxx) encourages team dinners to further build relationships and teamwork. When the competition approaches, all members of the team are eager and excited to showcase the Rover they developed together. Students do so well in the program because the students are required to build 90% of the rover, so when something breaks, the students know how to fix it properly and quickly together.

Figure 5: 2020 MTSU Rover Team 1

Our Human Exploration Rover Challenge team members are (left to right) Ali Zand, Kamuran Yalcin, Jeanna Blanco, Joseph Mays, Derrick Morris, Dr. Saeed Forodastan (Faculty Advisor), Kari Williams, Sam Fassnacht, Christopher Winfrey, Brandon Stahl, Christian Warden, Elijah Little. Not pictured Rick Taylor (Machining Consultant).

Industry Partners

The MTSU Rover Team is an organization that operates solely on faculty sponsored associations with local industries, who graciously donate to the university. The Rover team prefers to invest in parts from local businesses such as Murfreesboro Electric Department, Murfreesboro Outdoor and Bicycle Shop, and Motion Industries.

The business formality of meeting with various companies has provided past members with a greater potential for a position at a local business for a first step to improving their professional career. Some internship can provide an opportunity for the superior to become a mentor and help guide students in the best direction for their project. If anything at all, the program members can benefit from local partnerships to grant access to a copious amount of resources for the sole purpose of designing and creating vehicles.

Student Advantages

Through the development of the Rover, students gain hands on experience and real-world application which makes them appealing to employers. Many of these students are ahead of their classmates in several courses because they are trained in programs like “Inventor” during the design phase of the Rover. Seniors that assist in the design and manufacturing of the Rover choose to use the Rover as their Senior Capstone Project. These students gain recognition for their hard work when the vehicle enters the competition. Along with the various awards these students receive, there are great advantages to assisting in the completion of the Rover. The seniors also act as mentors to the underclassmen that are interested in being a part of the Rover team. The students work tirelessly together to complete the project which ultimately forms friendships that will last a lifetime. Industries seek out these students for employment based on their strong knowledge in engineering and mechanics and their leadership qualities. In the construction of the Rover, students are educated in Project Management as they are required to complete the project from the implementation phase to the project closeout phase. Many of these student's land internships with prominent organizations like Boeing, Lockheed Martin, and more, that eventually lead to full time careers averaging $60,000 up to $200,000 annually.

Exit Survey and 5 Year Program Review Questions	Rover 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?	97%
Was the Rover a talking point in your interview process to be hired? If so, do you feel like being a part of the Rover helped you in acquiring your job?	100%

Table 1: Rover Project Exit Survey [5]

Table 1 displays the outstanding results the Rover project provides for members who participate. After the project is completed, graduate students receive a survey of 15 questions, three of which are listed in Table 1. From the survey, 100% of members said that the Rover Project helped them learn the technical skills required to be successful in the industry. All of the students who have worked on the Rover project 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 Rover project, 95% receive highly desired jobs upon graduation both at the national and international level.

Conclusion

Although the Rover program requires a substantial amount time and effort on top of the routine lecture courses, the students exit the program with a superior understanding of their chosen field of study. International students who have participated in this program feel their experience was worth their time and would recommend other international students to participate in EVP. Additionally, these projects help students to sharpen their intellect for their future career by implementing techniques learned in class. Many prestigious awards have been received continuously for several completed vehicles and the teams' participating members. This distinguished research program continues to provide an undergraduate learning experience with the latest advancements in technology. Additionally, the Rover students gain an invaluable experience and lifelong relationships while working with international partners.

The distinguished Rover program strives to provide more than just the traditional course structure of lecture and lab. It also offers a great opportunity to meet potential places of internships. This hands-on program has created leaders who have developed notable traits that can be carried into their future endeavors, ingenuity, accountability, tenacity, and self-motivation.

References

[1] NASA, “Human Exploration Rover Challenge: About the Challenge”, May 2020. https://www.nasa.gov/roverchallenge/home/index.html
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