Final Design Report

Wheelders

EDES 120 - Introduction to Engineering Design

12/12/2025

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Project Summary

The Rice Robotics Club is participating in the University Rover Challenge (URC) for the first time. As part of this competition, our client has tasked us with designing a set of non-pressurized rover wheels to replace the team's current temporary, low-performance wheels. The objective is to provide wheels that can support a 50 kg four-wheel rocker-bogie suspension rover in completing the URC Delivery Mission, which involves navigating diverse Mars-like terrain, including soft sand, gravel, rocky and boulder fields, steep and loosely consolidated slopes, and vertical drops.

[Figure 1: Image of URC Delivery Mission terrain]

The rover must meet strict competition constraints, including a 50 kg total mass limit, non-pneumatic wheel requirements, tolerance for extreme environmental conditions, timely on-field replacement, and manufacturability with limited resources accepted by competition regulations. Current wheels do not provide sufficient traction, durability, or reliability, which hinders the rover's performance. A new design would address these limitations, enhance competitiveness, and potentially lead to greater recognition and engagement for the Rice Robotics Club.

[Figure 2: Current temporary wheels used by Rice Robotics]

Furthermore, the client also encouraged us to explore unconventional concepts alongside established and proven wheel designs. While the rover is still in development, we will have access to a similar test rover to evaluate prototypes. Our wheel design must also be flexible enough to accommodate the rover's evolving leg-to-wheel connection, shown in Figure [1]. The wheels are expected to be complete by early December in time for the qualifying event, and may be featured in the competition's System Acceptance Review video.

Background

The Rice Robotics Club is participating in the URC. Their 50kg rover requires wheels that enable it to complete tasks throughout the competition, including maneuvering through steep slopes, sand, and rocky fields. Within a 4-month timeframe, our team must design a rover that meets the URC's non-pneumatic wheel requirement, allows the rover to weigh less than 50 kg, withstands extreme desert operating conditions [9], and operates within a flexible $500 budget. Ultimately, the task at hand is to replace the wheels the team is currently using, which lack sufficient traction and durability, with new wheels that maximize traction on challenging terrain while adhering to the competition's strict rules.

From our research, we learned that traction is a key factor in rover mobility, relying on a balance between wheel-soil interaction and controlled slippage to prevent digging in or loss of motion[11]. In terms of material, we have learned that the most common method of increasing traction is using rubber in wheels, although some alternative options could include using grousers. This explains why the most successful teams in the URC are those that have used both rubber and metal. [1] Regarding wheel design, it is worth noting that some unconventional designs may be effective, such as the wheel design developed at the Missouri University of Science and Technology. However, most top teams adopt a standard wheel design approach.

In terms of production, we also discovered that for the delivery mission, having a larger radius wheel would be beneficial[10]. The tradeoffs of this approach are, of course, increased weight and production cost, but the larger radius improves speed and the ability to scale large objects, such as rocks and hills, during the delivery mission. We can start prototyping using low-cost 3D printing. Once the structure is proven to be strong and durable enough to support the rover's weight, we can proceed with producing the final design.

Finally, we also found that common field failures at URC include wheels detaching [7] and wheels made from weak or poorly chosen materials [8], which directly compromise performance. These findings underscore the importance of designing wheels that maximize grip on loose terrain while also being durable and securely attached, as failures in either area can prevent a rover from completing its mission. The successful combination of rubber and metal materials in wheels is a significant design trend among top teams, so we should follow this example in some regard. It has helped these teams improve durability, traction, and maneuverability performance in the complex delivery mission.

Problem and Vision Statement

The problem we are addressing is the need for a set of rover wheels that meet the competition's rules while outperforming the team's temporary wheels. We aim to design and build four wheels that can be constructed within a budget of around $500, while maintaining high maneuverability and traction, enduring extreme conditions, and allowing for quick and easy replacement.

By improving traction and durability, the wheels will directly improve the rover's performance on the URC Delivery Mission, where terrain is one of the most significant obstacles. Our solution has the chance to increase the rover's chances of completing the mission successfully and help Rice Robotics earn more points throughout the competition, thereby improving their standing. In the longer term, a successful rover design has the potential to bring the club greater recognition, participation, and support within the Rice community.

Design Criteria

Design Criteria Table			
	Criterion	Target Value (units)	Justification
Constraints	Regulations	Be eligible	Must follow rules established by the URC rulebook
	Replaceablity	< 1 min per wheel	The wheels should be consistent in taking a minimal time to replace
	Durability	Handles 75 kg	Handles the maximum weight outlined in the regulations
	Size	125mm	The wheels should be between 125-150mm
	Traction	3.91N per wheel	Minimum force for the robot to have the grip to be able to move under the 50kg rover weight + 10kg mission package on a steep incline (15 degrees)
	Weight	1.5kg	Each wheel should we around 1.5kg
	Coolness	Values from UDS	The wheel design should resemble rice and look menacing
	Replicability	Values from UDS	The amount of effort taken to assemble another wheel using the design

[Table 1: Design Criteria table]

Our Design Criteria Table has eight criteria that we identified as critical for the success of our project. These criteria, from most important to least important, are traction, durability, replicability, replaceability, weight, size, and coolness.

1. Traction is our most important factor(score: 6.0) because it is vital for the success of the wheels in maneuvering the terrain of the delivery mission. If the wheels don't have sufficient traction, then the rover will not be able to navigate the terrain in the given time, resulting in a damaging score towards the performance of the Rice rover team.
2. Second, we designated durability as important (score 5.0) but a bit below traction in terms of criticality. If the wheels are durable, they do not need to be replaced often, saving money and manufacturing time. Durability will also be necessary during the competition itself, as the wheels will need to survive the forces and wear applied to them during missions.
3. Following this, we have replicability and replaceability as medium to high importance criteria (scores: 3.0). The Rice Robotics club needs to be able to easily replicate and then replace the wheels on the rover so that the team can function self-sufficiently without requiring us to make the wheels and attach them for them. Also, in the field during competition, the wheels need to be easily replaceable in case something happens to them, so that the team doesn't get any penalties while spending time replacing wheels.
4. Following this, the weight (score: 2.0) and size (score: 0.5) of the wheels are both of lower priority because they are not directly regulated by the competition or Rice robotics. The weight would be better if it were on the lower end because the rover does have a maximum weight limit of 50kg, so the less we take of that, the better, but we don't want to sacrifice any performance in pursuit of this.
5. Size (score: 0.5) is purely a trade-off criterion, as a bigger wheel will be faster but more expensive and heavier, and a smaller wheel is cheaper and lighter but slower.
6. Next is coolness, which we also designated as low priority (score: 0.5). We would like our wheel to be interesting and perhaps have something to make it stand out, but we aren't willing to sacrifice much, if anything, to do this.
7. Lastly, a criterion that we designated in our Design Criteria table but did not include in our Pairwise Comparison Chart is regulations. We did not include this since it is a constraint we must satisfy. If our wheels break the regulation rules, the robotics team will not be able to use them. at all

To quantitatively evaluate on User-Defined Scales, we designed two criteria: Coolness and Replicability. For coolness, a range from 1 to 5 was set up, where one meant that people are not attracted to the design and decoration of the wheel, and five suggested that people would take photos of the wheel, discuss the design of the wheel, or even be a bit nervous to compete with our team due to the wheel design. Our target value is around 3.5, as we expect people to be attracted by the design. However, more effort should still be put into the wheel's structure instead of the decoration. For replicability, the range of the criterion is also from 1 to 5, and the attribute was ranked from people feeling exhausted and giving up trying to replicate the wheel to the wheel being modular in structural design, the parts can be easily obtained locally, and the whole wheel is easy to assemble. Our target here is to aim for a level of 4.5 to 5 because modularity is relatively essential in assembling the wheel, and we hope that our design helps the robotics team succeed in the URC competition.

Brainstorming & Evaluation

We began our brainstorming process with the goal of creating a wheel concept that combines structural flexibility with durability, utilizing a core that can be either hollow for lightness or solid for added strength. It could include an outer layer made of rubber for traction or aluminum for toughness. Grousers would be added to the surface to increase grip on slope terrain, and the shape would be round to ensure stable rolling. Since the wheel cannot be pressurized, it can't pop or crack, but must remain lightweight, yet strong enough to support the rover's weight.

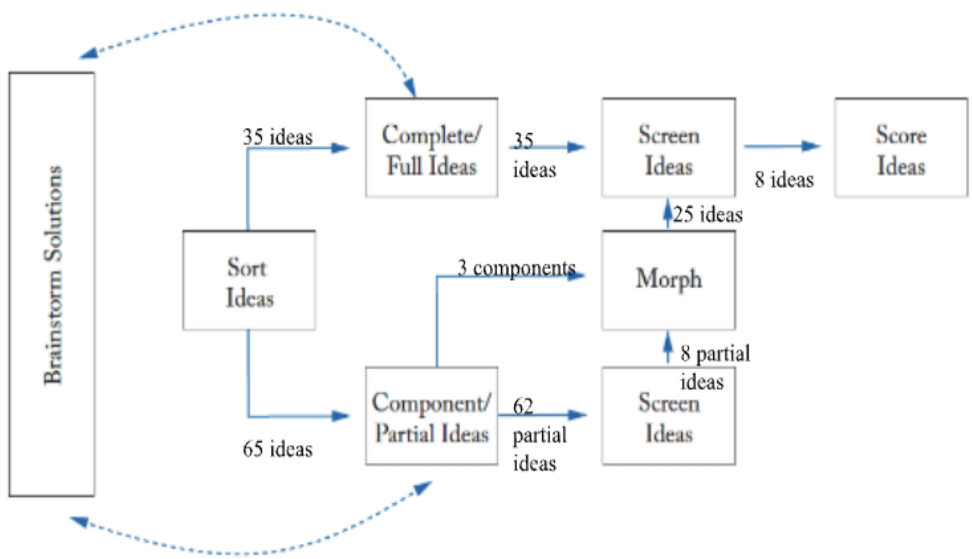
We began our first round of brainstorming and compiled a total of 87 ideas, and 80 complete ideas. In total, the team had 35 ideas, which correlated with a wheel's feature design, 21 ideas related to alternative ideas for the wheel, 2 ideas focused on informational analysis of the wheel, and 2 ideas dedicated to ways the wheel can move. 21 ideas for different materials we can use within the wheel, and 9 duplicates. Giving us a total of 88 ideas. Upon further thought, we realised we had not included wheel manufacturing, thus this will be part of our agenda for the next brainstorming session. Moreover, our team felt that we could generate more ideas regarding materials. We were satisfied with the results regarding different feature ideas, as there were plenty of diverse designs, from spoked cores to grousers to cone-shaped wheels. Our next focus was to apply the same level of creativity to the other categories in the next brainstorming session.

In our next brainstorming session, we generated 20 new ideas. We grouped these ideas as varying material ideas and manufacturing methods. The new materials that we brainstormed consist of more diverse and far-out ideas than those we brainstormed in our first session. These materials will be used to make the core, the inner part, and the outer part of our wheels. This new set ranges from cheap and weaker plastic to expensive and stronger metals. We also looked at manufacturing methods. This group consisted of all the ways that we brainstormed to make our wheel. These ideas range from CNC machining to methods as simple as just using hand tools.

To summarize, our inspiration for our ideas came from a combination of research and direct feedback from our client. Earlier in the EDP, we gathered information about the problem, explored possible solutions, and researched what had failed. Some of our ideas were inspired by research into existing rover wheels and technologies, while others were conceived with features the client wanted and did not want in mind. This combination helped us guide our brainstorming toward solutions that were both practical and aligned with the client's needs.

With all of our brainstormed ideas, we needed a way to select the best option, so we screened and scored them. Our screening process spanned 3 days. During this time, we narrowed down 100 initial brainstormed ideas to 8 solutions that advanced to the scoring phase.

We began by categorizing our ideas into two groups. The first category was complete/full ideas, and we had 35, and the second category was partial/component ideas, and we had 65. We then spread partial ideas across four design blocks. Manufacturing methods had 16 ideas, materials had 25 ideas, modes of movement had 23 ideas, and movement types had 2. Then, we screened these partial ideas against our seven design criteria: traction, durability, replicability, replaceability, weight, size, and coolness factor. This initial screening reduced our partial ideas to 12 options. We ended up with 5 manufacturing methods, 4 materials, and 1 mode of movement, and we kept both movement types. A decision we made was not to screen the movement category, because we wanted to keep both combustion-based and vibration-based movement (tire treads). The "modes of movement" category underwent the most aggressive screening, and we reduced 23 ideas to just one (normal wheels), which indicated a clear winner on this design element.



[Figure 3: Engineering Decision Making flowchart,]

We then used a morph chart to combine the 12 screened partial ideas into 25 complete solutions, which we added to our original 35 complete ideas, resulting in a total of 60 complete ideas. After screening these 60 complete ideas, we reduced them to eight solutions.

Four solutions were from morphed combinations, and the other four were from brainstormed ideas. Some of the features that distinguished successful solutions from eliminated ones were their performance on critical criteria, such as durability and replicability, as well as manufacturing feasibility through methods like 3D printing and molding. Additionally, the material selection favored polycarbonate wheels and rubber-based options that balanced traction while keeping weight in mind. This approach allowed us to evaluate a large quantity of ideas while making sure the most promising concepts advanced based on measurable design criteria rather than our subjective preferences.

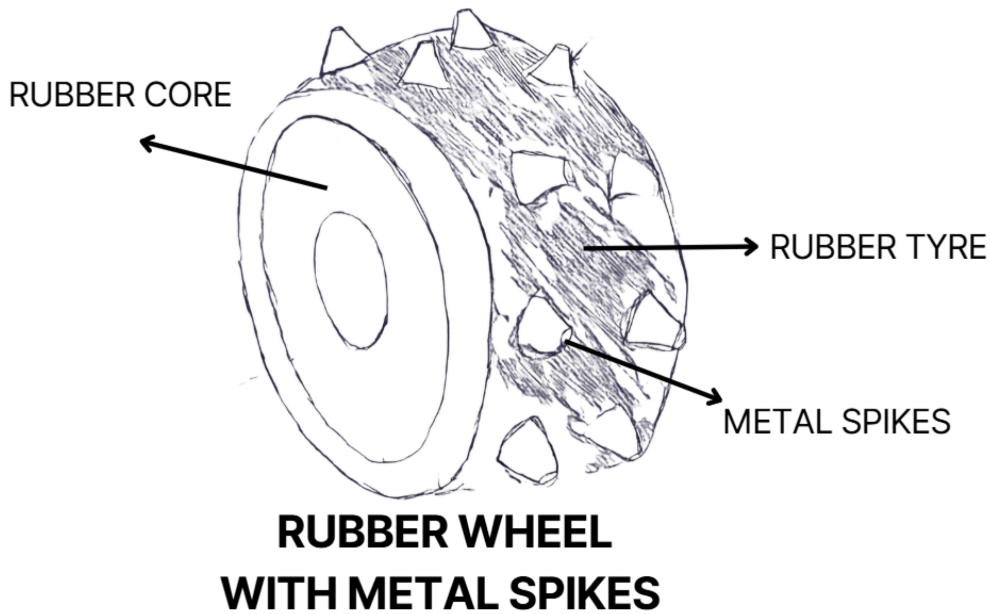
Table, Pugh Scoring Table

		Metal-based skeleton wheel with spikes and rubber outside		Rubber wheel with metal spikes		Metal star wheel with flattened rubber tips		Circular inner part wheel with ridged rubber grouser on the outer side		3D Printing + Only Rubber Wheel + Tire Treads		Resin Print + Only Rubber Wheel		Resin Print + Polycarbonate Wheel		Resin Print + Only Rubber Wheel	
Design Criteria	Weight	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
Traction	25%	5	1.25	5	1.25	4	1	4	1	3	0.75	3	0.75	2	0.5	2	0.5
Durability	25%	3	0.75	3	0.75	3	0.75	3	0.75	4	1	3	0.75	4	1	4	1
Replicability	20%	2	0.4	3	0.6	3	0.6	3	0.6	4	0.8	4	0.8	4	0.8	4	0.8
Replaceability	15%	4	0.6	5	0.75	3	0.45	5	0.75	5	0.75	5	0.75	5	0.75	5	0.75
Weight	5%	3	0.15	3	0.15	4	0.2	3	0.15	5	0.25	4	0.2	4	0.2	4	0.2
Size	5%	4	0.2	5	0.25	4	0.2	4	0.2	2	0.1	3	0.15	3	0.15	3	0.15
Cool	5%	4	0.2	3	0.15	5	0.25	3	0.15	3	0.15	2	0.1	2	0.1	2	0.1
Total Score	100%	3.55		3.9		3.45		3.6		3.8		3.5		3.5		3.5	
Rank		4		1		6		3		2		5		5		5	

[Table 2: Pugh Scoring table]

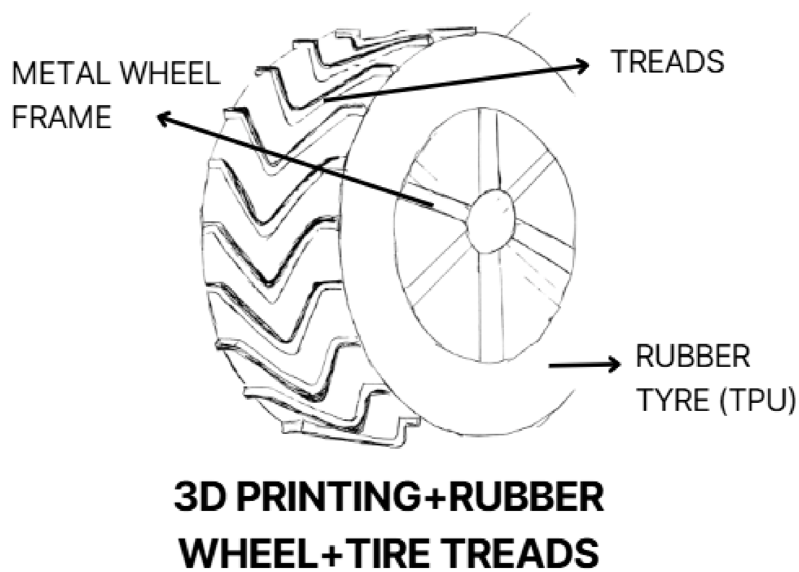
Overall, we evaluated eight wheel designs using the Pugh screening method to sort out complete ideas and partial ideas. We weighted the criteria by mission priorities: traction 25%, durability 25%, replicability 20%, replaceability 15%, weight 5%, size 5%, and "coolness" 5%. The most important factors are durability and traction, which will help the team to succeed in the URC competition. Then, the replicability and replaceability are a bit less important. Lastly, the weight, size, and coolness are weighted the least because they are not crucial in determining the wheel's performance. Each criterion was rated on a scale of 1–5, multiplied by its corresponding weight to obtain a weighted score, and then summed to determine the total score. The first winning design is the rubber wheel with metal spikes, with the highest score of 3.6. It wins not by maximal traction score, but because it combines top durability from the combined use of rubber and metal with high coolness and replicability while keeping replaceability, mass, and size at a relatively acceptable value. The main feature that affects the score was durability and replicability. Among combined partial ideas, A1 B2 C1: 3D-printed rubber wheel + tire treads placed second on high traction and replicability, but was weakened for durability.

Proposed Solution 1: A durable, solid rubber wheel construction with integrated metal traction spikes for increased traction on loose terrain.



[Figure 5: Sketch of proposed solution, rubber wheel with spikes]

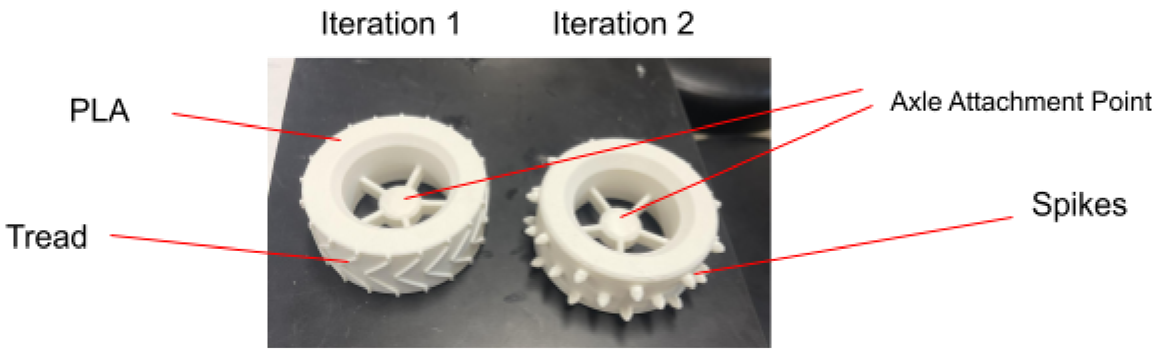
Proposed Solution 2: A 3D-printed TPU wheel with a tread pattern for enhanced grip and terrain adaptability. TPU's natural flexibility provides excellent shock absorption and object conformity, while deep, well-spaced treads offer traction.



[Figure 6: Sketch of proposed solution, TPU printed wheel with treads]

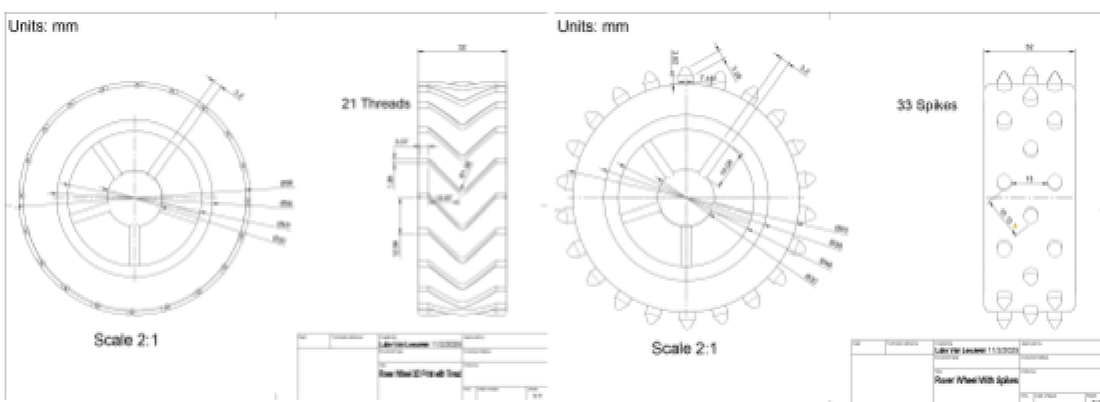
Prototyping

During our prototyping process, we ended up having six key iterations of our design. At the beginning of our prototyping journey, we identified a minimum of three key features: the wheel's axle attachment structure, non-pneumatic tires, and spikes/treads for increased traction.



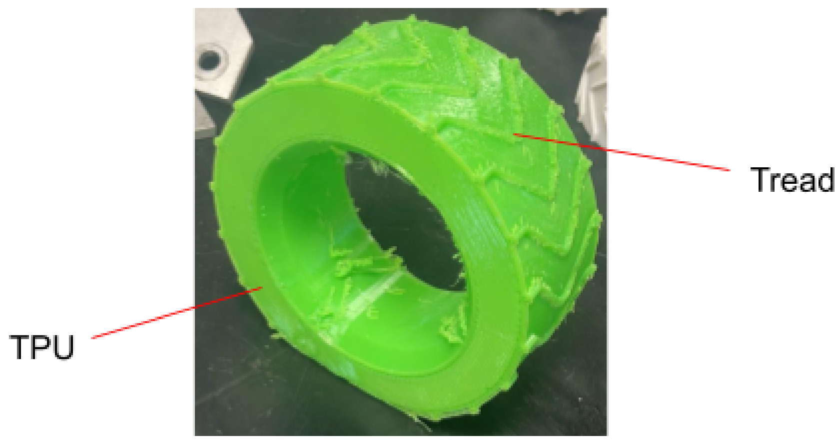
[Figure 7: PLA Low Fidelity (Iteration 1 & 2)]

For our first two iteration, we created a low-fidelity prototype that was both representative and a proof–of–concept. This included making two wheels that were the same in terms of their structure and dimensions but differed in the wheel exterior, either having treads or spikes. We pursued both of these exterior designs in this iteration due to the CAD process for designing these wheels to 3D print being almost a copy-and-paste of each other.



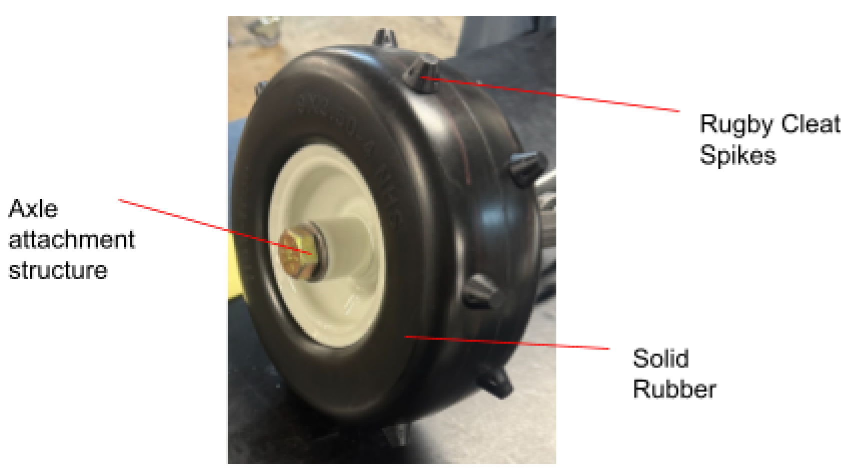
[Figure 8: CAD Technical Drawing (Iteration 1 & 2)]

We incorporated all of the features we identified in this low-quality 3D printed model. The axle attachment structure was created in the center of the wheel after we discovered the type of motor that Rice Robotics was considering using in the Rover. The spikes and treads were made with similar dimensions to what we planned to use in our final design. The purpose of this prototype was to translate our idea into a 3D space and see how our wheel design compared to the pre-existing low-fidelity wheels that Rice Robotics had made for their low-fidelity prototype of their Rover. From this prototype, we discovered that PLA did not give a satisfactory amount of traction or wheel compression. We also found that we needed to ensure that the spikes were securely attached and wouldn't take excessive damage or fall off, as they were a weak point of this iteration. As a result of these findings, we decided to move on and 3D print in TPU, which is known for having a better grip and a higher compression factor than stiff PLA.



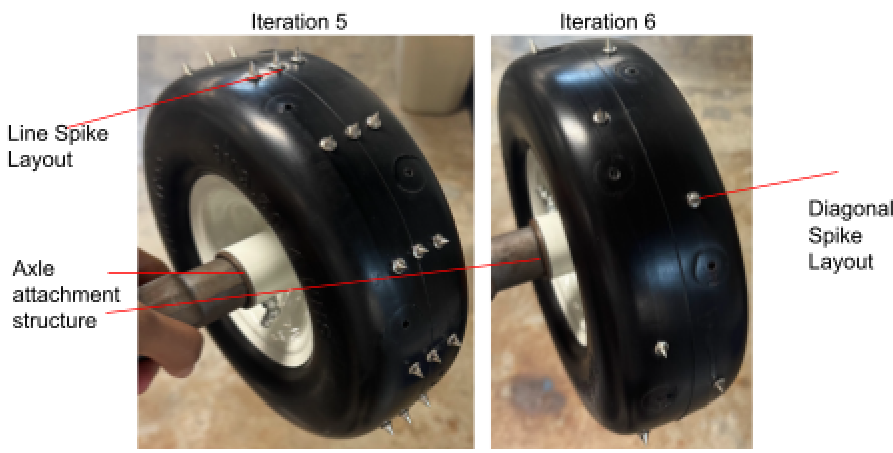
[Figure 9: TPU Medium Fidelity (Iteration 3)]

In our second iteration, the main goal was to explore the possibility of printing our final design with a TPU exterior and a PLA core structure. To do this, we cut the center structure out of the CAD models from our first iteration and printed just the outside of the wheels. However, we faced challenges in the printing process of this wheel and struggled to get a print that came out with decent quality. Finding the right balance of extruding speed, extruder temperature, and keeping overall print time down proved a difficult task. From this prototype, we saw that the time put into making just this single low-quality wheel was not feasible to scale up and repeat four times in our final design. As a result of this iteration and the first one, we decided to move on to purchasing a pre-existing wheel and modifying it to gain the desired attributes we wanted in our final design.



[Figure 10: Medium-High Fidelity (Iteration 4)]

In our third iteration, we purchased and modified a wheel that met our needed scale and was non-pneumatic. This wheel allowed us to test manufacturing methods on it for our final design, and we also used this wheel to perform our first durability and traction tests since it was at the needed size and just slightly over our goal weight. We modified the existing wheel by drilling holes into the exterior and then fitting the screws of rugby cleat spikes into the holes with adhesive. We tried to excavate some of the rubber from the exterior to make treads, but this proved very difficult given the wheel's hardness. We made a make-shift axle and attached it to the wheel for testing purposes and to check the ease of use of the axle attachment structure. We also began exploring spike layout designs in this prototype, trying to find what would offer us the greatest traction result. Ultimately, this iteration gave us a lot of information, and we realized that we would achieve the most successful final design by using this purchased wheel as a base for further modifications. This showed us that using the spike exterior design would be best moving forward, and we stopped pursuing the idea of treading our wheels. The spikes did have a tendency to fall out, so improving the connection method was needed for higher durability. In the testing of this prototype and meetings with Dr. Holmes and Dr. McGlamery, we saw that these spikes were too large and didn't allow us to maximize surface area with the ground, resulting in less traction. As a result, we purchased more of these wheels and continued modifying them, but with different spikes, and we manipulated the spike layout.



[Figure 11: High Fidelity (Iteration 5 & 6)]

In our fifth and sixth iterations, we used the same wheel from iteration 4, but used track spikes instead of rugby cleats, and we varied the spike layout. In attaching the spikes, we precisely measured out the distances between each spike and used precise drilling and adhesive to ensure a high-quality and strong attachment for each spike. We used a fresh set of wheels as well to ensure that the tread excavation on the wheel from iteration 4 wouldn't lower the quality of these iterations. In our testing, we saw that these wheels performed the same in terms of traction, but iteration 6 performed better in durability and replicability. Due to this, we selected iteration 6 as our final prototype. This model has our three key features: wheel axle attachment structure, non-pneumatic tires, and spikes/treads for increased traction. It performed best in most of our tests and met all of our clients' requirements. We made sure to make this iteration with sourcing the highest quality parts, and we took time to accurately place and secure all of the spikes. Ultimately, at the end of this process, we have created a prototype that incorporates all the elements we sought at the beginning, and performs above our target goal in our most important criterion, traction. All the features and the high performance of this recent iteration were made possible as a result of the systematic iterative process.

Testing

To evaluate whether our rover wheel design met the performance goals established in our EDP test plan, we conducted a structured series of tests aligned with our seven design criteria: traction, durability, replicability, weight, size, replaceability, and coolness. Each test was defined in the EDP, along with its corresponding methods, pass or fail thresholds, and required materials. Our testing results and raw data are referenced in Appendix E. The testing included both intermediate prototype testing (Iteration 4) and final prototype evaluations (Iterations 5 and 6), allowing us to assess how design changes impacted performance.

To assess traction, we conducted a standard incline test on a sand-covered wooden board intended to simulate the competition conditions in Utah. We made a makeshift axle to attach two wheels to and placed it on the incline. We increased the incline gradually to achieve angles from 6 - 20 degrees and the wheel assembly passed at a given angle if it remained static. Using the wheel systems weight of 3.4kg we calculated the frictional force as each angle using $F = \mu W \sin(\theta)$. The coefficient of friction was from the contact of rubber to sand.

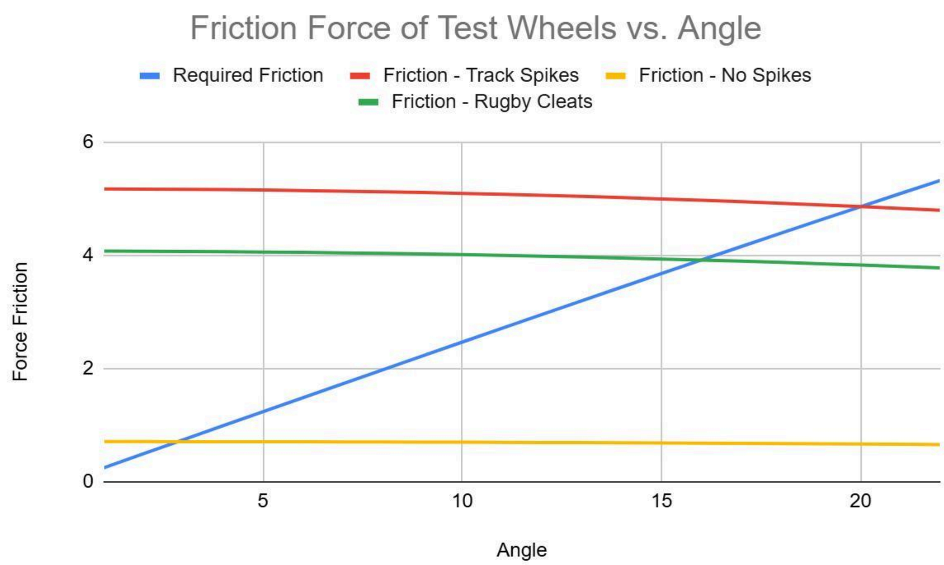
[Figure 12: Traction Test of High Fidelity Prototypes (Iteration 5 & 6)]

Durability was evaluated using a drop test in which each prototypes where dropped from 10, 20, 30, 40, and 50 inches onto hard gravel. The wheel failed if spikes detached or had significant blunting.

Replicability was testing by timing the manufacturing process to make a copy of the wheel from start to finish. Weight and Size were measured using standard instrumentation and where compared to the dimensional constraints from the beginning of the project. We did not end up carrying out any tests for replaceability as is needed to be tested on Rice Robotics to scale prototype which upon the time of writing this report it has not been finished to the extent needed. Coolness was tested from peer feedback on the wheel design and response where compared to our target and matched to a numerical value as per our UDS (Appendix H).

Intermediate testing of iteration 4 demonstrated that the rubber rugby spike concept provided moderate traction but poor durability. Traction remained sufficient up to an incline of 15 degrees, where the wheel provided 3.91 N of frictional force compared to the 3.68 N required. At 16 degrees, however, slipping occurred as the required force exceeded the wheel's capability. Durability results were more concerning: rubber spikes visibly deformed at 30 inches and detached at 40 inches, failing our targets for durability. Weight (1.5 kg) and diameter (8.5 in) met the design constraints, but the shortcomings in spike resilience indicated the need for design changes. Based on these findings, documented in EDP 6b, we transitioned to metal track spikes and updated both the attachment method and use of adhesives to address the failures observed.

Final testing of iterations 5 and 6 showed substantial performance improvements. Both prototypes, which differed only in spike layout, were tested simultaneously on the same axle and each trial was repeated three times for consistency. In traction testing, both designs remained stable at all tested angles up to 20 degrees which exceed our target by 5 degrees. Slipping occurred only beyond this threshold, at angles where the required force (5.09 N) exceeded the wheel's limit (4.82 N). Durability results further validated the design shift as both versions survived drops up to 50 inches with no spike detachment. Some spikes loosened and displayed minor wear with iteration 5 taking the most damage. This led us to choose the diagonal spike layout of iteration 6 as our final design as the metal spikes distributed impact forces more effectively and also had almost the exact same friction test results of iteration 5. Replicability testing showed that reproducing iteration 6 could be done in 6 minutes and 50 seconds with relative ease. The only required tools where a drill and glue. This ease met our target for our UDS (Appendix H) for this criteria. Weight and size remained consistent with our intermediate testing, confirming that durability and traction improvements did not come at the expense of increased mass. Our feedback on the coolness criteria of iteration 6 was mostly indifferent as most people saw the spikes as cool but nothing particularly captivating about the design.



[Chart 1: Friction Force of Test Wheels vs. Angle (Iteration 5 and 6 and control)]

Drop Height (in)	Wheel with Rugby Cleats	Wheel with metal spikes in linear layout	Wheel with metal spikes in diagonal layout
10	No damage	No damage	No damage
20	No damage	No damage	No damage
30	Light damage	No damage	No damage
40	Loss of 2 spikes	Light damage	No damage
50	Loss of 2 more spikes	Heavy spike blunting	Light damage

[Table 3: Durability Tests Results]

Together, these results show that our final prototype (iteration 6) met or exceeded the traction and durability goals outlined in our design criteria, while also highlighting opportunities for refinement. Future iterations should focus on strengthening the spike attachment, potentially through mechanical fasteners or higher-strength adhesives Additionally strengthening the spikes themselves to reduce wear and blunting would be beneficial for wheel longevity. These recommendations arise directly from the data collected across all prototypes and provide a clear path forward for enhancing performance in conditions representative of the Unviersity Rover Challenge.

Project Hand-off & Conclusion

Throughout the design analysis stage, we were able to gain a greater understanding of the problems we needed to solve, and we gained foundational knowledge in wheel design and creation. Through our research, we identified several factors that impact wheel performance in extreme terrain, and we discovered previous University Rover Challenge wheel designs that had been successful for previous teams, such as using pre-made rubber wheels with either a spike or tread exterior design.

After exploring some important factors that we identified in our research, we made a set of design criteria to guide our brainstorming of an idea that we felt could become our final prototype. In the brainstorming process, we generated over 60 complete potential solutions and identified the most viable concept using Pugh scoring and screening matrices.

The prototyping stage of the design process consisted of several iterations that built on each other, improving quality, functionality, test results, and adherence to our design criteria as we developed a better understanding of what worked well and what didn't with each prototype. Initial prototypes focused on representing and integrating our different features and following iterations explored manufacturing methods and where improved through use of more quality materials, purchased base wheels, and small modifications based on our observations.

As a team we hope that our wheel design will aid Rice Robotics in having a good performance in their first ever appearance in the University Rover Challenge. At this point in our process we have transitioned to handing off our project. All relevant documents, prototypes, and testing data will be physically handed off or emailed to our client by Dec 31st, 2025. Any further communication regarding our project should be directed to our client Rice Robotics at riceroboticsclub@gmail.com or our main point of contact at Rice's Robotics team, Ryan Purdy, rpp6@rice.edu.

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Appendix

Appendix A: Interview Questions and Responses

Interview Questions:

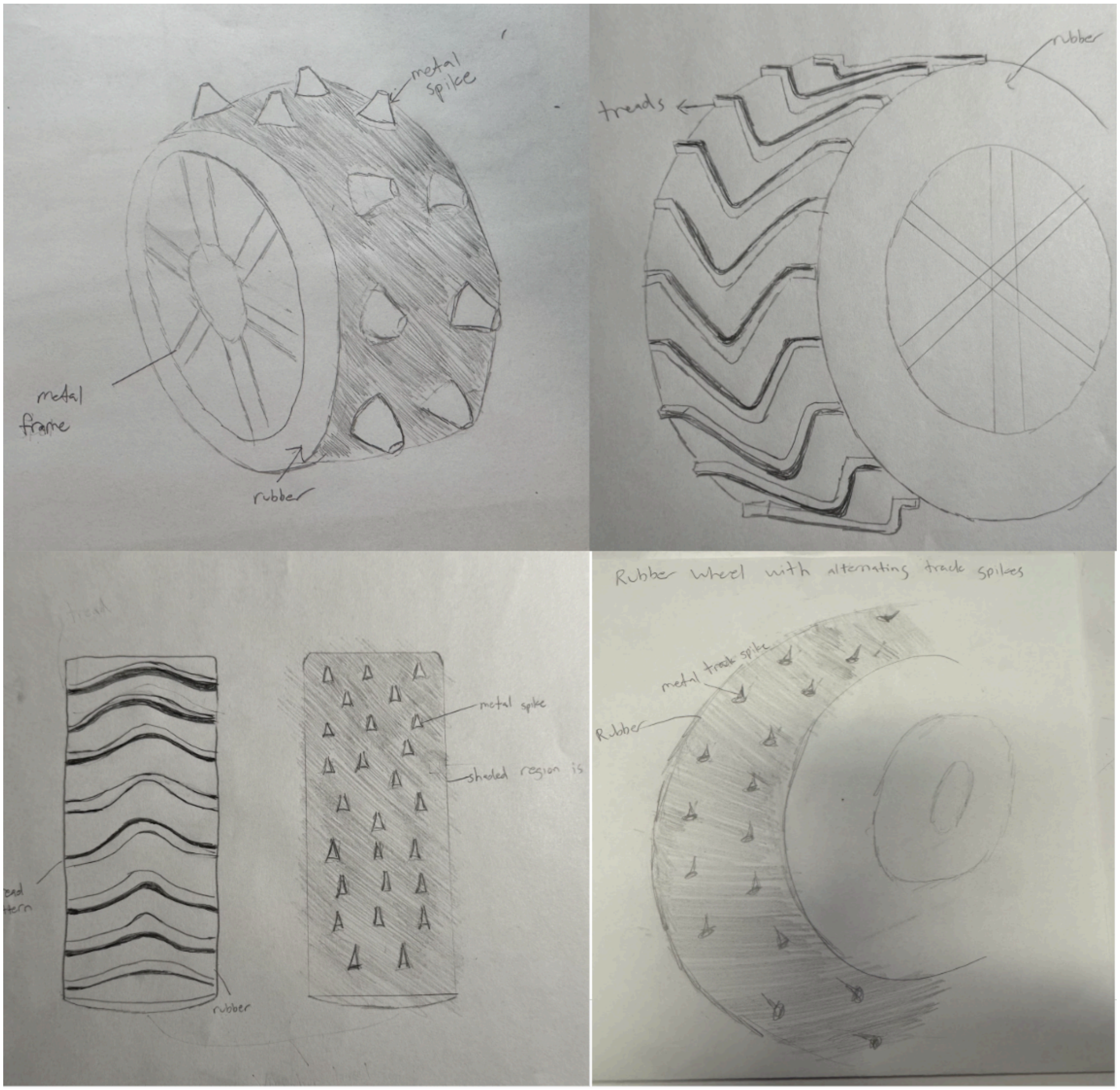
1. Can you give us an introduction to the competition that you are competing in, and what are some of the basic guidelines for Rover construction?
2. What is y'all's expected budget and timeline for a prototype and solution? Do we need to hasten our efforts to have the wheel ready for something like a qualifier for the competition?
3. What wheel design systems have you looked into before? What is y'all's reasoning behind your 6-wheel design as opposed to more or fewer wheels on the rover?
4. You mentioned in your presentation that other teams within the competition use non-pressurized wheels. What's a popular trend or design you see among the other competitors? What are their strengths and weaknesses?
5. What do you see as the most important functions the rover wheels must accomplish during the competition?
6. How easy should it be to replace or repair a wheel in the field?
7. How would you prioritize between speed, durability, cost, and maneuverability?
8. What diameter/thickness are we looking for?
9. What does the part that connects to the wheel look like? Can we get its dimensions and its CAD design?
10. What was the thinking behind a wheel-based system as opposed to a track-based rover?
11. What materials are commonly used by other competitors in the competition?
12. How heavy a payload do you expect to carry for the rover?
13. Do you have any idea what percent of the overall weight the wheels should be?
14. What speeds and pressures do the wheels need to handle?
15. What are some common problems with other teams' wheels?
16. Are there specific terrain types (sand, gravel, rocks, slopes) that concern you more than others?
17. What are some common problems with other teams' wheels?
18. What is the most important feature of the wheel?
19. Are we expected to design the hub for the wheel, or the stokes, or just the outer part?
20. What materials are banned/supported in the competition?

Interview Answers:

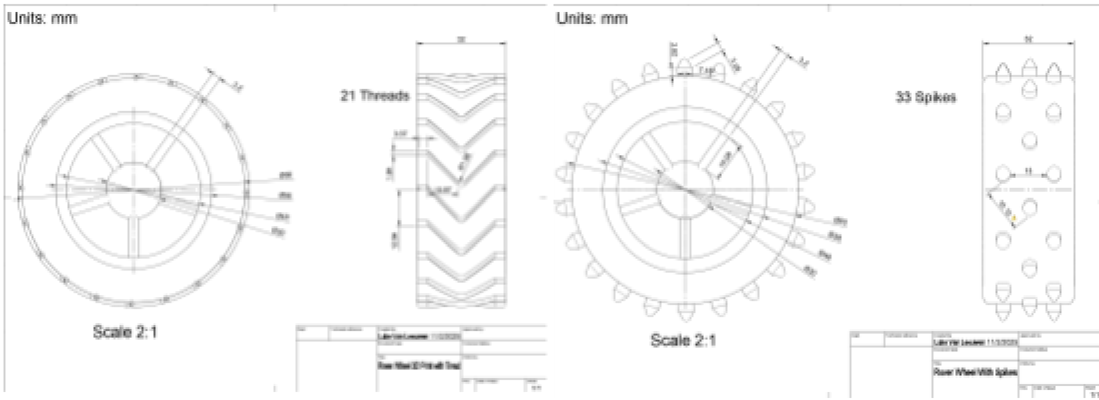
- The Rover that we are making will be competing in the URC competition. This is a robotics competition that happens in Utah every summer. It consists of two main parts. There is a system acceptance review (SAR) in February, where we take a video and present our rover and our concepts and ideas behind its construction. After that, if our team is selected, we will then be invited to compete in the final competition in May. The rovers themselves have to fit within a certain space and weigh at most 50kg. What we really want from you guys, though, is to look into some more complex wheel designs and come up with something that might be considered more “far-out”. As of right now, our rover doesn’t exist. We have been doing research and
- Don’t really know about the budget, but in terms of a timeline would be nice to have the wheels done in early December so that we can start working on our SAR.
- 6-wheels is just the route we wanted to take; past teams have had success with it.
- I haven’t been to the competition before, so I can’t really answer that.
- Just need them to be able to handle the payload delivery mission. There's a lot of varied and rough terrain that the rover is going to have to navigate. Also, there are some steep inclines that the rover will have to overcome.
- Hopefully, pretty easy. We might have to take apart the Rover for inspection during the competition, or also change out parts when they get damaged, so ideally, the wheel can be replaced quickly.

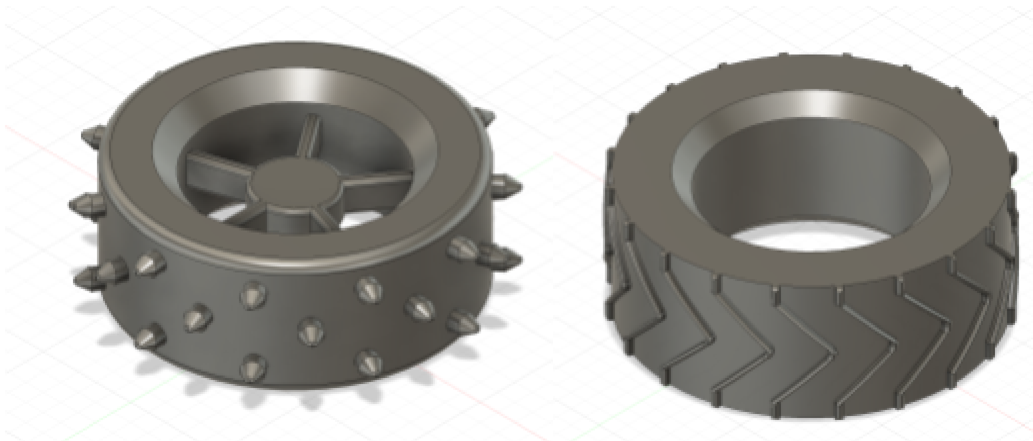
- Ultimately, maneuverability is going to be the most important, and then replaceability.
- That's really up to you guys, and however you want to design the wheels.
- We can't provide you with that right now, but hopefully, soon we will get some CAD designs done of the rover and can get the file to you. It'll probably just be pretty standard, nothing too crazy.
- (Skipped over because it was already addressed in the previous answer, question 3)
- Don't really know the answer. I am sure that some of the other teams published SAR videos; they might mention it.
- The rover will carry a 10 kg package in the delivery mission, so the wheels would have that plus about 50kg of the rover acting on them.
- Don't really have an answer for that since we haven't built the rover yet. I would hope not too heavy, but I don't really have a number right now.
- (Skipped over because it was already addressed in the previous answer, question 12)
- Again, I haven't been to the competition before, so I can't really answer that.
- The major thing is the steep inclines and probably the sand.
- (Skipped over because it was already addressed in the previous answer, question 15)
- Just need it to be able to handle the rough terrain and slopes well while also being replaceable and durable.
- Really just want you guys to make the wheel as a whole, so whatever parts that are.
- Don't know the answer to that, but I'll share the URC competition rulebook with y'all, and it'll likely be in there.

Appendix B: Sketches



Appendix C: Technical Drawings (Files located in shared drive)





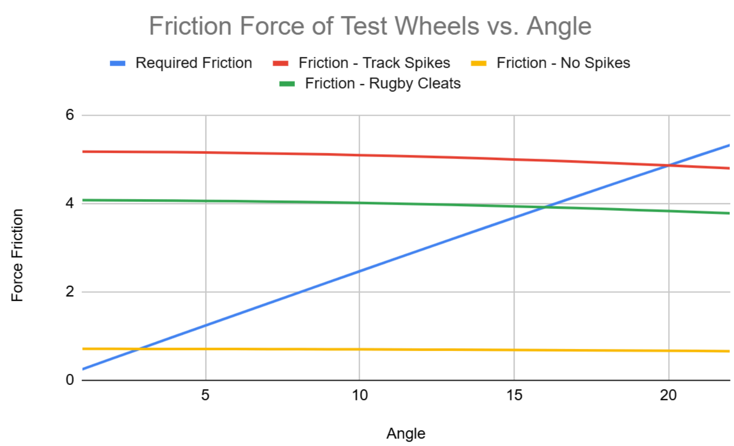
Appendix D: Expenditures

Item	**Quantity**	**Price**
Rugby Spikes	3	$9.49
Leather Rivet Kit Spikes	1	$14.39
Lawnmower Wheels (2)	4	$29.99
Track Spikes	2	$9.99
Total Cost		$182.80

Appendix E: Testing Results

Friction Test Results and Calculations

	Angle	Required Frictio	Friction - Track S	Friction - No Spi	Friction - Rugby Cleats
0.01745329252	1	0.2479986955	5.171652212	0.7103917874	4.073386509
0.03490658504	2	0.4959218481	5.169289089	0.7100671826	4.071525225
0.05235987756	3	0.7436939382	5.165351351	0.7095262844	4.068423715
0.06981317008	4	0.9912394919	5.159840196	0.7087692577	4.064082924
0.0872664626	5	1.238483104	5.152757304	0.707796333	4.058504173
0.1047197551	6	1.485349463	5.144104832	0.7066078067	4.051689163
0.1221730476	7	1.73176337	5.133885417	0.7052040407	4.04363997
0.1396263402	8	1.977649765	5.122102169	0.7035854628	4.034359044
0.1570796327	9	2.222933748	5.10875868	0.701752566	4.023849213
0.1745329252	10	2.467540605	5.093859014	0.6997059085	4.012113679
0.1919862177	11	2.711395824	5.077407709	0.6974461138	3.999156017
0.2094395102	12	2.954425127	5.059409776	0.6949738703	3.984980172
0.2268928028	13	3.196554482	5.039870698	0.692289931	3.969590465
0.2443460953	14	3.437710136	5.018796426	0.6893951135	3.952991581
0.2617993878	15	3.677818631	4.996193381	0.6862902996	3.935188578
0.2792526803	16	3.916806826	4.972068447	0.682976435	3.916186878
0.2967059728	17	4.154601924	4.946428972	0.6794545291	3.89599227
0.3141592654	18	4.39113149	4.919282767	0.6757256548	3.874610905
0.3316125579	19	4.626323475	4.890638101	0.671790948	3.852049296
0.3490658504	20	4.860106237	4.860503699	0.6676516071	3.828314315
0.3665191429	21	5.092408563	4.828888741	0.663308893	3.803413193
0.3839724354	22	5.323159692	4.795802857	0.6587641287	3.777353514



Durability Test Results

Drop Height (in)	Wheel with Rugby Cleats	Wheel with metal spikes in linear layout	Wheel with metal spikes in diagonal layout
10	No damage	No damage	No damage
20	No damage	No damage	No damage

30	Light damage	No damage	No damage
40	Loss of 2 spikes	Light damage	No damage
50	Loss of 2 more spikes	Heavy spike blunting	Light damage

Replicability Test Result

- Time to replicate iteration 6: Wheel with diagonal spike layout - 6 minutes and 50 seconds per wheel

Weight and Size

- Iterations 4, 5, and 6 meet targets of size and they are 10% over target weight

Appendix F: Bill of Materials

- 8.5-inch lawnmower wheels (quantity as needed)
- Metal track spikes - 12 per wheel
- Super glue
- Drill with an appropriate bit size for the spike shaft
- A marker or pencil for marking
- Ruler or measuring tape
- Safety Equipment: safety glasses, work apron, work gloves
- Clamps or vice to secure wheel during drilling

Appendix G: Assembly Instructions

Step 1: Plan Spike Placement

1. Calculate spike spacing: Divide the wheel circumference by 12 to determine equal spacing
    - For an 8.5-inch wheel: approximately 2.25 inches between each spike
2. Mark 12 evenly spaced points around the outer circumference of the wheel
3. Create an alternating pattern by marking points at two different depths or angles from the wheel edge

Step 2: Prepare for Drilling

1. Secure the wheel flat on a stable work surface
2. Wear safety glasses and a dust mask
3. Select a drill bit slightly smaller than the spike shaft diameter for a tight fit

Step 3: Drill Holes

1. Drill straight through at each marked location
2. Drill to a depth that will accommodate 3/4 of the spike length
3. Keep the drill perpendicular to the wheel surface for straight holes
4. Clear away any plastic shavings or debris from each hole

Step 4: Test Fit Spikes

1. Insert each spike into its hole without glue first
2. Ensure all spikes fit snugly
3. Verify the alternating pattern is correct
4. Make any necessary adjustments to the hole size or position

Step 5: Apply Super Glue

1. Work on one spike at a time
2. Apply a small amount of super glue inside the drilled hole
3. Apply glue to the spike shaft as well
4. Avoid over-application to prevent glue seepage

Step 6: Insert and Secure Spikes

1. Firmly press each spike into its hole
2. Hold in place for 30-60 seconds until the glue sets
3. Wipe away any excess glue immediately
4. Repeat for all 12 spikes
5. Allow full cure time (typically 24 hours) before use

Step 7: Final Inspection

1. Check that all spikes are firmly secured
2. Test each spike by attempting to wiggle it
3. Verify spikes are oriented in the intended alternating pattern
4. Re-glue any loose spikes if necessary

Appendix H: UDS

Table, Coolness

Level	Attribute
1	People feeling Boring with the design of the rover wheel
2	When looking at the rover, people tend to focus more on the wheels
3	The design of the wheels are memorable, and the decoration stands out
4	People start to chat and discuss the wheel, and they started to compare it with other team's design
5	People start to take photos, calling their friends or other teams to come and see the unique design

Table, Replicability

Level	Attribute
1	People feel exhausted and give up from replicating the rover wheel
2	People spending large amount of effort trying to figure out the structure of the design inorder to replicate
3	Eventhough it takes a some time, replicating the wheel is still feasible
4	The design is relatively easy to replicate, assembling the wheel does not take much time
5	The wheel is modular in structure. The parts can be easily obtained and can be assembled in a short time.