5 December 2021
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Glassboro, NJ 08028

Melissa Montalbo-Lomboy, PhD
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Dear Professor Montalbo-Lomboy:

This report describes the analytical and experimental process of designing a set of rubber tires for a car that were created with the constraints of accurate movement, amount of material used, and all-terrain utilization. The group members for this project, named the "Fast and the Furious Tire Team," collaborated on the design process and 3D printing of the tires that were tested with a model RC car.

The team deliberated on which parts of the report would be covered by which member. For the design process, each team member submitted initial designs either sketched by hand or modeled using 3D-modeling software, such as SolidWorks. The team split up the report with different responsibilities for each member. James was responsible for the report's front matter, Jason was responsible for the Problem Definition, Noah was tasked with the Design Description, and Matt, Jason, and Zach collaborated on the Evaluation section. The team worked together on the references and appendices.

The attached report includes the tire design that was created in SolidWorks and 3D printed at Rowan University. Dimensions for the tire design, prototypes for the model, sketches, and errors in the design process are included in the report as well.

Sincerely,
The "Fast and the Furious" Tire Team
Noah Carey, James MacAulay, Zach Waldman, Matthew Tobino, & Jason Repmann

Encl: Tire Design Report

3D Printed Rubber Tire Design

James MacAulay, Noah Carey, Matthew Tobino, Zachary Waldman,
Jason Repmann

December 5, 2021

Sophomore Engineering Clinic I

Rowan University
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Executive Summary

The main purpose of the report is to describe the design process that was followed in designing the rubber tire. The team shared sketches of different tire designs with different treads and chose the best designs from the first sketches. From there, the team used SolidWorks to model the tire and then submitted the design to the Rowan University 3D printing lab for printing the physical prototype. The team printed the tires three times because of unavoidable errors. The first two misprints were the cause of miscommunication by the printing lab printing the tire incorrectly. However, after overcoming the design constraints that were too finite for the 3D printer and by using the printing lab at the business building, the 3D prototype was printed successfully. Once the final design was completed, the tires were attached to the model RC car to be tested on a model testing track. On the testing track, the tires had to ensure that the car could keep its load, a ping pong ball, attached to the car's roof. The tires also had to make sure that the car did not "yaw" or veer off the course. For the test, the tires seemed to outperform those of other groups that were tested at the same time. The car that used these tires got a perfect score on the testing track test as it completed the course while keeping its load, a ping pong ball, secured to the car. The tire design ensured that the tires were fit to traverse different terrain and did not veer off-course. If the tires were to be re-designed to further improve on the design a more simplistic design might be selected over the final printed design because of the print time. The tires designed were the last to be printed compared to other groups' tires. This is likely due to the unavoidable errors on the printing lab's side, but this is also a cause of the complex design. While the tires performed exceedingly well, the design could be simplified in the future so that manufacturing is easier and more efficient.

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1. Problem Definition

1.1 Scope:

For this project, we were given a model car and were tasked to create four tires, made from 3D printed rubber, and a tread pattern that would fit the given rims and maintain traction on four different surfaces, sand, gravel, grass, and ice without causing the car to yaw or change direction.

1.2 Technical review:

Rubber was first thought to be discovered in 1600 B.C.E by native south Americans who used natural rubber to create balls for primitive bouncing games. Although mainly used for games at that time, natural rubber was also found in stone and metal tools as a connection between the wooden handle and the tooling material. In 1770, natural rubber was introduced to English society and Joseph Priestley discovered that it could rub out pencil marking, naming it "rubber"(Softschools, 2017; Harris, 2020). This natural rubber was sticky, brittle, and smelly, this caused it to see very limited use in the 18th and 19th centuries until 1844 when Charles Goodyear used sulfur-based processing called vulcanization to create the first solid rubber with much higher durability. The first automotive tire was made out of completely solid vulcanized rubber and was used on low-speed vehicles. In 1888, the first pneumatic tire was used on automobiles seeing major industrialization and development in the 20th century including the invention of tubeless tires, radial tires, and run-flat tires(Holz Company, 1970). Tires are tested through endurance and load testing until the tire fails. Then the tire is subjected to accelerated aging through increased oxygen levels, simulating oxygen degradation. Next, the rolling resistance and force exerted on the tire at different angles are tested. traction is then tested in wet, dry, and icy conditions, and stopping distance is tested. Finally, the tire is given a unique tread pattern which is stated to be somewhat of an art because there are a huge amount of variables to consider. Most tire companies use a large assortment of compounds such as Natural rubber, synthetic polymers, steel, textiles, fillers, antioxidants, antiozonants, and curing systems(Burt Brothers 2019;Niknam et. all 2017). Having good tires with a tread that maintains traction in a variety of different conditions is important because the tires are the major source of control for a car, they dictate the direction that car is going and are directly controlled by the driver. If the tire cannot maintain traction and control of the car, then that puts the driver and the occupants of the car at risk for serious injury or worse. Tires are important because they directly correlate to the control and safety of the driver and passengers of the car.

1.3 Design Requirements:

The design requirements for the tire were to maintain traction and direction in different environments. The tires also needed to fit onto the rims and into the wheel wells of the car supplied to our team. The stakeholders of the tire design are the people using the car for transport and businesses that sell or use tires in their products. The purpose and requirement of the problem is to test the tires and ensure that they can maintain direction and traction at all times in tests consisting of traveling over sand ice, bumps, and other environments commonly found when driving. The tires will be graded by their ability to maintain direction and traction in different environments.

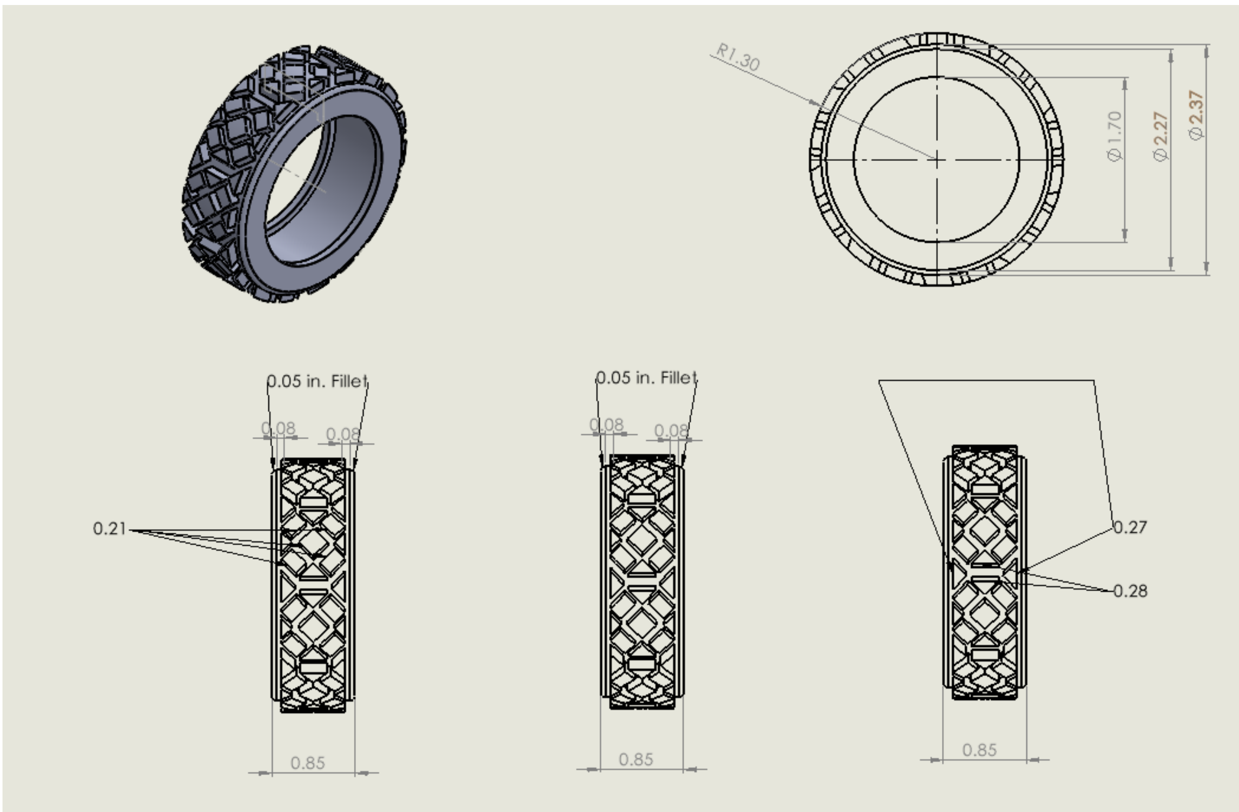
<u>2. Design Description</u>

2.1 Overview of Final Design:

The final tire design was vastly different from the original prototype. The tread design was changed, along with the overall shape of the tire. The only thing that was kept the same was the tire bead dimensions. The overall final design resembles a care tire, unlike the original design which resembled a bicycle tire.

2.2 Detailed Description of the Tire Design:

The Tire Design featured in this report is made out of TPU 95 filament. The overall diameter of the tire is 2.6 in. and the width of the tire is 0.850 in. In the cross-section of the tire, each bead is 0.0870 in. wide, 0.0870 in. high, and 0.6760 in. apart. The radius of the bead is 0.8495 in. The sidewall is 0.250 in. high and between the sidewall is solid filament in the shape of a rectangle with dimensions of 0.25 in. by 0.850 in. The outside edges of the tire are filleted with a radius of 0.05 in. The tread design consists of an array of rectangles and triangles evenly spaced out along the outside of the tire. This pattern is repeated 9 times around the tire. The tread is 1.3 inches in radius. The tread design is vertically symmetrical. The triangle at the bottom of the first pattern has a horizontal base with a length of 0.28 in. and a height of 0.14 in. Above this triangle is a square with a side length of 0.21 in. rotated up 45°. The bottom corner of the square is vertical to the top point of the triangle and is 0.07 in. above it. To the left of the square is a triangle with a vertical base of 0.21 in. and a height of 0.11 in. The left corner of the square is horizontal to the right point of the triangle and is 0.07 in. away from it. Between the two triangles is a 0.15 in. by 0.21 in. rectangle. The longer sides of the rectangle are parallel to the square, while the shorter sides are parallel to the legs of the two triangles. The rectangle is 0.10 in. away from the square and 0.05 in. away from the triangles. Directly above the square is an upside down triangle with a base length of 0.28 in. and a height of 0.14 in. The bottom point of the triangle is located 0.07 in. away from the top corner of the square. In between this triangle and the middle triangle is another 0.21 in. by 0.15 in. rectangle. Like the other rectangle, the shorter sides are parallel to the two legs of the neighboring triangles and the longer sides are parallel to the square. Above the top rectangle is a triangle with a vertical base of 0.27 in. and a height of 0.14 in. The bottom leg of this triangle is parallel to the rectangle below it and is 0.07 in. apart. The bottom point of the triangle is located 0.12 in. above the top corner of the square. We chose this design because we believed that this was the optimal tread amount in a tire to make it be suitable for every type of terrain.



2.3 Design Use:

Although tires have been around for two hundred years, biomimicry can be used to help improve them. One way this can be done is by examining the spines of hedgehogs. The spines of hedgehogs have a square honeycomb core. This acts as an internal shock absorber for when the animal takes a fall from a high ledge. This honeycomb design can be implemented into the interior of car tires, to create an extra shock absorber. As the vehicle travels through different types of terrain, the honeycomb interior can absorb the impact of rocks and other small objects to allow for a smoother and more comfortable ride.

One way to make tires sustainable is to use recycled tread. This allows for a tire to be used for a longer period of time. To do this, the tread must be produced in a factory using recycled rubber and put on an adhesive surface. This surface is then applied to a bald tire, extending the life of the tire by a few thousand miles. Once the tread is worn down, it is melted off of the tire, and a new tread is put on.

The automotive industry uses rubber in various places in the cars. The most noticeable area that rubber is used is in the tires, but it can also be found in gaskets, hoses, floor mats, and door seals. Rubber in the hoses allows for flexibility and durability, along with resistance to chemicals that are used in cars.

3. Evaluation

3.1 Overview of design evaluations:

To start the project, each team member came up with a tire tread design. In this process, we discussed phasic design techniques to ensure that we were coming up with the best possible design. We started off by modeling the tires after bike tire. After each member came up with a design, we discussed which tire tread would be able to handle all of the parameters set by the professor. From there, we decided to switch from having the inspiration being bike tires to the inspiration being sand tires. This process of choosing the tire threads covered our phasic design. The parametric designing process involved us printing the tire and making adjustments to the design based on what worked and what did not. This process was very long as our prints were coming out choppy, were misprinted, or the 3D printing lab would not print the requested amount.

3.2 Prototypes:

The initial print, as seen in Image 5, was going to be more related to a bike tire in shape, with a thinner body and larger radius. This print had many problems, some of which stemmed from incorrect set up in the printing file. One of the main issues with this design came from the size of the tire. Since it was a thinner tire, the tire itself with larger lengthwise. This caused the tire to be too larger for the wheel well. Another problem with the design was that the inner wall of the tire, which separates the inside of the tire from the tread, was not thick enough. This caused this print of the tire to have holes in the tread and become even more impractical. This tire was a failure, however, we were able to gather valuable data from it to work on the next prototype.

The second prototype, as seen in Image 6, was also a complete failure. However, this tire failed more due to printing errors rather than design errors. The tread of the tires was changed in this print; however, we could not test them properly as the entire tire was completely mispinted. From this failure, we were able to learn the proper techniques to print the tires. From what we were able to salvage from the print, we could see that the tire would fit on the wheel more properly and would be able to fit inside the wheel well. The group decided to keep the treads used in this design as they were not able to be properly tested. The group acknowledged that maintaining this tread design would mean more work on our end as we would have to manually remove all of the support layers in between each tread.

The third prototype, as seen in Image 7, was not a complete failure. This tire did not suffer from the improper printing that destroyed the second prototype. However, due to all of the support layers, the tire looked visually unappealing. Although we learned in the second prototype that the tire would fit, seeing the third prototype fit on the wheel and fit within the wheel well was a nice bonus. The tire did sit a little funny on the wheel, however, it was determined by the group that it would not cause an issue with the steering of the car. The main issue we had with this prototype was the lack of cooperation from the 3D printing lab. On several occasions, we emailed them the file and specified the number of tires we would need. However, each time they printed a single tire. This prevented us from being able to test this prototype on the course.

The final prototype, as seen in Image 8, was a complete success. This final prototype was printed by Studio 231 in the Business Hall. The workers at Studio 231 printed us the correct amount of tires on the first try and printed in such a way that we had very little support to remove. This led to an overall cleaner tire that looked more visually appealing. The tire also sat on the wheel much better than the third prototype. This tire was able to complete the entire course without losing the payload. With the full completion of the course, the tire can be deemed a true complete success.

3.3 Testing and Results:

Over the course of this project, we did a few different tests and obtained a few different results. In said tests, we created different types of tires through 3D printing. The first test ended in a failure. The tire was modeled after a bike tire being thinner and having a large radius. This test failed due to design and printing errors. The tire's design made it too large to fit in the wheel well and the printing left holes in the tread. We were able to use information from this failure to improve our next tire design.

The second tire design ended in a failure as well. This design failed because of a printing error. The wrong nozzle was used resulting in the tire being printed completely incorrect. The results we were able to get showed that our design should work if printed correctly. The tires should fit into the wheel wells with no issues and be able to function as expected.

3.4 Assessment:

The final tire design did the best overall. With some extra work, we could have better treads while still not being too complex for the 3D printer to print. The final design mimics actual all-terrain tires allowing for better traction in adverse conditions. The only drawback of this is the amount of time it will take to prepare each tire. For each tire, there are supports between the treads that need to be taken out. This adds potentially hours of work making it somewhat undesirable in terms of design and practicality.

3.5 Next Steps:

In order to increase the manufacturing process, traction and overall performance of the tire, the next steps taken would consist of changing the tire's tread pattern and its inner structure. The tread pattern was intricate and carefully designed; however, during the 3D printing process of the tires, there were mistakes made by the printer, due to the tire pattern’s complexity. To combat printer mistakes we could change the tread pattern to create a more “printer-friendly” design that maintains the same amount of traction. Next, we would change the inner structure of the tire to allow it to conform to the road better for a bigger road contact patch for more traction. The easiest way to do this would be to create a tire with a small infill.

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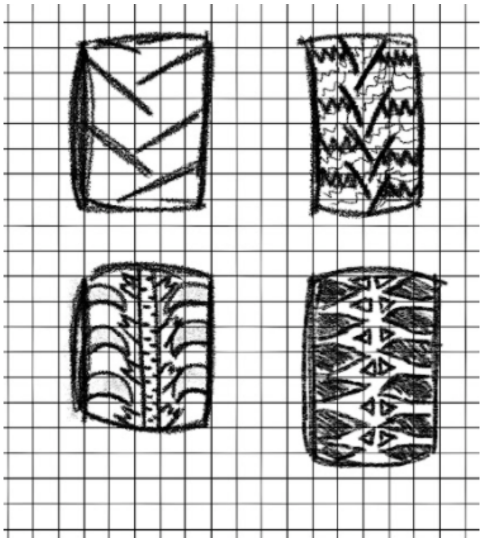
Appendix:

Image 1:



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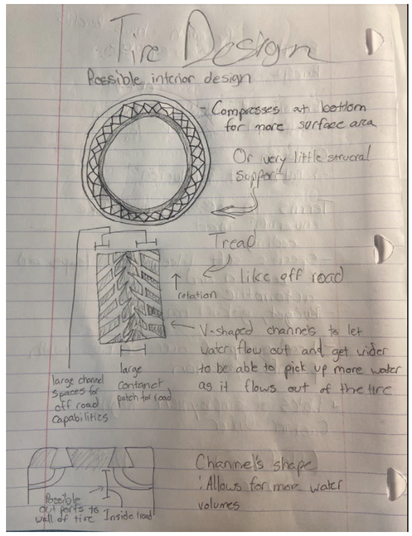

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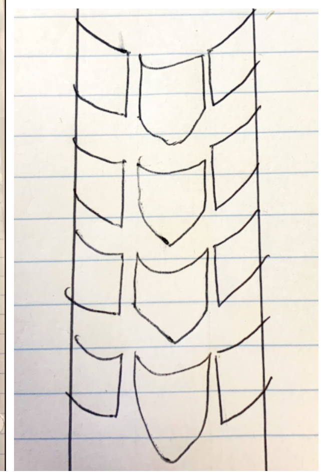

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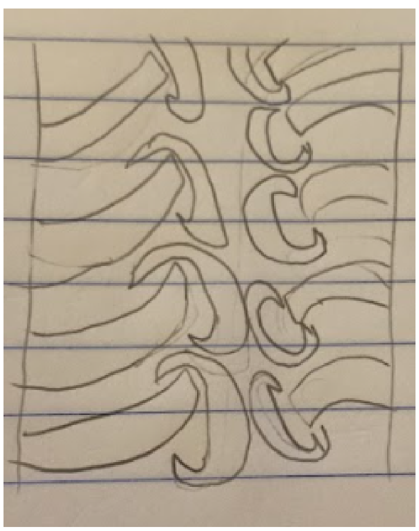

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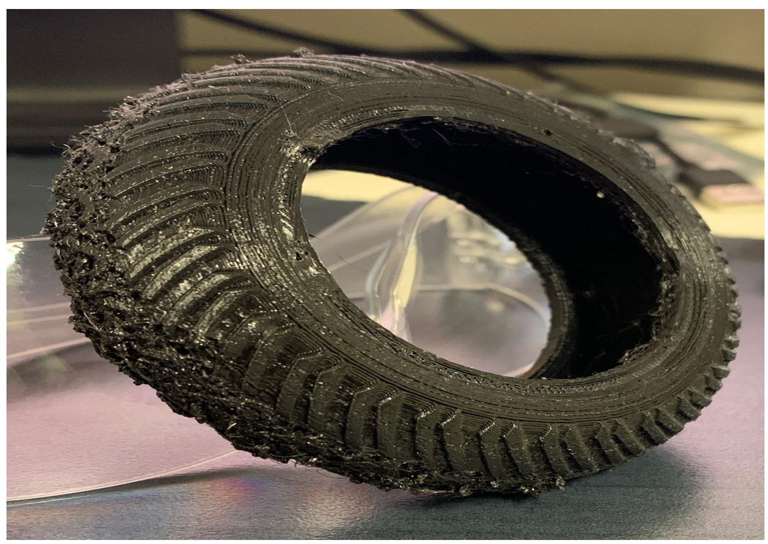

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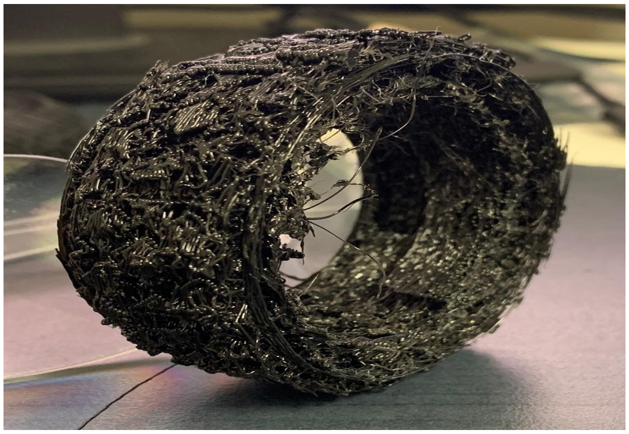

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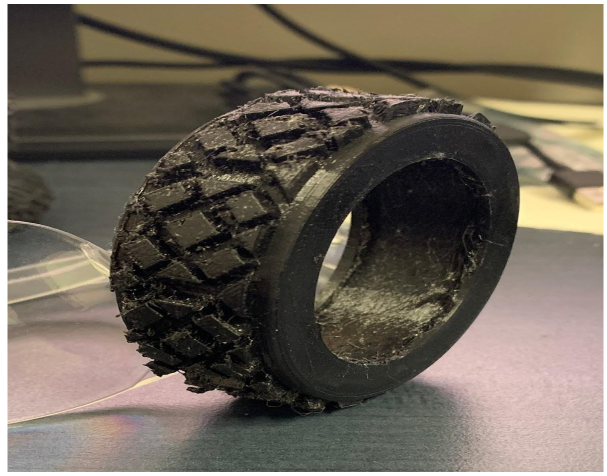

Image 8:

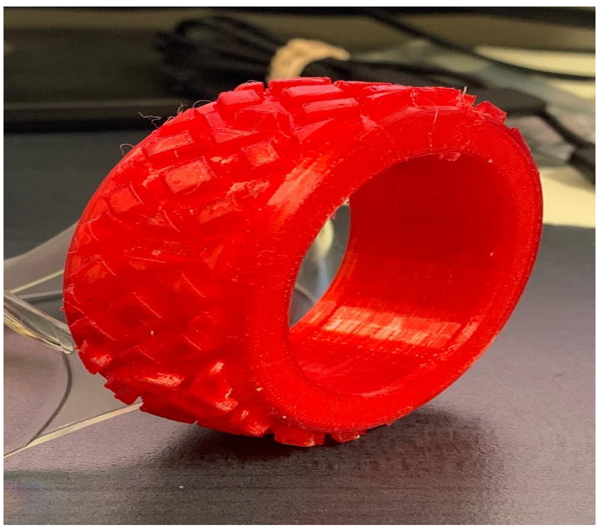

Image 9: