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The Tera Multi Terrain Mobility Aid Chassis

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Abstract—

The natural environment poses a significant number of obstacles and dynamic settings that makes mobility difficult for those with physical and mobility impairments. To approach this problem, a suspension was designed using inspiration from the early Mars rovers developed by NASA for traversing the varied Martian landscape. The course of the project followed the direction of a start-up through problem identification, early design generation and review, and final design production. The project outcome, through client request and proven market research, aimed to produce a multi-terrain wheelchair. The final product is a kinematic body with mobile front "legs" and a rotational degree of freedom between the two supporting halves, allowing for uneven terrain changes between the two sides and for overcoming step height obstacles. A linkage suspension system was designed to create mobility in the basic design and another suspension piece was created in order to provide payload or patient stability on the product. The final project outcome delivered a 3D modeled package of components and assemblies as well as basic material strength analysis to verify design strength and support qualifications before physical assembly.

Keywords—Wheelchair, Multi terrain, Rocker Bogie, Mobility

I. Introduction

The project for the design of a novel multi terrain wheelchair was proposed by the tech start-up company Natraverse, a lab based entrepreneurial venture through the biomimetics and robotics lab in the University of Akron. The lead sponsors of this project are the current doctoral candidate Colleen Unsworth and Dr. Henry Astley. Early funding came from awards received by the lab from the Be The Change pitch competition and the National Science Foundation's I-Corps Program. The project was aimed at using early biological concepts to create a bio-inspired mobility aid device for those with mobility impairments. The bio-inspired concept became a less concentrated focus as the project progressed in its development.

The client defined goals which included creating a first design mock-up and a potential prototype for first stage product development. The wheelchair's product tasks included the ability to travel on uneven and rough terrain, to design a suspension for the patient, and moderate stability.

Initial design considerations and early product research detailed a series of multi-terrain wheelchairs already on the market. A popular wheelchair with manual controls and all terrain capabilities is the Mountain Trike [1], a hand cranked wheelchair that is both low to the ground and light. Electric powered wheelchairs include such categories as the HexHog [2], a large 6 wheeled ATV like wheelchair capable of ascending slopes up to 60%. In patent US 9,289,338 B1 [3], the motorized wheelchair is able to carry large patients, traverse muddy terrain, and adjust its seating for patients with significant muscular degeneration.

These available wheelchairs come with significant drawbacks. The mountain trike is cheap, but requires a patient capable of self-propelling themselves with only hand cranks. the HexHog is fast, but comes at the expense of size, cost, and weight. Another motorized wheelchair, designed by Timmy R Swenson and marketed by Action Trackchair [4], is prohibitively expensive at costs ranging from 15,000 USD to 22,000 USD.

The patients requiring these devices tend to have mobility impairments and can suffer from a range of physiological challenges. These impairments can stem from injury, muscular dystrophy, cerebral palsy, amputation, multiple sclerosis, pulmonary disease, heart disease, or congenital diseases. Less obvious users would include patients suffering heart or lung conditions. These patients do not have the stamina to move very far on their own [5]. In the United States of America alone, physical impairment statistics report nearly 17.2 million non-institutionalized adults 18 years and older are either unable or find it very difficult to walk a quarter of a mile.

Based on the team's market research, there exists a niche space in the market for a more economical motorized wheelchair, capable of achieving moderate speeds, traversing a range of moderate environment conditions, and can operate in similar environments as the typical patient with mobility aids would require. Through the design of this wheelchair suspension and chassis, a prototype to satisfy these conditions and the marketplace is closer to full development.

II. Design Requirements

A. *Design Requirements*

Determining core design specifications was the first project task. While keeping the client goals of a bio-inspired, multi terrain wheelchair in mind, the team researched competitive products in the field and conducted interviews with potential customers within the determined market. Based on the venture start-up Natraverse's preliminary market research and customer profiling, the design team conducted product question interviews with individuals that were within middle to upper class financial circles and had either family history or personal history of being physically active and very mobile.

Using this information, one team member conducted 3 customer interviews ranging from the age of 46 to 86 years of age, all male, and all using a different wheelchair variation. The electrical wheelchairs were attributed with having a tight turn radius, ability to hit speeds from 5 to 10 miles per hour, required minimal maintenance requirements, and stability on a variety of substrates. The largest negative feedback included short battery life and high device pricing. In contrast, other interviewees described the manual wheelchair as a better alternative for them. They stated that manual wheelchairs required low maintenance, had higher comfort and flexibility compared to powered wheelchairs, and were less costly. A fourth interview was conducted with a local medical aid device and wheelchair sales associate. The results suggested that the majority of wheelchair devices lack the ability to enable out of state travel or simple outdoor travel activities? such as gardening. In the interview, cost was discussed, where it was stated that specialty wheelchairs are not often covered through medical insurance and would require significant out of pocket expenses.

Other resources made a crucial point to describe wheelchair sizes and accessibility. The most noteworthy resources detailing the laws and regulations on accessibility comes from the American Disabilities Act (ADA) of 1990, the United States Access Board, and the United Nations (UN). In each resource, they continued to cite importance of wheelchair size and the major impact it had on ease of travel.

To hold to both the goals of the client and some of the interviewed responses, the team decided to focus on maneuverability of the device. This included the devices turn radius, climbing ability for step heights, angle of ascent, ability to move on varied substrates, and the systems overall dimensions.

B. *Defining Engineering Requirements*

The core engineering goals were set based on the combination of ADA regulations, civic transportation and construction regulations, and preliminary competitor research information. Based on the ADA's regulations for minimum turn diameters for electric and motorized vehicles, a minimum turn diameter of 60 inches was set by section 304 of the 2010 ADA regulations [6]. Similarly, length needed to remain within the designated clear floor space of 48 inches in length and 30 inches in width, as described by section 205.3 of the 2010 ADA regulations.

The desired step height was based on environmental and civil engineering codes published in the Title 8 Regulations from the state of California and the Occupational Safety and Health Administration (OSHA) as well as the Seattle Construction Design Standards Standard plan 410. According to the Seattle designs, a curb cannot exceed a height of 6 inches [7] while according to the California and OSHA Title 8 subchapter 7 on stairways, a rise in a step-in public settings cannot exceed 7.5 inches [8]. The goal of the design is to reach a step clear height of 6 inches and set a secondary goal of 7.5 inches for the aim of clearing stairs in the future.

Further in the Occupational Safety and Health Administration (OSHA) and California documents, they describe the slope angle of stairs to range from 30 degrees to 50 degrees. In order to climb typical wheelchair slopes and be able to ascend above typical slopes, a desired travel angle of 30 degrees was defined by the group.

Finally, defining weight distribution and its impact on mobility is difficult to study without full assembly of the wheelchair's design. A qualitative goal of the design is to place the weight distribution over the driving wheels. Weight distribution is critical to decreasing the amount of energy necessary for accelerating the system [9].

III. Design and Methodology

The process of design development requires multiple stages of review and verification. Through the process, initial product specifications, general design concepts, and final design parameters are all to be gathered and evaluated. During this process, verification and review of previous designs is necessary to ensure there is a viable product. Through the coursework done by the engineering team, a similar review was necessary, and allowed for final completion of the project.

A. *Initial Design Requirements*

The first task was to define the initial engineering specifications. They were found through medical aid device regulations, competitor searches, and patent searches. The final results of this research process has already been described in the design requirements.

A quality functional deployment (QFD) document was used to compare the fundamental concepts of a wheelchair. Its purpose was to prove that focusing on the suspension of the wheelchair design would be able to satisfy the main customer requirements. The QFD guided us to focus on the wheelchair's weight distribution, turning radius, stopping distance, and wheelchair tilt. The crucial values were determined through regulatory research that was done during the production of the 3D CAD model. The SolidWorks software was used in building

During the first round of evaluating the customer goals and engineering specifications, a quality functional deployment (QFD) document was used. Due to the lack of focus on the specifics of the given project and the lack of specific engineering requirement values, it led to issues further in the process as it could generate the final numerical and engineering guidelines it was meant to provide.

Later on in the process, after trying to build the model, new documents were found and detailed as described in the introductory design requirement section. Full comparison charts were not used due to lack of time before the project deadline. It required contrasting against organizations such as the World Health Organization (W.H.O), the United Nations, OSHA, RESNA, and competitor groups.

B. *Initial Concept Design and Generation Process*

After the first stage of defining the engineering requirements, and focusing on the qualitative issues, the team then attempted to use the engineering constraints and design goals from the QFD to begin generating preliminary design concepts. The team conducted both brainstorming sessions between the four members as well as conducted repetitive solution searches. To first create the concept, the chassis was broken down into 3 main subassemblies: these were the wheels or ground effectors, the suspension, and the power source. Preliminary concept comparisons were created to provide documented evidence for the differences between the possible design choices. After further evaluation, the suspension assembly would be further divided depending on the chosen suspension system.

The different concept proposals were chosen based on cost, feasibility, and quantitative design comparison matrices. The wheel subassembly was decided to be a semi inflated wheel, due to ease of implementation, price, and general ground traction. The power source subassembly was decided to be motorized, due to feasibility issues with learning fluid power controls. Manual power was not pursued due to the goal of making a design that could serve a larger population, including those that would be physically too weak to propel themselves. The suspension was decided using a decision matrix to compare different designs and their ability to handle different situations. After researching different suspension designs for terrestrial vehicles, a matrix was created. The matrix lacked conclusive engineering values for support and was based on qualitative descriptions of the materials. From the suspension matrix, the group decided to pursue the Rocker Bogie suspension system, an inspired design created from National Aeronautics and Space Administration.

The Rocker Bogie design was first used in the Sojourner Rover. It was designed for providing even weight distribution among each wheel, and allowed for zero point turning, eliminating the need for a small wheelchair that would turn about an axis outside of its own body. Another benefit of the design was its ability to separately handle uneven terrain between its left and right halves. The rocker bogie design was already employed in space exploration, and rescue and safety operations for both the military and civilian purposes due to its dynamic ability to handle unstructured terrain [10]. The rocker bogie concept was then further broken down into the Rocker, Bogie, and differential mechanisms.

To finally build the model required an evaluation of the final dimensions for the project. These dimensions were to be drawn from the completed concept design as well as the engineering requirements first defined through research and the QFD. The preliminary calculations ensured the Rocker Bogie leg subassembly would be designed to evenly disperse the centered weight and would comply to ADA sizing regulations including necessary space for turning as described earlier.

To ensure the concept would work, a failure mode and effect analysis (dFMEA) was conducted on the design. The document compared the chosen design against possible failure modes and dictated how these problems would be solved. Correction methods were then developed to make up for these risk factors. The team dFMEA was qualitative, showing that the design needed to focus on maintaining stability and allowed for responsiveness from the controls to keep the patients safe from injury.

To ensure the project design was understood by the entire group, a low fidelity prototype was built. In doing so, the team could better model and improve upon the system's modes of failure. After completing the prototype, it was determined that the differential of the rocker bogie would require the most rework to be properly modeled.

C. *Final Design Production*

The production of the final design required rework and review of the project goals, engineering requirements, and design which will be described later in this paper.

The final model design was done using SolidWorks provided by the University of Akron and conducted in the Biomedical Engineering Department computer labs. The final model was then broken down into subassemblies and drawings for future production. The resulting 3D model is shown in Appendix-1.

D. *Design Challenges*

The largest design hurdles came from a lack of early focus on engineering requirements. The first months of design focused on concepts rather than setting actionable design parameters and values. The lack of defined dimensions leads to significant issues when modeling the CAD package. This led to a significant amount of research to find them. Early concepts had to modified, as the defined dimensions would not allow the team to implement what was first considered.

The second key issue came from team cohesion. The concept development required the entire team understanding the problem and proposed solutions. Communication and presentation became key for moving the design process forward. After the team produced a low fidelity prototype, the early design concept was cemented, and work was able to continue.

IV. Results

The final project delivered a first-generation model for future prototype iterations. The team also provided crucial research, values, and regulatory bodies for development purposes. The resources focused on providing guidance for improving the design, a set of interface guidelines for the public, and a list of potential parts and costs for the prototype design. It gave an analysis of possible failures as well methods for solving these issues. A final prototype was the goal of the project. Due to the sudden onset of the Covid-19 pandemic, the final production of the prototype was put on hold. With the provided materials, future design iterations can be produced and improved upon.

Before project completion, the design required a verification that it would satisfy regulatory and consumer standards. To do so required documenting sources for testing, designing future test fixtures, and conducting another FMEA to further guarantee the final design model would not have unacceptable risk. The model was evaluated using finite element analysis (FEA) software to prevent major part failures in the future. The ANSYS software package was used for the FEA testing..

A. Static Load Simulation Test and Verification

The ANSYS model utilized a velocity of 0.8m/s, an assumed passenger weight of 300lbs, and assumed the total weight of the wheelchair to be 250 lbs. Under these conditions it was calculated that normal force experienced by the chair would be 5941.64 N if it were to impact a curb 6 inches tall. This force was applied as a static loading in ANSYS to evaluate the structural integrity of the design when traveling at its top speed, carrying its maximum weight capacity with a safety factor of 1.7. The calculations for this can be found in Appendix-2. The purpose of this analysis was to serve as a preliminary test with extraneous forces to make sure the design would not fail.

The results of the analysis in ANSYS are broken into two components. This was done because of the limitations of the student license. The first result shows the effect of the normal force on the main weight bearing shaft, and the second result focuses on the rocker bogie frame. In the first analysis the stress and strain are denser at the center of the shaft with a maximum strain of 0.00189 m/m at the center with a gradual decrease toward the ends. In the second analysis the force is applied as a bearing force where the main shaft connects to the pillow bearing, and the locations of wheel attachment are defined to be fixed in the vertical direction. This results in a maximum strain of 0.0014 m/m at the welds of the bogie section.

The results of the finite element method analysis show that the frame and shaft of the suspension are capable of safely supporting the force experienced when extreme situations are imposed. While these results support the safety of the design, they are not absolute, but an acceptable precursor for further testing. The limitations of the software license cannot be overlooked, and further physical testing should also be conducted in order to confidently approve the design. The final ANSYS Displayed results are shown in Appendix 3 and 4, depicting the deflection.

B. Validation Plans and Resources

The prototype would also need physical testing after production testing. Doing so would require both a team designed structure to evaluate crucial engineering figures as well as testing according to regulatory standards.

Core medical aid device and wheelchair regulations are published by the International Organization for Standardization (ISO). ISO standards 7176 are focused specifically on wheelchairs. For early testing, it would be beneficial to use the 7176-01:2014 ISO [11] method to test static stability, 2776-08:2014 ISO method for static impact and fatigue [12], ISO 7176-05:2008 for mass and dimensions [13]. Further development will need ISO 7176-03:2012 to determine brake effectiveness [14].

The designed test fixture was focused on testing the major goals of this project, by providing a source of irregular tracks to simulate uneven terrain with 6-inch blocks spaced 24 inches apart, a 180 degree turn radius, and a slope of 30 degrees for it to climb. The outcome would be physical validation that the design and prototype would be successful in accomplishing the initial engineering goals. A SolidWorks model of the team designed test course is shown in Appendix-4.

C. Prototype Cost Analysis

The production of the prototype for effective testing would be difficult without a power source, which was outside of the scope of this project. Parts were chosen to build a quarter scaled model, rather than a full user sized one to save on costs and still serve for proof of concept. Steel tubing, bearings, rods, wheels, and motors were all chosen based on similar dimensions and approximate strength. Material tests were conducted in ANSYS Workbench, but further analysis should be done on motor strength before purchasing. With the quarter model steel suspension, the cost approximated 315 USD. The largest spending came from the purchase of the motors and battery, which were sourced from RTH through Amazon [15] and Mighty Max Batteries [16] respectively. Together, these alone incurred a 90USD and 62USD cost. After further development, these may increase once better controls are implemented.

Still, compared to the median cost range of powered wheelchairs covered by Medicare at 1,699 to 3,888 USD, and not including specialized wheelchairs similar to the HexHog referenced earlier that can range from 15,000USD to 22,000 USD, early project costs suggest that the design can be economical [17].

V. Discussion

The project was not able to satisfy all of its goals. It was not able to provide a functional suspension or chassis prototype to the client. It however, did provide the resources for the future iterations that need to be made and were already planned for the future. The completed 3D model provides a source for reference and possible production if so chosen. The design would most closely serve as a proof of concept, showing that an alternative design to the standard wheelchair designs can provide more maneuverability to the user.

Greater verification could be run in the future, as well as further addressing issues of stability. The current design does not incorporate any form of spring or damping systems, which would help absorb unwanted instability. The dFMEA indicated that stability could be a major issue, and by incorporating the springs and damping systems into the design, it can decrease the chance for injury.

A. Challenges

There were three major design challenges during the course of the project. The first being the lack of specific engineering requirements at the beginning of the design period. Early on, there was a greater focus on defining customer goals and then jumping to engineering values. It could have been easier to have defined these values first, conducted questions around the numbers so the team was knowledgeable about the problem before the interviews, and then reevaluated their engineering requirement goals from there.

The second was the lack of focus specifically on the client's proposed project of the wheelchair suspension. Defining whether or not the suspension was a useful project to focus on set the team back during crunch time.

Thirdly, there was a lack of clear direction. It would have been more helpful to have a full understanding of the project phases early on, to understand the purpose of what the group is supposed to focus on. The slow transition and not knowing what to do to prepare for the project ended up in misinterpreting the goals of the design phases.

VI. Conclusion

The project served as a lesson in project design and teamwork. To reach the end of the project required each member to be capable of independent work, accurately communicate their difficulties, and collaborate when their work overlapped with others. The project lacked direction early on, missing core details and example explanations for how or why the project required the steps involved.

To fix early team issues and speed up project completion, the second half of the project required weekly team meetings to check on group progress and get work done. It required greater planning to determine what could only be accomplished with as a team and break it down into individual parts for the project.

Each team member contributed to the project. Daniel Nicole provided a large chunk of early patent and scientific literature searches, worked on the dFMEA, and worked on rocker bogie leg, wheel, assembly, models and drawings, cost analysis, and the ANSYS verification. Ibrahim Suleiman worked on patents, regulations, documenting group meetings, the suspension decision matrix, modeling and concept research of the rocker bogie wheel assembly and differential assembly, cost analysis, the test course design, and poster presentation. Colton Kemp worked on the regulation and searches, Gannt scheduling and the DHF, concept research and comparisons, preliminary concept structure and dimension designs, calculations, preliminary modeling, reiterative research on regulations and regulatory testing, and report writing. Mohammed Alyami worked on the gate presentations, wheel comparison in the design, cost analysis, testing and ISO standards research, and poster presentation work.

The team overall managed to deal with extraneous scheduling difficulties and show proof of concept for the project's design.

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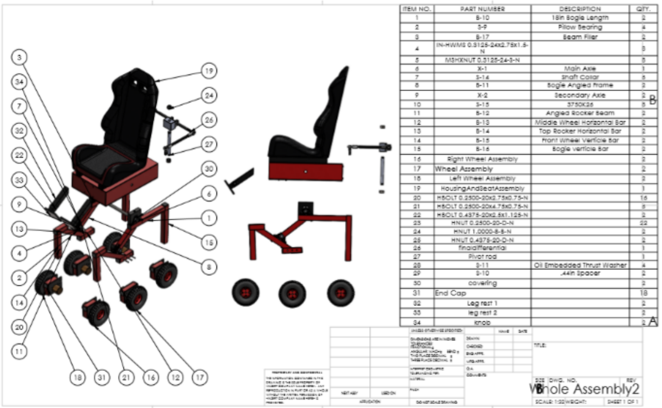
References

1. *Mountain Trike*, Accessed on March 1, 2020. Available: https://www.mountaintrike.com/
2. Sion Pierce, *Hexhog All-terrain Wheelchair ATV*, Disabled World, 2014-08-06 Accessed on: March 1, 2020 [Online] Available: https://www.disabled-world.com/assistivedevices/mobility/wheelchairs/allterrain/hexhog.php
3. Swenson, "US 9,289,338 BI Multi-terrain motorized wheelchair", USPTO Patent Full Text and Image Data Base, March 22, 2016 Accessed: 4/2/2020 Available: patft.uspto.gov/netacgi/nph-Parser?Sect1=PTO1&Sect2=HITOFF&d=PALL&p=1&u=%2Fnetahtml%2FPTO%2Fsrchnum.htm&r=1&f=G&l=50&s1=9289338.PN.&OS=PN/9289338&RS=PN/9289338
4. *Action Trackchair*, Accessed on: March 1, 2020. Available: actiontrackchair.com/
5. Disabled World, *Physical and Mobility Impairment Information*, Disabled World, 2019-01-17. Accessed on: February 20, 2020. [Online] Avaliable: https://www.disabled-world.com/disability/types/mobility/
6. 2010 ADA Standards for Accessible Design, Department of Justice, September 15, 2010. Accessed on: October 4, 2019 [Online] Available on: https//www.ada.gov/regs2010/2010ADAStandards/2010ADAstandards.htm#sec80922
7. "Seattle right-of-way improvements manual", Seattle Department of Transportation, December 1, 2017 Available Online: https://streetsillustrated.seattle.gov/
8. *Subchapter7. General Undustry Safety Orders Group1. General Phycical Conditions and Structure Orders Article 2. Standard Specifications*, California/OSHA, February 9, 2009. Accessed: February 20, 2020 [Online] Available on: https://www.dir.ca.gov/title8/3231.html
9. Ju-Tei Lin, MS PT Stephen Sprigle, PhD, PT, "The impact of wheelchair weight distribution and human physiological fitness on over-gorund maneuver", School of Applied Physiology of Feorgia Institute of Technology, 2016. Accessed April 2, 2020 [Online] Available on: https://www.resna.org/sites/default/files/conference/2016/pdf_versions/wheelchair_seating/lin.pdf
10. Sunxin Wang and Yan Li, "Dynamic Rocker Bogie: Kinematical Analysis in a High-Speed Traversal Stability Enhancement", Hindawi Publishing Corporation International Journal of Aerospace Engineering, August 23, 2016. Available on: http://dx.doi.org/10.1155/2016/5181097
11. "ISO 7176-01:2014 wheelchairs-part 1: determination of static stability", International Organization for Standards, Available: https://www.iso.org/standard/56817.html
12. "ISO 7176-08:2014", International Organization for Standards, Available: https://www.iso.org/obp/ui/#iso:std:iso:7176:-8:ed-2:v2:en
13. "ISO 7176-05:2008 wheelchairs-part 5: determination of dimensions, mass and manoeuvring space", International Organization for Standards, Available: https://www.iso.org/standard/46429.html
14. "ISO 7176-03:2012 wheelchairs-part 3: determination of effectiveness of brakes", International Organization of Standards, Available: https://www.iso.org/standard/53816.html
15. 2Pcs Universal 550 3500 RPM Electric Motor RS550 12V Motor Drive Engine Accessory for Kids Power Wheels RC Car Children Ride on Toys Replacement Parts", Amazon, Accessed: March 1, 2020 [Online] Available on: https://www.amazon.com/Universal-Electric-Accessory-Children-Replacement/dp/B078NN8W29/ref=sr_1_1?keywords=2+Pcs+Universal+550+40000RPM+Electric+Motor+RS550+12V&qid=1583774399&sr=8-1
16. "ML35-12 – 12 Volt 35 AH SLA Battery- Mighty Max Battery Brand Product", Amazon, Accessed: March 1, 2020 [Online] Available on: https://www.amazon.com/ML35-12-Battery-Mighty-Brand-Product/dp/B00K8V2VD0
17. "A comparison of prices for power wheelchairs in the medicare program", Department of Health and Human Services, April 2004, Available: https://oig.hhs.gov/oei/reports/oei-03-03-00460.pdf

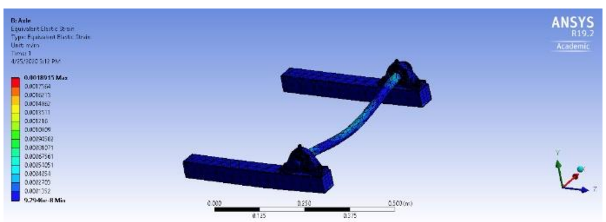
Appendix



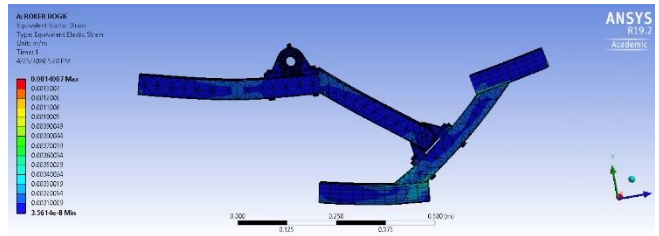
Appendix 1: Displays full exploded view of the SolidWorks 3D CAD Model

$F12N=mv2r+mg$
$F12N=124.740.820.1524+(124.74)(9.81)$
$F12N=1747.54\ N$
$F12N=(1747.54)(1.7)$
$F12N=2970.82\ N$
$FN=5941.64\ N$

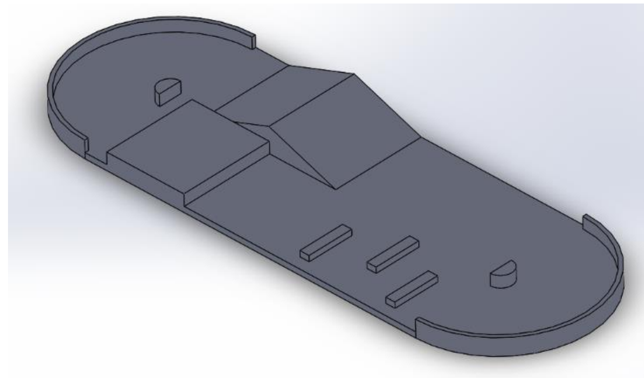
Appendix 2: Displays calculations for ANSYS Workbench Simulations



Appendix 3: Displays 300lb load on main supporting cross rod and resulting deflection



Appendix 4: Displays 300lb load on Rocker-Bogie Leg Sub Assembly and Resulting Deflection



Appendix 5: Displays 3D SolidWorks Model of Proposed Test Course for Team Engineering Requirements and Prototype Validation

	Purchasing order for small scale model			
Part purpose	Part description	Quantity	Total price	Source
Body frame	3/4 in. x 36 in. Plain Steel Square Tube with 1/16 in. Thick	4	$37.50	Home Depot
Axle Bearing	8mm Inner Bore Ball Mounted Pillow Block Flange Micro Vertical Bearing 4 Pcs (8mm)	1	$8.59	Amazon
Axle Rods	Two (2) 8mm x 406mm (.315" x 16") Case Hardened Chrome Linear Motion Rods	1	$12.48	Amazon
Axle lock collar	10 Pcs Lock Collar 8mm Shaft Lock Collar	1	$8.99	Amazon
Differential rod	Turnbuckle-Style Connecting Rod, 3/8"-24 Thread, 6" Overall Length	1	$27.70	Mcmaster Carr

Differential ends	Ball Joint Linkage, 3/8"-24 Internal Thread, Right-Hand Shank, Right-Hand Ball Stud	2	$11.74	Mcmaster Carr
Wheels	4pcs RC Tires and Wheel Rims Set Foam Inserts 12mm	2	$56.00	Amazon
Motors	2 Pcs Universal 550 40000RPM Electric Motor RS550 12V	3	$90.00	Amazon
Battery	ML35-12 - 12 Volt 35 AH SLA Battery- Mighty Max Battery Brand Product	1	62$	
Total		16	$315.00	

Table 1: Displays Purchase Order for projected costs for next stage prototype, associated costs, and part sources