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Zip Shoes

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Department of Mechanical Engineering

Honors Research Project

Submitted to

The Williams Honors College
The University of Akron

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THE UNIVERSITY OF AKRON
1870

ZIP SHOES

By

Derek Ford

Garret Freund

Final Report for 4600:497 Senior/Honor Design Spring 2022

Faculty Advisor: David Peters

Faculty/Honors Advisor: Dr. Scott Sawyer

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01 May 2022

Project No. 42

Abstract

Zip Shoes are self-propelled footwear on wheels, based off the brand Heelys. They are pictured below in *Figure 1*. They operate using two small electric drivetrains, one in each shoe. These drive trains are supported by a plastic chassis that contains all necessary electronic components and is embedded within the soles of the shoes. These drive trains provide power to two heel mounted wheels, one per each shoe. Such that when the user balances upon these wheels they can be propelled forward. These drive trains are controlled by remote controls held within the user's hands. Such that the amount of propulsion they receive can be changed by the user's input. This propulsion can then be used to transport the user between locations as a means of utility or recreation. The following text discusses the reasoning for their creation, further detail on their design, and prospects for the project.

Figure 1

Contents

1. Introduction

Zip shoes are designed to be used by the urban commuter, someone who cannot drive to work. Such that they can get to where they are going faster and expend less effort. They are designed to bridge the gap between walking and using a large electronic propulsion device. Examples of these large electronic propulsion devices include electric scooters, hoverboards, electric skateboards, and e-bikes. The reason for this is to streamline the user's experience. Such that they never need to be removed, carried, or locked up. The user simply puts them on at the beginning of the day and wears them throughout the day like a normal pair of shoes. Ultimately easing the users commute while being non-intrusive.

1.1 Product Development Process

To design Zip Shoes, we used the product development process, or PDP, pictured in *Figure 2* (Budynas & Nisbett, 2020). This process consists of 6 ordered phases. These phases are business planning, concept development, embodiment design, detail design, final testing and refinement, and production ramp up. In each phase we performed key tasks to move the design of our product forward. For the sake of continuity, the following text moves through each of these stages chronologically, detailing the activities and tests performed.

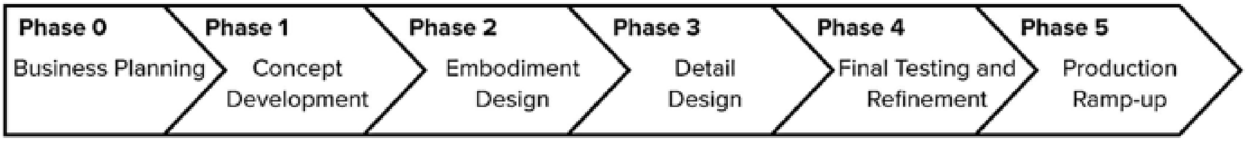


Figure 2

1.2 Business Planning

This was the first phase in the creation of Zip Shoes. The only requirement of this phases is that it "should be done before the approval of the product development process." (Budynas & Nisbett, 2020) As the name suggest, it entails planning out different aspects of the project prior to starting any form of design. As such, the time allocated for this section of the PDP was used to analyze the market. Performing actions such as searching for competing products and generating metrics of success that we wanted our design process to center around.

1.2.1 Market Research

Performing market research for Zip Shoes was a crucial first step. The most fundamental reason for this was to see if the product already existed. If such a product did exist, it would eliminate the need for designing Zip Shoes. Thankfully, after performing cursory searches of major retailers, primarily Amazon and Walmart, no identical products were found. However, we did find several somewhat similar products, these products were Razor Turbo Jetts (Razor, n.d.), Segway Ninebot Drifts (Segway, n.d.), and Voyager Space Shoes (Voyager, n.d.) pictured in *Figure 3, Figure 4,* and *Figure 5* respectively. What made these products similar was their compact design. What differentiated them, however, was their independence from the user's shoes. They are not integrated into the user's footwear at all and some of them are not connected to the user entirely. It is because of this we were confident our product was unique. However, because these products were still like our intended design, they became the baseline for Zip Shoes. As such, more in-depth research was performed on these products, looking into a variety of statistics. The most important of these statistics are summarized in *Table 1* below.

Figure 3

Figure 4

Figure 5

Market Research Comparison			
	Razor Turbo Jetts	**Segway Ninebot Drift**	**Voyager Space Shoes**
Top Speed	10 mph	7.5 mph	6.2 mph
Run Time	30 min	45 min	40 min
Weight Rating	176 lbs.	220 lbs.	200 lbs.
Size	7.7 x 5.94 x 10.8 in	11.5 x 6.4 x 4.8 in	6.5 in (tire diameter)
Weight	5 lbs. (powered unit)	7.72 lbs. (each unit)	6 lbs. (each unit)
Charge Time	Unknown	3 hr.	3 hr.
Cost	$129.99	$469.99	$185.00

Table 1, (GS Mag, n.d.), (Razor, n.d.), (Amazon, n.d.), (Segway, n.d.), (Voyager, n.d.), (Walmart, n.d.)

1.2.2 Metrics of Success

Metrics of success are generalized goals that are desired to be achieved by Zip Shoes. Broadly speaking, they are the framework that a designer will judge the success of their final design against. However, this does not set them in stone. Rather, for this project, they are fluid entities. As the product design process moved forward, they were able to change as necessary to conform to the abilities of the designers and other outside factors.

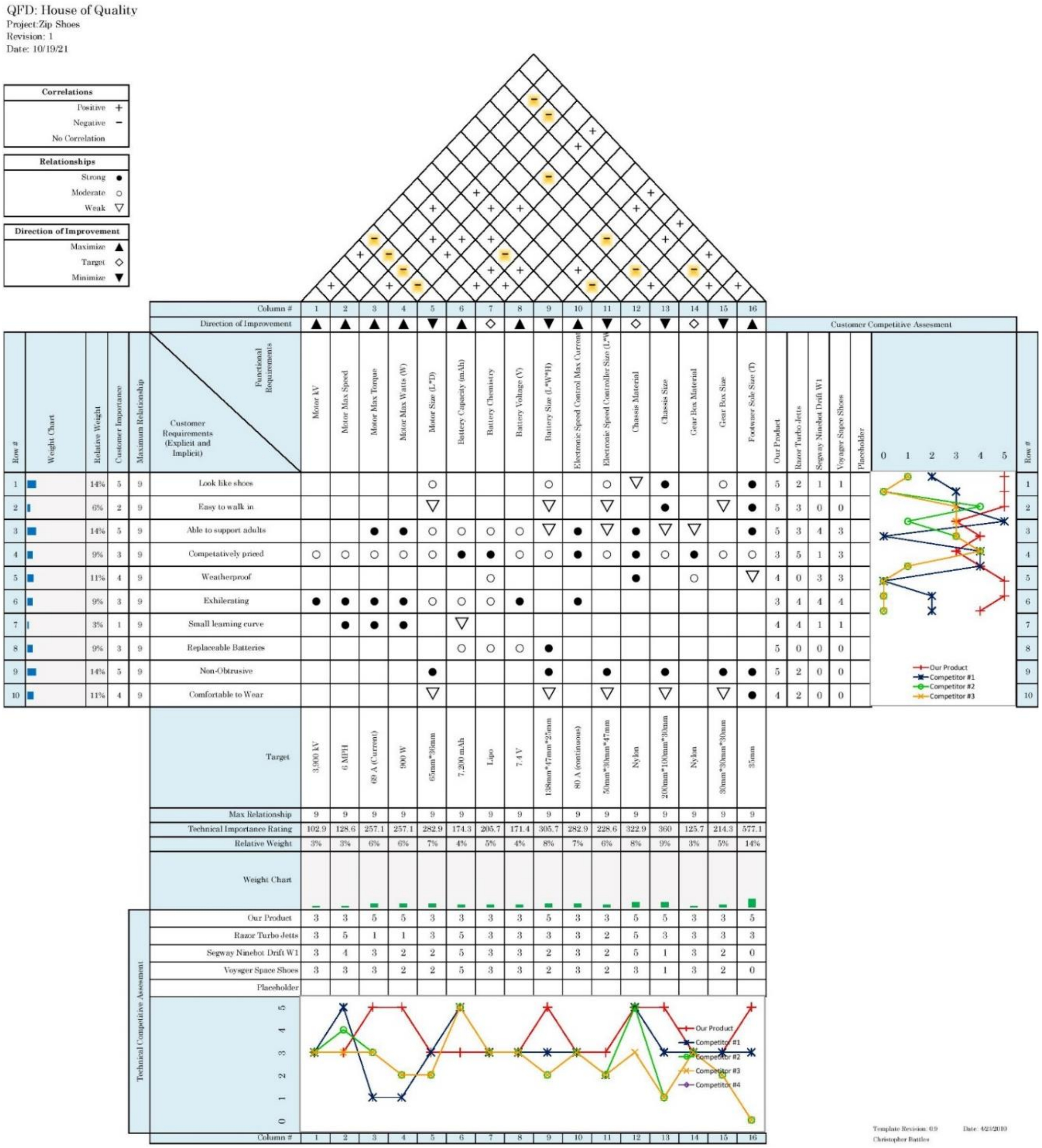
These metrics of success, listed in *Table 2*, were decided early on. Specifically, they were decided immediately after performing market research. These metrics are also included later in our House of Quality Diagram, *Figure 6*. This House of Quality diagram will be discussed in more depth in the design section of this report. These metrics each have their own reason for being selected. The top speed was selected to match the minimum performance of a competitor while also being safe and simple to design around. The run time was selected to approach that of similar products, while allowing for compactness. The weight rating was selected to allow full grown adults to use the product. The size, weight, and comfort were selected to achieve the project's goal of being as streamline as possible. The charge time was selected to undercut competitors and accommodate a shorter run time. Finally, the cost was selected to be on par with competitors. In summation, the design of Zip Shoes desires to achieve all these listed metrics for these listed reasons.

Metrics of Success	
Top Speed	6 mph
Run Time	20 min
Cost	$200.00
Weight Rating	225 lbs.
Size	Fit within the footprint of a shoe
Added Weight	3 lbs. per unit
Charge Time	1.5 hours
Comfort	Be able to walk normally while wearing

Table 2

2. Design

Having completed business planning, the next PDP phases are all design related. They consist of Concept Development, Embodiment Design, and Detail design. They make up phases one, two, and three, respectively. Throughout these phases the designer goes from having a problem they wish to solve to developing a solution. Furthermore, a common tool was used throughout these three phases know as a house of quality, which is picture in totality in *Figure 6*. The excel sheet layout used for this house of quality was obtained online (Battles, 2010). This house of quality diagram is rather large, such that pieces of this tool will be extracted and zoomed in upon to further discuss.



QFD: House of Quality
Project:Zip Shoes
Revision: 1
Date: 10/19/21

Correlations	
Positive	+
Negative	−
No Correlation	

Relationships	
Strong	●
Moderate	○
Weak	▽

Direction of Improvement	
Maximize	▲
Target	◇
Minimize	▼

					Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Customer Competitive Assesment					
					Direction of Improvement	▲	▲	▲	▲	▼	▲	◇	▲	▼	▲	▼	◇	▼	◇	▼	▲						
Row #	Weight Chart	Relative Weight	Customer Importance	Maximum Relationship	Functional Requirements / Customer Requirements (Explicit and Implicit)	Motor kV	Motor Max Speed	Motor Max Torque	Motor Max Watts (W)	Motor Size (L*D)	Battery Capacity (mAh)	Battery Chemistry	Battery Voltage (V)	Battery Size (L*W*H)	Electronic Speed Control Max Current	Electronic Speed Controller Size (L*W	Chassis Material	Chassis Size	Gear Box Material	Gear Box Size	Footwaer Sole Size (T)	Our Product	Razor Turbo Jetts	Segway Ninebot Drift W1	Voyager Sapce Shoes	Placeholder	Row #
1		14%	5	9	Look like shoes					○				○		○	▽	●		○	●	5	2	1	1		1
2		6%	2	9	Easy to walk in					▽				▽		▽		●		▽	●	5	3	0	0		2
3		14%	5	9	Able to support adults			●	●	○	○	○	○	▽	●	▽	●	▽	▽		●	5	3	4	3		3
4		9%	3	9	Competatively priced	○	○	○	○	○	●	●	○	○	●	○	●	○	●	○	○	3	5	1	3		4
5		11%	4	9	Weatherproof							○					●		○		▽	4	0	3	3		5
6		9%	3	9	Exhilerating	●	●	●	●	○	○	○	●		●							3	4	4	4		6
7		3%	1	9	Small learning curve		●	●	●		▽											4	4	1	1		7
8		9%	3	9	Replaceable Batteries						○	○	○	●								5	0	0	0		8
9		14%	5	9	Non-Obtrusive					●				●		●		●		●	●	5	2	0	0		9
10		11%	4	9	Comfortable to Wear					▽				▽		▽		▽		▽	●	4	2	0	0		10

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	Target	3,900 kV	6 MPH	69 A (Current)	900 W	65mm*36mm	7,200 mAh	Lipo	7.4 V	138mm*47mm*25mm	80 A (continuous)	50mm*30mm*47mm	Nylon	200mm*100mm*30mm	Nylon	30mm*30mm*30mm	35mm
	Max Relationship	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
	Technical Importance Rating	102.9	128.6	257.1	257.1	282.9	174.3	205.7	171.4	305.7	282.9	228.6	322.9	360	125.7	214.3	577.1
	Relative Weight	3%	3%	6%	6%	7%	4%	5%	4%	8%	7%	6%	8%	9%	3%	5%	14%
	Weight Chart																
Technical Competitive Assesment	Our Product	3	3	5	5	3	3	3	3	5	3	3	5	5	3	3	5
	Razor Turbo Jetts	3	5	1	1	3	5	3	3	3	3	2	5	3	3	3	3
	Segway Ninebot Drift W1	3	4	3	2	2	5	3	3	2	3	2	5	1	3	2	0
	Voysger Space Shoes	3	3	3	2	2	5	3	3	2	3	2	3	1	3	2	0
	Placeholder																
	Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16

Template Revision: 0.9 Date: 4/23/2010
Christopher Battles

Figure 6

2.1 Concept Development

“Concept development considers the different ways that the product and each subsystem can be designed.” (Budynas & Nisbett, 2020) This step of the PDP is more commonly referred to as brain storming. During this step we created six different concepts, of which we would select only one for further development. Furthermore, as part of this step, all concepts were considered, operating under the mantra that there are no bad ideas. These six concepts are shown in their original drawing in *Figure 7*.

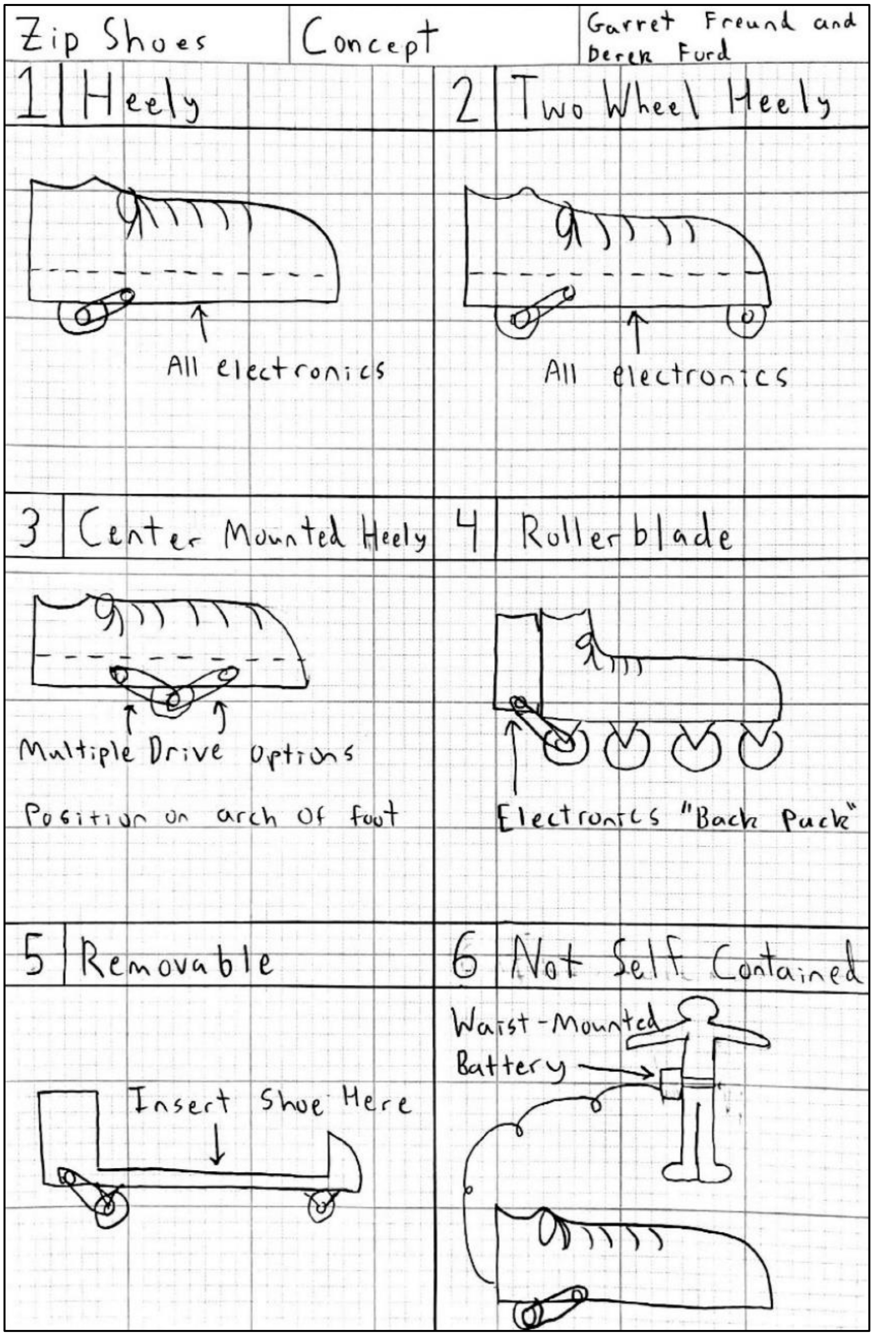


Figure 7

Concept 1 is a Heely concept, based off the brand Heelys namesake product (Heelys, n.d.). The reader can note this is the eventual design that was chosen to be used for Zip Shoes. It is a one wheeled design, in which the user would balance upon their heels to roll. It is also self-contained, such that all the electronics for it to operate, omitting the remote control, are located within the shoe itself. The advantages and disadvantages for this design are stated in *Table 3*.

Concept 1: Heely	
Advantages	**Disadvantages**
Compact	Larger learning curve for balancing
Most available sole space for components	Limited component space
Already evaluated form factor	N/A

Table 3

Concept 2 is a two wheeled Heely design. This design is like a roller skate with only two wheels. This would help provide the user better means by which to balance but would drastically cut down on space for electronic components. This is based off a two-wheeled version of a Heely that is already produced by Heelys as a children's product (Heelys, n.d.). The advantages and disadvantages for this design are stated in *Table 4*.

Concept 2: Two Wheel Heely	
Advantages	**Disadvantages**
Compact	Limited component space
Already evaluated form factor	Added level of complexity
N/A	Base design not available in adult sizes

Table 4

Concept 3 is a center mounted Heely design. This design, much like concept 1, is a one wheeled design that would require balancing. Contrary to the first design though, it puts the rider's weight more towards the center of the shoe. This is theorized to help balancing and is like the Segway Ninebot Drift (Segway, n.d.) and Voyager Space Shoes (Voyager, n.d.). The advantages and disadvantages for this design are stated in *Table 5*.

Concept 3: Center Mounted Heely	
Advantages	**Disadvantages**
Compact	Awkward component placement
Already evaluated form factor	Limits battery size
Easier balancing	N/A

Table 5

Concept 4 is a rollerblade design. It is the first design to depart from the general idea of electrifying Heelys. It focuses around modifying a standard pair of rollerblades to provide driving power to the wheels. However, because of the many wheels taking up space, we theorized that external electronics would need to be connected. The advantages and disadvantages for this design are stated in *Table 6*.

Concept 4: Rollerblade	
Advantages	**Disadvantages**
Already evaluated form factor	External electronic components
Easier balancing	Cannot walk normally
N/A	Look awkward

Table 6

Concept 5 is a removable design. This design is like that of the Razor Turbo Jetts (Razor, n.d.). Its removability presents design opportunities that are not available for other concepts. However, it ventures away from the core idea of Zip Shoes being a streamlined part of your day. The advantages and disadvantages for this design are stated in *Table 7*.

Concept 5: Removeable	
Advantages	**Disadvantages**
Allows for the most freedom in design	Not a streamlined part of your day
Easier balancing	Cannot walk normally
N/A	Look awkward

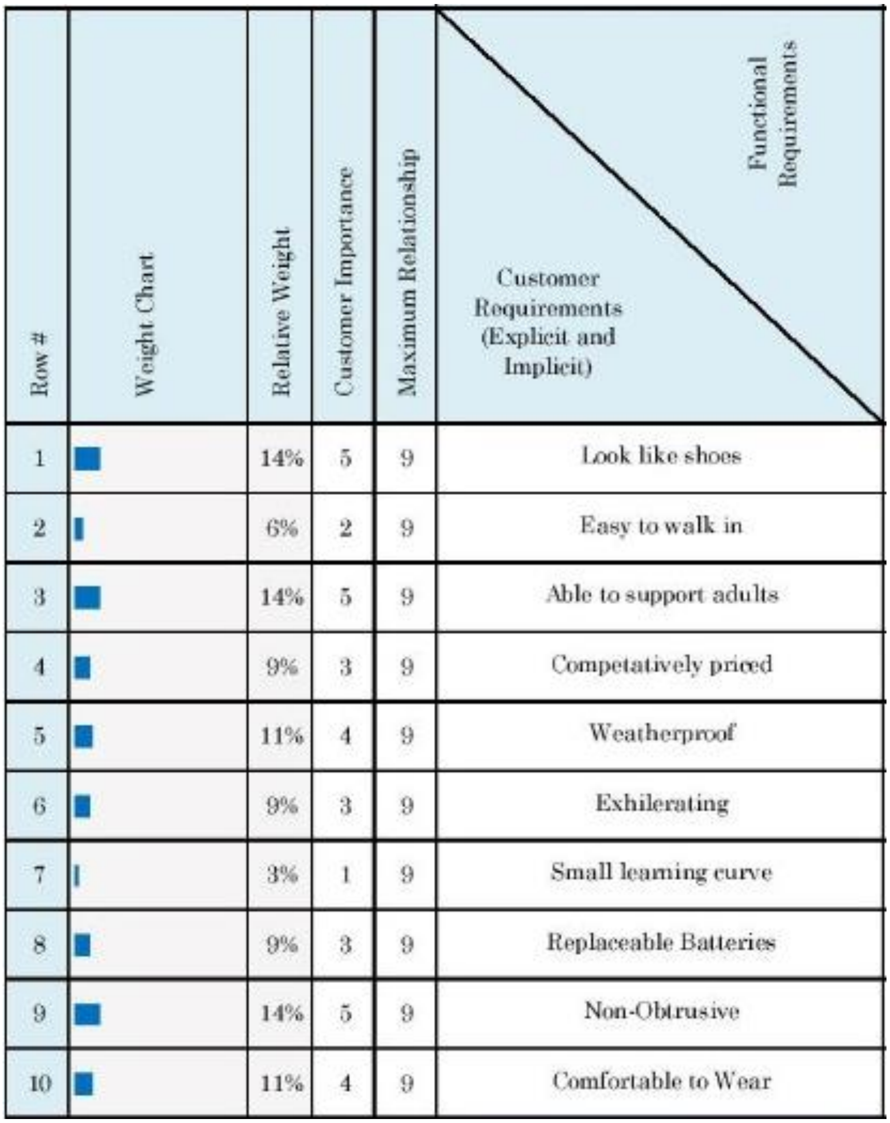
Table 7

Concept 6 is a not self-contained design. It is based off concept 1, however it takes key electronic components and puts them in a separate wearable device. In theory this externalization of components could be applied to any of the concepts thus far. However, like concept 5, it goes against the core idea of Zip shoes being as streamlined into your day as possible. This is because it requires an extra step to strap these external components to one's body. The advantages and disadvantages for this design are stated in *Table 8*.

Concept 6: Not Self Contained	
Advantages	**Disadvantages**
Allows for the most freedom in design	Not a streamlined part of your day
Easier balancing	Cannot walk normally
N/A	Look awkward

Table 8

Having created all six of these concepts, and analyzing their advantages and disadvantages, the decision was made to go with concept 1, the Heely concept. This is for a variety of reasons, most pertinently by comparing the advantages and disadvantages against a weighted decision matrix which is a part of the house of quality shown in *Figure 8*. The designs that best aligned with this weighted decision matrix were concepts 1 and 3, the Heely and center mounted Heely designs. Of these two designs, the Heely design presented itself as a less complex option, because components would not need to straddle a wheel. As such this design was our final selection.



Row #	Weight Chart	Relative Weight	Customer Importance	Maximum Relationship	Functional Requirements Customer Requirements (Explicit and Implicit)
1	■	14%	5	9	Look like shoes
2	■	6%	2	9	Easy to walk in
3	■	14%	5	9	Able to support adults
4	■	9%	3	9	Competatively priced
5	■	11%	4	9	Weatherproof
6	■	9%	3	9	Exhilerating
7	■	3%	1	9	Small learning curve
8	■	9%	3	9	Replaceable Batteries
9	■	14%	5	9	Non-Obtrusive
10	■	11%	4	9	Comfortable to Wear

Figure 8

2.1.1 Product Use Safety Considerations

Having selected the Heely design for Zip Shoes, the first use consideration made was that of safety. In selecting a design that inherently requires the user to balance, which could lead to falling, safety was of the utmost consideration. As such research was done into seeing what safety considerations were made for normal non-powered Heelys. The following is a direct quotation from the Heelys brand on their safe use.

> *EQUIPMENT CHECK & SAFETY TIPS*
>
> - *Read through this equipment check list every time before you start rolling with your Heelys. Thoroughly read and understand the manufacturers' warnin*
>   *using. Be aware of single-use protective gear and helmets.*

- *Make sure all your protective safety equipment is not cracked, broken, or damaged in way. If you have any single-use gear (particularly a helmet) that gets damaged impact, make sure you replace it immediately.*
- *Only use a helmet that fits you properly and keep it fastened. Never wear the strap too loose around your chin in order to prevent it from shifting or falling off.*
- *Make sure the wheels are not obstructed. This could include rocks, paper, or any other objects that could be lodged in the wheelbase.*
- *Check the laces to make sure they are not worn out nor have tears. Always keep your laces tied while skating for a smooth ride.*
- *Make sure the wheels are not worn down, have dents or cracks. If you notice any of these problems or any other damages, be sure to replace the wheels before you skate. You can find replacement wheels on our website.*
- *Once you have all your protective gear and Heelys on, practice braking to make sure you can stop at any time necessary. If you need to stop or slow down quickly, practice transitioning from skating to walking or stopping by simply putting your toes down.*
- *After you've guidelines, you're ready to go out and s*
  these safety orget to go through the whole checklist every time before you put on your Heelys. Always be courteous and skate safely!

> *Please remember that although using your Heelys skate shoes is extremely enjoyable, there is a learning curve. Skating with Heelys is a sport, and the key is to learn how to heel safely and properly.*
>
> *While using protective gear cannot guarantee your safety, it could greatly reduce your chances of injury. We therefore always recommend wearing full protective gear when using your Heelys skate shoes including: helmet, wrist guards, knee pads, and elbow pads.*
>
> *Be sure to avoid cracks and skate only on smooth, stable, dry surfaces.*
>
> *DO NOT SKATE OVER ROCKS, SAND, OR WATER* (Heelys, n.d.)

To ensure the safe use of Zip Shoes, these safety instructions would be adopted for any finalized version of the product. Furthermore, additional instruction would be adopted regarding keeping away from any powered apparatus of the Zip Shoes while they are running. Thus, ensuring the user of Zip Shoes understands the inherent risk in their use and makes attempts to alleviate the possibility of injury.

2.2 Embodiment Design

"Embodiment Design examines the functions of the product and leads to the division of the product into various subsystems." (Budynas & Nisbett, 2020) As such during the embodiment design process the generalized design, derived in concept development phase, was further broken down. This break down will be explored through the lens of a function diagram, sketch, and house of quality. Specifically focusing on subsystem selection and variable correlation.

2.2.1 Subsystem Selection

Having selected the concept for Zip Shoes, the next step was dividing the project into smaller easier to manage pieces. This was achieved by segmenting the concept, which is one large system, into a variety of subsystems. This was done by producing a function diagram, shown in *Figure 9*.

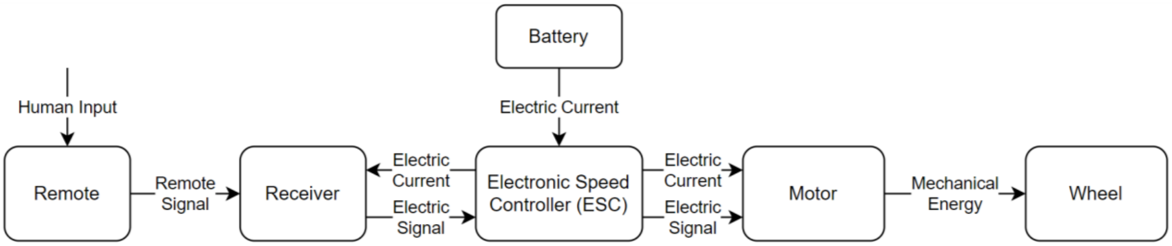


Figure 9

This function structure diagram helps lay out the necessary components needed to covert a human input into usable torque. Thus, it helps segment the whole system into subsystems. In this case the subsystems are a remote, receiver, electronic speed controller, motor, wheel, and battery. These subsystems were then sketched out on a scale layout of the shoes sole in *Figure 10*. This helped determine their orientation as they would fit in the shoe. It should be noted that you can see there is a gearbox included in this sketch. However, it was deemed unnecessary and omitted in later designs.

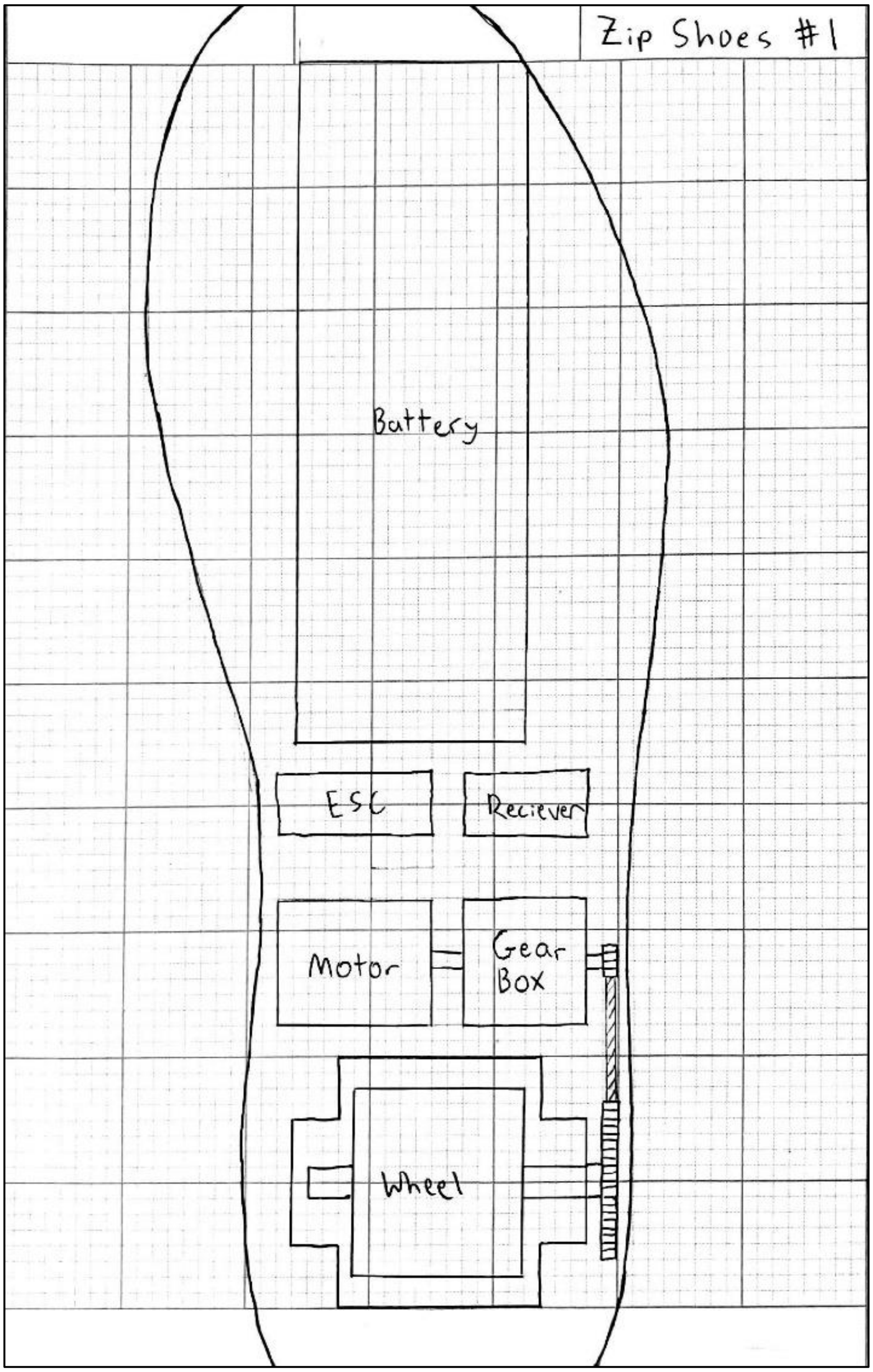


Figure 10

2.2.2 Variable Correlation

Variable correlation is the name given to the decision process used in relating subsystem specifications to both customer requirements and other subsystem specifications. This was performed using the house of quality. The comparison of customer requirements is shown in *Figure 11*.

Functional Requirements / Customer Requirements (Explicit and Implicit)	Motor kV	Motor Max Speed	Motor Max Torque	Motor Max Watts (W)	Motor Size (L*D)	Battery Capacity (mAh)	Battery Chemistry	Battery Voltage (V)	Battery Size (L*W*H)	Electronic Speed Control Max Curren	Electronic Speed Controller Size (L*W	Chassis Material	Chassis Size	Gear Box Material	Gear Box Size	Footwear Sole Size (T)
Look like shoes					○				○		○	▽	●		○	●
Easy to walk in					▽				▽		▽		●		▽	●
Able to support adults			●	●	○	○	○	○	▽	●	▽	●	▽	▽		●
Competatively priced	○	○	○	○	○	●	●	○	○	●	○	●	○	●	○	○
Weatherproof							○					●		○		▽
Exhilerating	●	●	●	●	○	○	○	●		●						
Small learning curve		●	●	●		▽										
Replaceable Batteries						○	○	○	●							
Non-Obtrusive					●				●		●		●		●	●
Comfortable to Wear					▽				▽		▽		▽		▽	●

Figure 11

In this diagram the customer requirements are given on the left and the specifications that effect different subsystems are shown on the top. Then a symbol is given where the two categories intersect, specifying the type of correlation between the two. The solid circle (●) shows a strong correlation, the hollow circle (○) shows a moderate correlation, the hollow triangle (▽) shows a weak correlation, and the lack of a symbol shows no correlation. For example, there is a strong correlation between the ability of Zip Shoes to support adults and the motor max torque. Furthermore, the comparison of subsystem specifications to each other is shown in *Figure 12*.

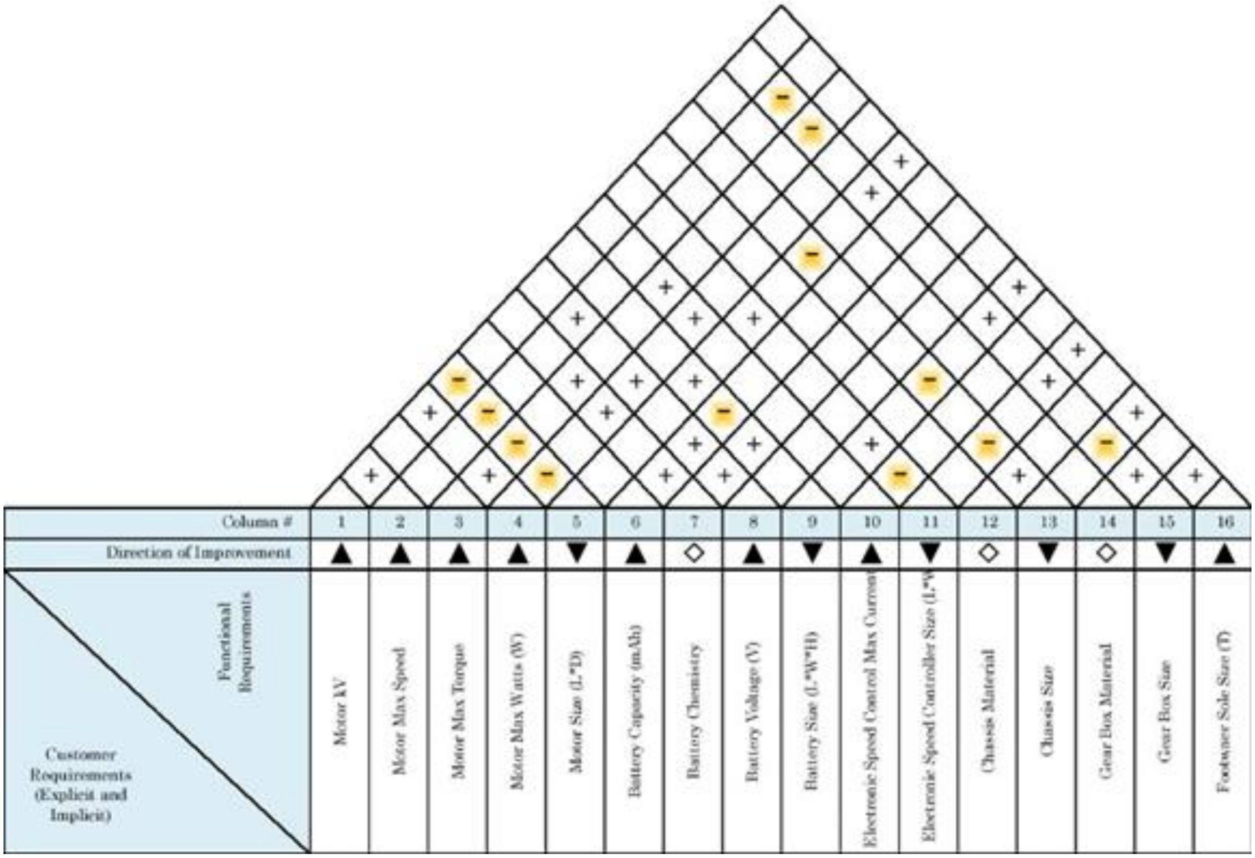


Figure 12

In this diagram the specifications that affect different subsystems are given along the bottom. Then a matrix correlating them sits atop them. For this diagram, the correlation between different specifications is given using a different nomenclature. A positive correlation is shown using a plus sign (+), a negative correlation is shown using a highlighted minus sign (-), and the lack of a correlation is shown by the lack of a symbol. For a positive correlation, the improvement of one of the specifications will also improve the other specification. For a negative correlation, the improvement of one specification will have a detrimental effect on another specification. For example, increasing the motor kV rating will also increase the motor max speed. However, increasing the motor kV rating will also increase the motor size, which is not a desired outcome.

2.3 Detail Design

"Detail Design is the phase where the design is brought to the state of a complete engineering description of a tested and producible product." (Budynas & Nisbett, 2020) Throughout this next section it will be described how this was accomplished for Zip Shoes. Specifically, there will be a focus on each individual component. Describing the design process for either custom or procured components. The components that were custom manufactured were the chassis and drive axle. While the components that were procured were the gear, chain, electric motor, electronic speed controller, battery, receiver, remote control, adapter, and Heely shoes.

2.3.1 Chassis

Of the two custom manufactured components for this project, the chassis is by far the more complex one. It is designed to hold up the entire weight of a user while also housing every electronic component and being as compact as possible. Furthermore, as this chassis needed to be rapidly manufactured for a prototype, the chassis needed to be 3D printed out of PLA plastic. As such, it went through many evolutions of its design, being reprinted along the way. However, this paper will focus primarily on three designs, the first design, a revised design, and the final design.

The first design, pictured in *Figure 13* is the first true attempts at making a chassis. It follows the general layout previously picture in *Figure 10* which was derived in the embodiment design process. It features form fitting slots for each electrical component with small plastic tabs to hold them in place.

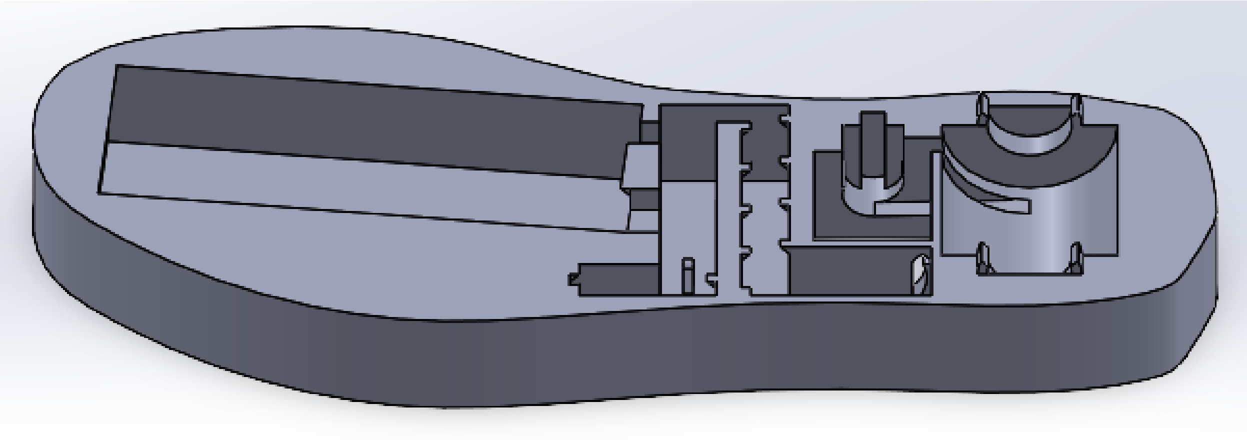


Figure 13

The second design picture in *Figure 14*, known as the revised design, makes four significant changes from the previous one. First and foremost, it replaces the form fitting electrical component slots with larger open cavities. This helps to accommodate the amount of wiring needed to connect components. Second, it changes the tolerances for snap in components. For the first design the mistake was made of making slots the same size as the components that would fill them, not leaving enough space. This was a fatal flaw that prevented most components from fitting. Thus, for this new design, 5/100th of an inch spacing was added to most slots. Third, this design shrinks the whole chassis outline. In the first design not enough space was given to allow the entire chassis to fit inside the sole of the shoe, thus this was fixed for this design. Fourth and finally, dust guards were added next to where the bearings would snap in to hold the wheel. This was a consideration made to help increase the products durability.

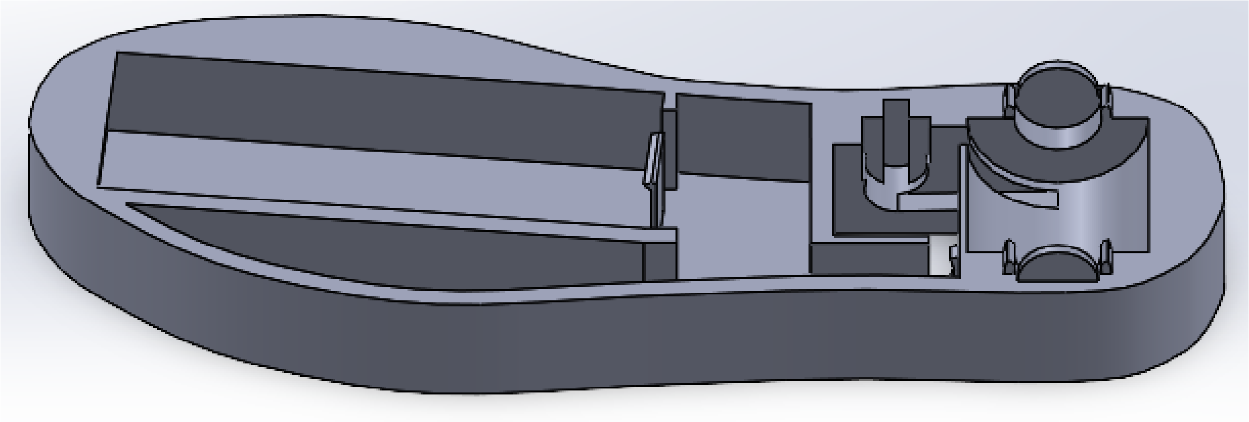


Figure 14

The final design is pictured in *Figure 15*, with the actual completed parts pictures in *Figure 16*. It is very similar to the previous design and only had three minor changes. Visually they are near identical, but the changes made were critical none the less. First, this design features further refinement to the tolerancing for individual components. It widens some gaps while narrowing others. Second, this design adds material to better hold the bearing for the motor in place. Third and finally, this design widens the gap where the chain drive runs to prevent the chain from rubbing against the chassis.

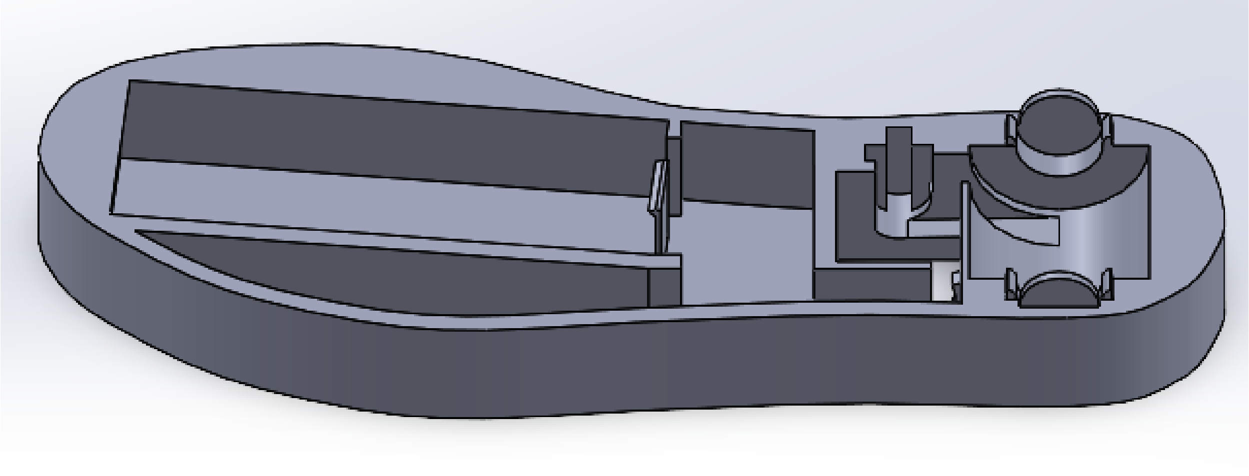


Figure 15

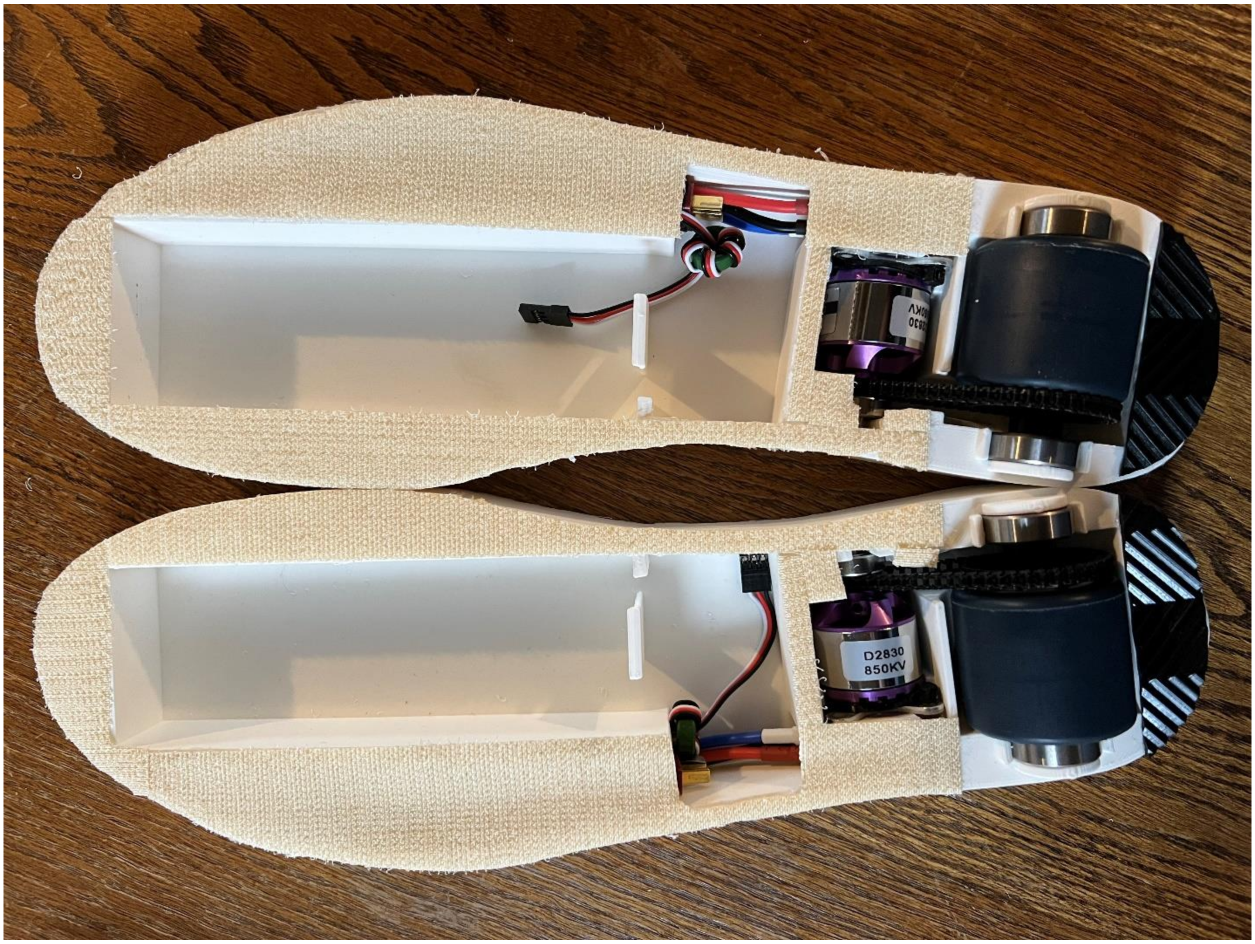


Figure 16

Overall, as the design progressed, many changes were made. However, despite these changes, the chassis still maintained its general form and function. Furthermore, it will be discussed later on in the "Final Testing and Refinement" section of this report how this chassis is able to handle the weight of a user.

2.3.2 Drive Axle

Like the chassis, the drive axle was a custom manufactured component. However, that is where the similarities end. Contrary to the chassis, the drive axle only had to go through a single design iteration. This is because its simplicity allowed for it to be designed correctly the first time. This design is pictured in *Figure 17*.

This design features a cylinder made of 1144 carbon steel with changing diameters along its length. This is because it is designed to fit multiple components with different interior diameters around it. The largest diameter section of the cylinder is designed for the wheel to fit. The second largest diameter section is designed for a gear to fit. Finally, the third largest diameter sections are designed for bearings to fit on each end of the shaft.

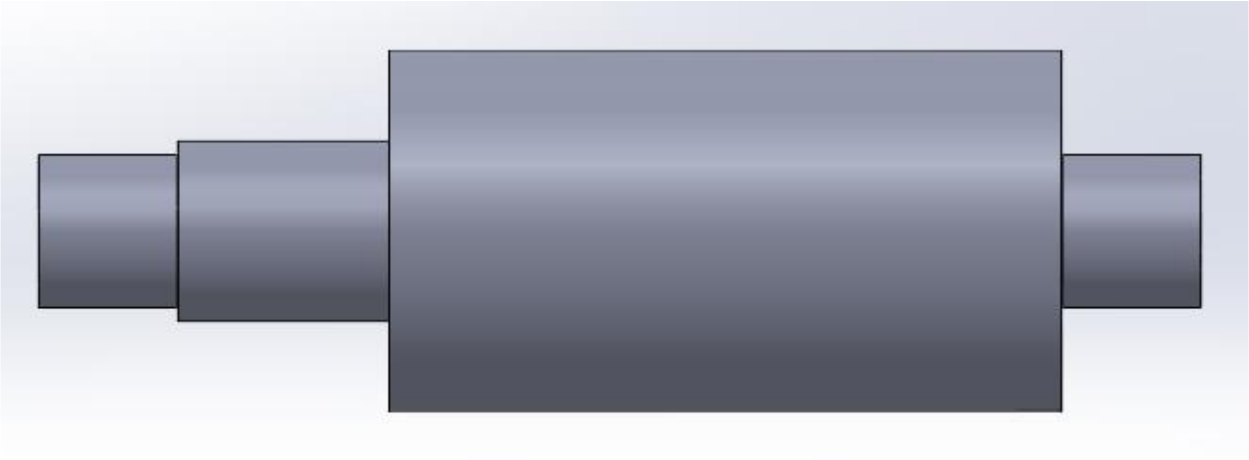


Figure 17

Furthermore, unlike the chassis, this part needed to be manufactured by hand. This required the use of a lathe to machine a base piece of material to the specified dimensions. As such, a formal drawing of the part had to be created, pictured in *Figure 18*. This allowed the machinist to make the part accurately by hand.

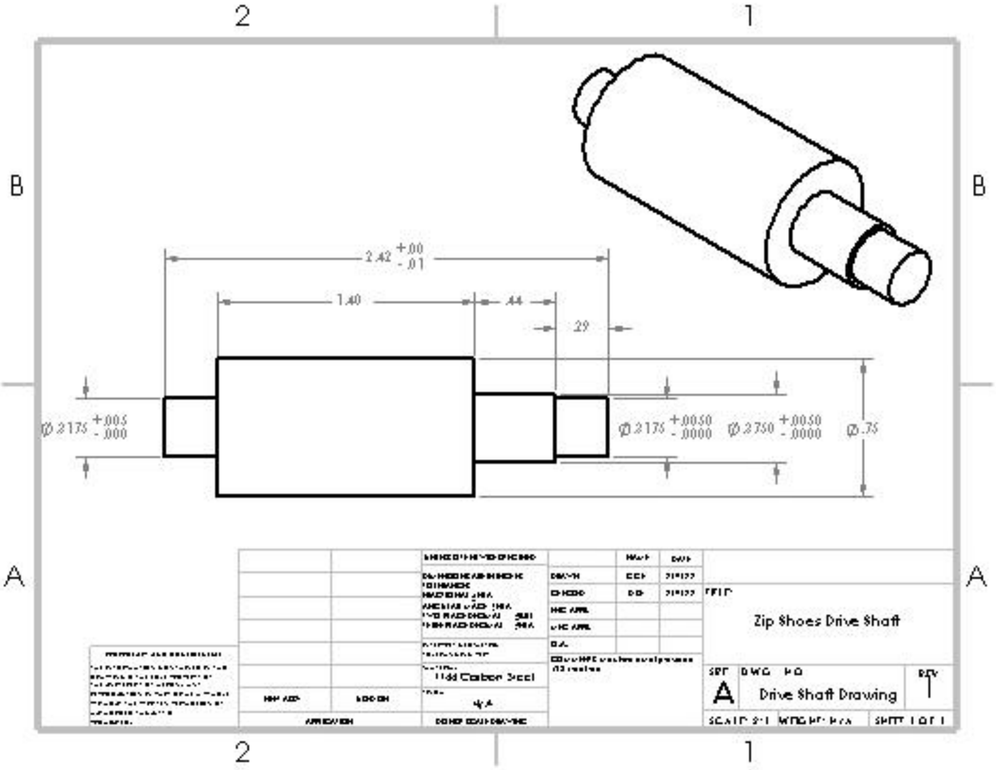


Figure 18

Finally, like the chassis, the discussion on this components abilities to withstand the forces of someone riding atop it are discussed later in the "Final Testing and Refinement" section of this report.

2.3.3 Gear and Chain

The Gear and chain setup for Zip shoes is used to transfer power from the motor to the wheel. The gears and chain are both procured components. The whole system consists of a drive gear, a driven gear, and a chain.

The drive gear chosen for Zip Shoes is an 8-tooth press fit sprocket with a 0.1227 in pitch and a 0.125 in bore. This gear was chosen because it has a low tooth count, which when paired with a high tooth count driven gear, will help amplify the torque produced by the motor. This gear is also compatible with the motor shaft through an interference fit, which requires it to be pressed onto the motor shaft. This gear is shown in *Figure 19*.

The driven gear chosen for Zip Shoes is a 36-tooth press fit sprocket with a 0.1227 in pitch and a 0.375 in bore. This gear was chosen since it had the highest number of teeth for a gear of its type while also being smaller than the drive wheel itself. This helps amplify the torque produced by the motor. This gear is shown in *Figure 20.*

The chain chosen for Zip Shoes is a 1 X 0.1227 in pitch plastic chain. This chain was chosen due to its compatibility with the gears and because its tensile strength was high enough to transmit the power necessary. The tensile strength of the chain is 14 pounds force, from the manufacturer. This chain is shown in *Figure 21.*

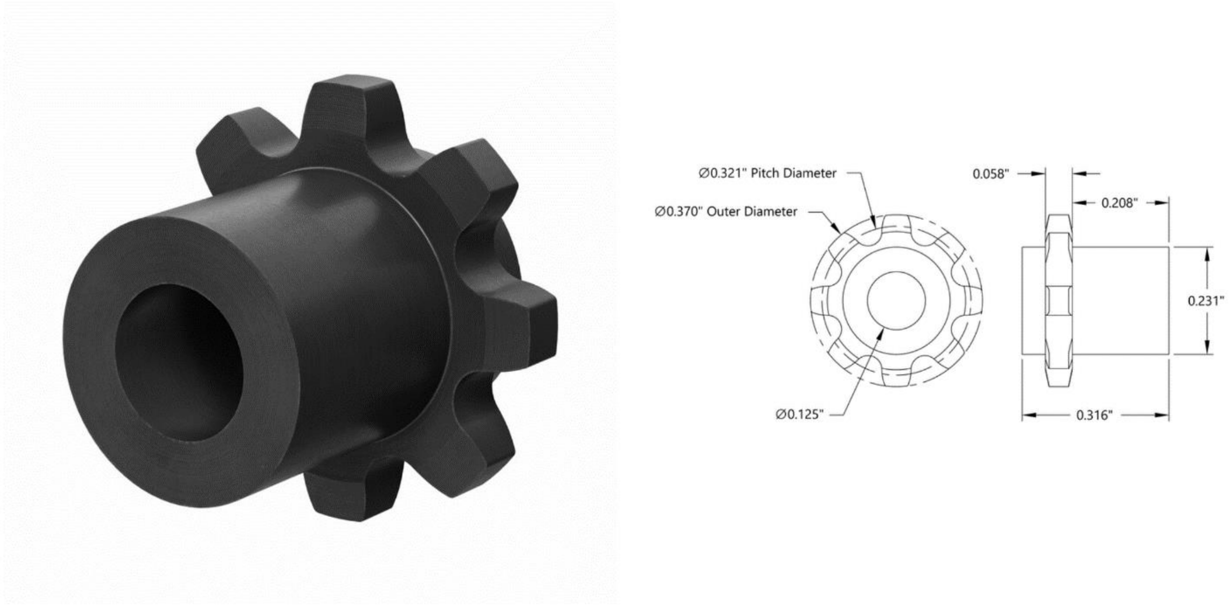


Figure 19

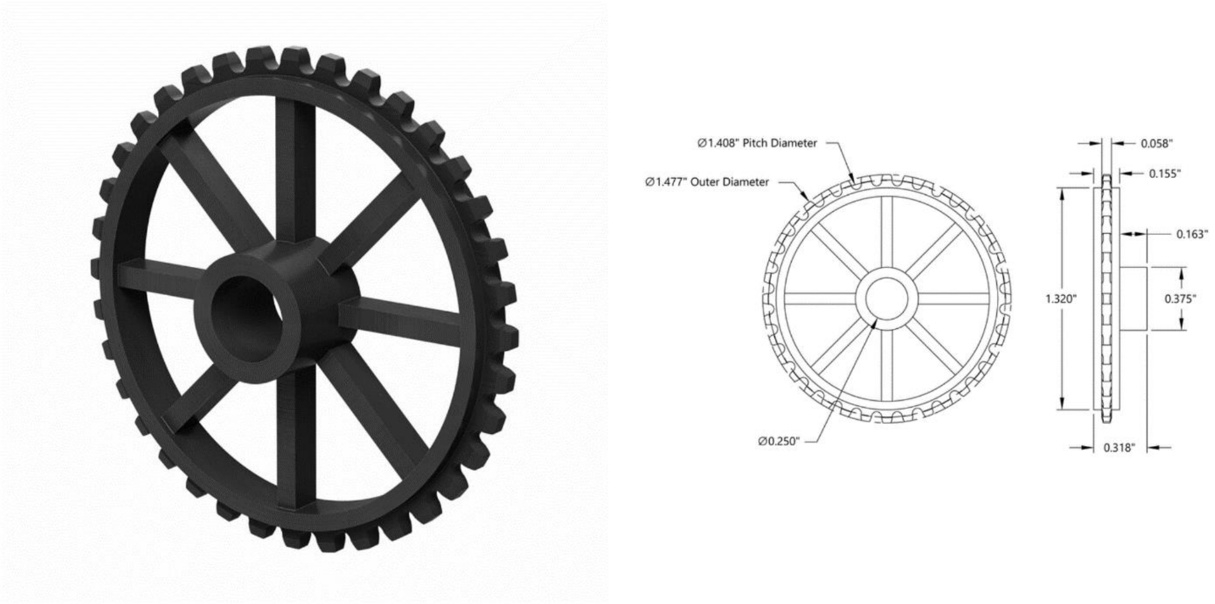


Figure 20

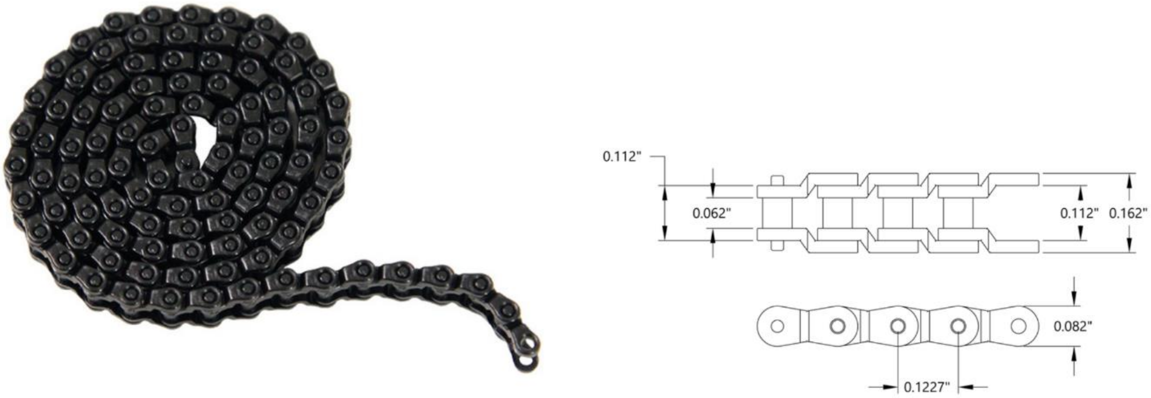


Figure 21

2.3.3.1 Chain and Gear Calculations

$$F = \tau / l \tag{1}$$

$$F = \frac{0.209\ lbf \cdot ft}{0.0154\ ft} = 13.57\ lb \tag{1}$$

$$Gear\ Ratio = \frac{\#\ of\ teeth\ on\ driven\ gear}{\#\ of\ teeth\ on\ driving\ gear} \tag{2}$$

$$4.5 = \frac{36}{8} \tag{2}$$

$$torque_{wheel} = torque_{motor} \times gear\ ratio \tag{3}$$

$$0.943\ lbf \cdot ft = 0.209\ lbf \cdot ft \times 4.5 \tag{3}$$

2.3.4 Electric Motor

The motor is one of the procured components in Zip Shoes. The motor used is a Flash Hobby D2830 850Kv motor. The decision to go with this motor came down a couple of factors. The first factor is its 850 Kv rating. A motor's Kv rating is the ratio of the motor's RPM to the voltage applied to the motor. For example, the Flash Hobby D2830 used in Zip Shoes will spin at a rate of 850 RPM with no load attached when it is supplied one volt of power. Similarly, it will spin at a rate of 1700 RPM when two volts of power are supplied to the motor. Such that this motor will spin at a rate of 6290 RPM with no load attached when the 7.4 volts from the battery is applied to the motor. This low Kv rating implies that the motor will provide more torque than other motors in this family. For example, the 1000Kv and the 1300Kv versions of this motor will spin faster with the same applied voltage, however the 850Kv motor will provide more torque due to its lower rotational speed. (Minipro, n.d.)

The second factor that contributed to this motor selection is size. The Flash Hobby D2830 850Kv motor has a diameter of 1.1 in and an overall length of 1.77 in. Size is a factor due to the space limitations of the sole of the shoe. This motor fits in the space provided which further qualified it for Zip Shoes.

The third factor that contributed to this motor selection is its power output. This motor has a maximum power output of 187W. As shown in latter calculations, the amount of power needed to overcome aerodynamic drag is 10.583W. Since there is a motor in each shoe, the maximum power output for a pair of shoes using this motor is 374W. Since this is greater than the minimum 10.583W needed, the Flash Hobby D2830 850Kv motor was chosen for Zip Shoes. (Amazon, n.d.) This motor is shown in *Figure 22*.

Figure 22

2.3.4.1 Electric Motor Calculations

Variable	Value
V_{max}	6mph = 2.682 m/s
ρ	1.225 kg/m^3
c_D	1.3 (engineering toolbox)
A	0.686 m^2
F_{drive}	*121.88N=27.14lbf*
h_{CG}	41 in = 1.041 m
F_g	*225lbf*
$d_{rearwheel}$	6 in = 0.152 m
m	225 lbm = 102.058 kg
r (wheel radius)	0.8 in =0.020m
a_g	9.81 m/s^2
P_{motor}	10.583W

(The Engineering Toolbox, n.d.)

$$P_{motor} = \frac{V_{max}^3 \rho c_D A}{2} \tag{4}$$

$$P_{motor} = \frac{2.682\,\frac{m^3}{s^3} * 1.225\,\frac{kg}{m^3} * 1.3 * 0.686\,m^2}{2} = 10.538\,W \tag{4}$$

Maximum Acceleration

$$\Sigma M = 0 \tag{5}$$

$$(F_{drive} * h_{CG}) - (F_g * d_{rearwheel}) = 0 \tag{6}$$

$$(F_{drive} * h_{CG}) = (F_g * d_{rearwheel}) \tag{7}$$

$$\frac{F_{drive}}{F_g} = \frac{d_{rearwheel}}{h_{CG}} \tag{8}$$

$$\frac{m * a_{drive}}{m * a_g} = \frac{d_{rearwheel}}{h_{CG}} \tag{9}$$

$$\frac{a_{drive}}{a_g} = \frac{d_{rearwheel}}{h_{CG}} \tag{10}$$

$$a_{drive} = \frac{a_g * d_{rearwheel}}{h_{CG}} \tag{11}$$

$$a_{drive} = \frac{9.81\,\frac{m}{s^2} * 0.152\,m}{1.041\,m} = 1.432\,\frac{m}{s^2} \tag{12}$$

Torque Required to Achieve Maximum Acceleration

$$F_{max} = m * a_{drive} \tag{13}$$

$$F_{max} = 10.0258\,kg * 1.432\,\frac{m}{s^2} = 14.1647\,N \tag{13}$$

$$T_{max} = F * r \tag{14}$$

$$T_{max} = 146.147N * 0.020m = 2.923\,Nm \quad (14)$$

Torque Produced by the Motor

$$P_{out} = \tau * \omega \quad (15)$$

$$\tau = \frac{P_{out}}{\omega} = \frac{187W}{850\frac{rpm}{V} * 7.4V * \frac{2\pi}{60}} = 0.284\,Nm \quad (16)$$

Theoretical Acceleration of Zip Shoes with a 225lb Rider

$$F = ma \quad (17)$$

$$\frac{F}{m} = a \quad (18)$$

$$\frac{2.714\,lbf}{225\,lbm} = 0.121\,ft/s^2 \quad (19)$$

Theoretical Top Speed

$$Motor\ Speed\ (RPM) = Motor\ Kv\ Rating\ x\ Voltage\ Applied\ (V) \quad (20)$$

$$6290\,RPM = 850\,Kv\ x\ 7.4V \quad (20)$$

$$Wheel\ Speed\ (RPM) = \frac{Motor\ Speed\ (RPM)}{Gear\ Ratio} \quad (21)$$

$$1397.777\,RPM = \frac{6290\,RPM}{4.5} \quad (21)$$

$$Ground\ Speed = \omega\ x\ 60\frac{min}{hr}\ x\ Wheel\ Circumference\ (in)\ x\ \frac{1}{63360} \quad (22)$$

$$6.66\,MPH = \omega\ x\ 60\frac{min}{hr}\ x\ 5.03\,in\ x\ \frac{1}{63360} \quad (22)$$

2.3.5 Electronic Speed Control

The electronic speed controller (ESC) is another procured component for Zip Shoes. It is an RC Electric Parts 30A ESC. The ESC controls the speed of the motor by varying the voltage applied to the motor. This effect of voltage on the motor is discussed above. This ESC was chosen due to its size, power rating, and compatibility with other components.

The size of this ESC was one of the main factors in its selection. The ESC is 2.09 in long by 0.98 in wide by 0.43 in thick. These measurements do not include the wires coming from both ends of the ESC. As stated previously, size is a major consideration for every procured component in Zip Shoes. This is due to the limited space inside the sole of the shoe.

The second factor that contributed to this ESC selection is the power rating of 30 amps. This rating is high enough for the Flash Hobby D2830 850Kv motor to achieve its maximum power output of 187W. The motor needs a current of 28.07 amps to produce 187W, this is with an assumed efficiency of 90 percent. Furthermore, Flash Hobby also suggested a 30-amp ESC be paired with the motor.

The third factor that contributed to the selection of this ESC, was its compatibility with other components. As seen previously, the manufacturer of the motor recommended a 30-amp ESC be paired with the motor. Furthermore, this ESC has connections compatible with both the motor and receiver that were selected. Unfortunately, it was not compatible with the selected battery connection, such that adapters needed to be purchased. (Amazon, n.d.) This ESC is shown in *Figure 23*.

Figure 23

2.3.6 Battery

The battery is another procured component for Zip Shoes. It is a Zeee 8000mAh 7.4V 2s lithium polymer battery (LIPO). This battery was chosen due to its physical size, battery capacity, and compatibility with other procured components.

The physical size of the battery is 5.43 in long by 1.85 in wide by 0.98 in tall. The battery has a weight of 11.3 ounces. Weight is a larger factor with the battery than it is with the other components, since the battery is the heaviest procured component. This battery fits in the sole of the shoe and its weight was acceptable due to its positive impact on run time.

The second factor that contributed to the selection of this battery was its battery capacity. The battery capacity is listed as 8000mAh. Thus, this battery can provide eight amps of power for an hour before it is depleted. This battery is one of the largest capacity two cell batteries on the market currently. It also is very cost competitive for its capacity rating.

The third factor that contributed to the selection of this battery is compatibility with the other components in the system. Regarding this, the primary compatibility factor is battery voltage. The voltage of this battery is 7.4 volts. This is compatible with the motor and the ESC. The ESC is rated for up to a three cell LIPO battery with an 11.1-volt rating, so these batteries 7.4V rating is within the specifications of the ESC. (Amazon, n.d.)This battery is shown in *Figure 24*.

Figure 24

2.3.6.1 Run Time Calculations

$$Run\,Time\,(Hr) = \frac{Battery\,Capacity\,(Whr)}{Motor\,Power\,(W)\,X\,0.75} \quad (23)$$

$$0.341\,Hr = \frac{5.92\,Whr}{23.086\,W\,X\,0.75} \quad (23)$$

$$Motor\,Power\,(W) = \frac{Rated\,Motor\,Power\,(W)}{\eta motor\,x\,\eta ESC} \quad (24)$$

$$23.086\,W = \frac{18.7\,W}{0.9\,X\,0.9} \quad (24)$$

Assumptions: the entire battery capacity is used between charges, both motor and ESC are 90 percent efficient, and the rider is using ¾ throttle for the duration of the ride.

2.3.7 Receiver

The receiver used for Zip Shoes is a Traxxas 6519 TQ 2.4GHz three channel micro receiver. The receiver takes power from the battery and turns the radio signal from the remote into an electrical signal that the ESC can use. The receiver tells the ESC how much power to send to the motor from the battery. There are two contributing factors that led to the choice of the receiver, its size, and its compatibility.

As discussed before, size is a major concern for Zip Shoes. The receiver is 1.5 in long by 1.02 in wide by 0.581 in tall. The size of the receiver allows it to fit in the chassis better than some larger 4 channel receivers. (Amazon, n.d.)

Furthermore, the receiver uses a JST 3 pin connector. That is the same connector that the ESC uses to connect to the receiver. Also, this receiver is compatible with the selected remote, a Traxxas TQ 2.4GHz three channel transmitter, which will be discussed later. This receiver is shown in *Figure 25*.

Figure 25

2.3.8 Remote Control

The remote control, also known as the transmitter, is a Traxxas TQ 2.4GHz three channel transmitter. The remote takes the human input and transforms it into a radio signal for the receiver to receive and interpret. This radio was chosen because of its compatibility with the receiver. Since the radio is not in the shoe, size is not a factor. (Amazon, n.d.) This remote control is shown in *Figure 26*.

Figure 26

2.3.9 Adapters

The ESC and battery selected for Zip shoes are compatible but have different electrical connection types. This is because the battery is designed for use in RC cars, while the ESC is designed for use in quadcopters. For the production ready model, the ESC and the battery would be compatible, however, for this prototype they are not. The main factors that went into the choice of an adapter were size and compatibility. The adapter has a female XT60 connector and a male Deans connector. The XT60 connector is for the ESC and the Deans connector is for the battery. Furthermore, the adapter is 1.58 in long by 0.67 in wide by 0.24 in tall making it rather compact. The adapter's compact size allowed it to fit into the chassis with the rest of the components. This adapter is shown in *Figure 27*. (Amazon, n.d.)

Figure 27

2.3.10 Heelys Shoes

For the base footwear, Zip Shoes uses Heelys GR8 Pro 20 in men’s size 11. The GR8 Pro 20, like many other Heelys, is a shoe with a removable wheel in its heel. This shoe was chosen based on a variety of different factors. These factors are product availability, cost, engineering considerations, large sole space, and color.

The first factor that contributed to the choice of the GR8 Pro 20 was product availability. Put simply, these shoes were in stock when procurement was taking place. This allowed for a speedy procurement to advance development of the prototype. The need for this availability was exacerbated by the general supply chain shortages related to the coronavirus pandemic. Thus, being able to procure a set of shoes for use quickly was of the utmost importance.

The second factor that led to the choice of the base footwear was cost. This pair of shoes was cost effective as compared to other shoes and even other pairs of Heelys. They were $55.00 when they were purchased. (Amazon, n.d.)That is less than many name brand tennis shoes, plus they have the bonus of already coming with a wheel and bearings that can be reused.

The third factor that led to the base footwear decision was their engineering considerations. Pertinently, Heelys are built to have a wheel installed. This was the most important factor that led to the base footwear decision. This is because they came with a wheel, bearings, and they could hold the weight of a person using the wheel while standing on one foot. In fact, for the prototype we used the wheel and bearings that cane with the Heelys GR8 Pro 20. This saved time and money since a wheel and bearings did not have to be purchased to finish the prototype. Furthermore, because they were already designed to be ridden, they were able to be reverse engineered. This helped for sizing and designation of wheel location in the final design.

The fourth factor that led to the decision to use the Heelys GR8 Pro 20 was its large sole space. The original assumption was that the sole was hollow and only reinforced on the edges where there was white rubber present, see *Figure 28* for visualization of the shoe. This would allow the chassis and the other components to fit inside the sole of the shoe without being obtrusive to the end user of Zip Shoes. This assumption turned out to be partly false when the sole was removed from the shoe. There ended up being more reinforcement within the sole area than anticipated, however a majority of this was able to be removed. Thus, the only major impact on the final shoe design was the addition of height to the shoes sole overall.

The last factor that led to the base footwear decision was color. This was not a major factor in the decision, but the Heely GR8 Pro 20 was available in blue. This is one of the colors of the University of Akron. Such that it held sentimental value to select such a color.

Figure 28

3. Final Testing and Refinement

“Final testing and refinement are concerned with making and testing many preproduction versions of the product.” (Budynas & Nisbett, 2020) Like many products, Zip Shoes underwent this process. However, they also underwent the additional step of simulated testing of individual components, which is included in this section as well.

3.1 Simulation

For the custom designed parts of Zip Shoes, more than just real-world testing needed to be performed. It needed to be mathematically verified, before the first prototype was created, that the shoes would be able to perform under load. This was to prevent the unnecessary risk of injury and allow specification of a factor of safety. As such the two custom components for Zip Shoes, the chassis and drive axle, both underwent a finite element analysis or FEA. As part of this analysis the deformation, stress, and factor of safety were analyzed.

3.1.1 Chassis Simulation

For the chassis’ FEA three main assumptions were needed. First it was assumed that the user of the shoes would need to, at times, place their entire load on a single shoe. Second it was assumed that the weight of the user could be evenly distributed over the top of the chassis. Third, and finally, it was assumed that the contact patch where the toe of the shoe touches the ground does not go beyond the start of the battery compartment. Having made these assumptions, an FEA analysis was performed for the chassis both while walking or riding, with the entire load on a single chassis. The end results were satisfactory and are as follows in *Table 9* and *Table 10*. It should also be noted that all deformations are visually exaggerated.

Chassis Walking FEA Results		Image Reference
Deformation	3.55*10^-4 m	*Figure 29*
Stress	1.62*10^8 Pa	*Figure 30*
Factor of Safety	1.54	*Figure 31*

Table 9

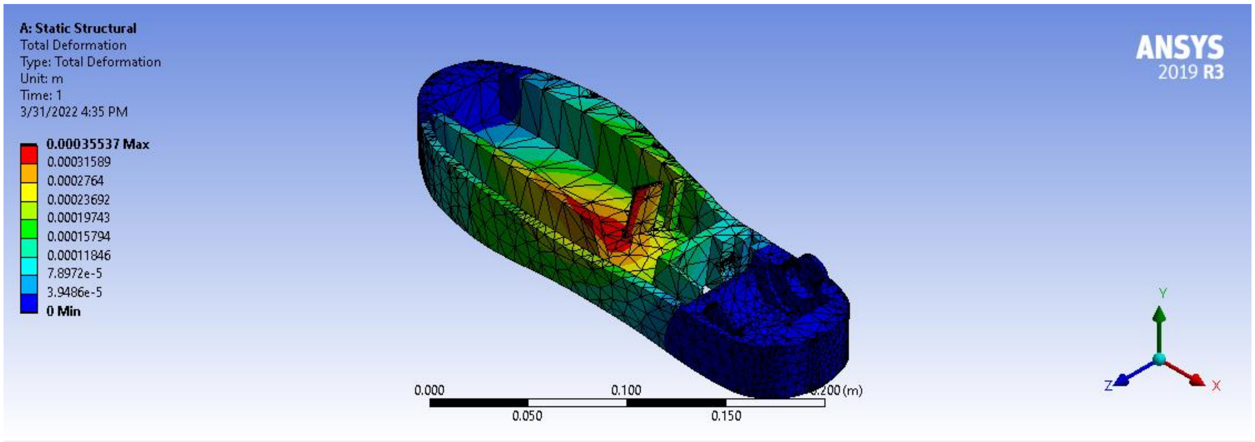


Figure 29

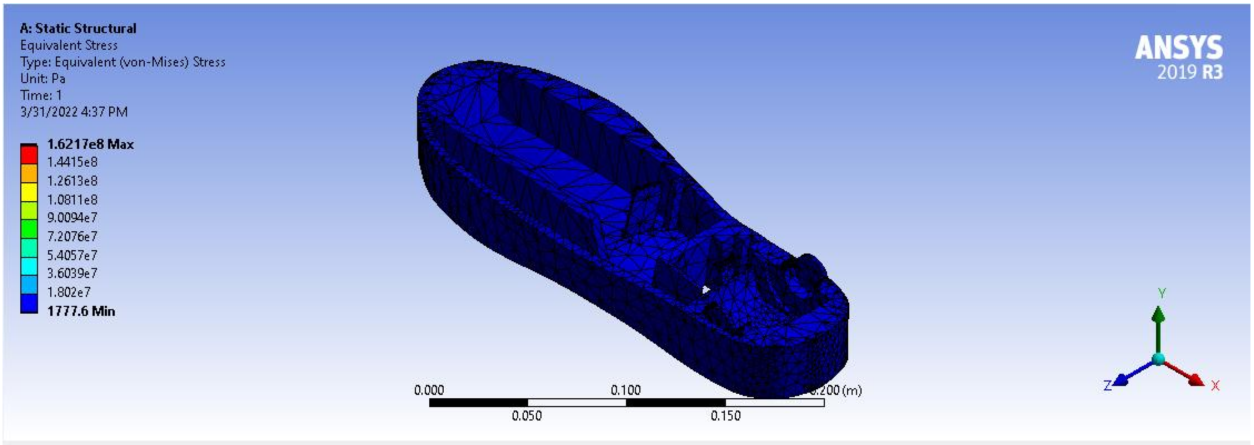


Figure 30

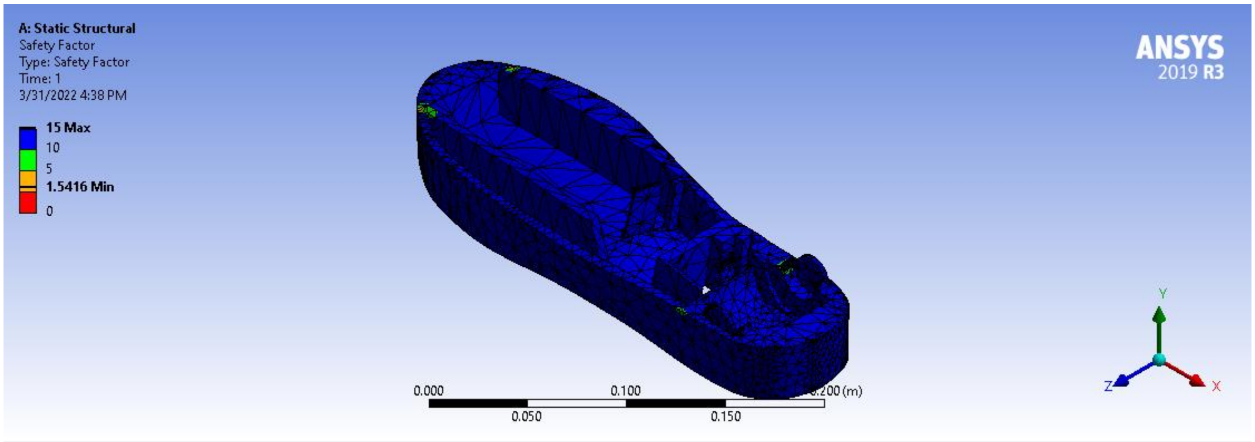


Figure 31

Chassis Rolling FEA Results		Image Reference
Deformation	1.62*10^-5 m	*Figure 32*
Stress	2.49*10^7 Pa	*Figure 33*
Factor of Safety	9.46	*Figure 34*

Table 10

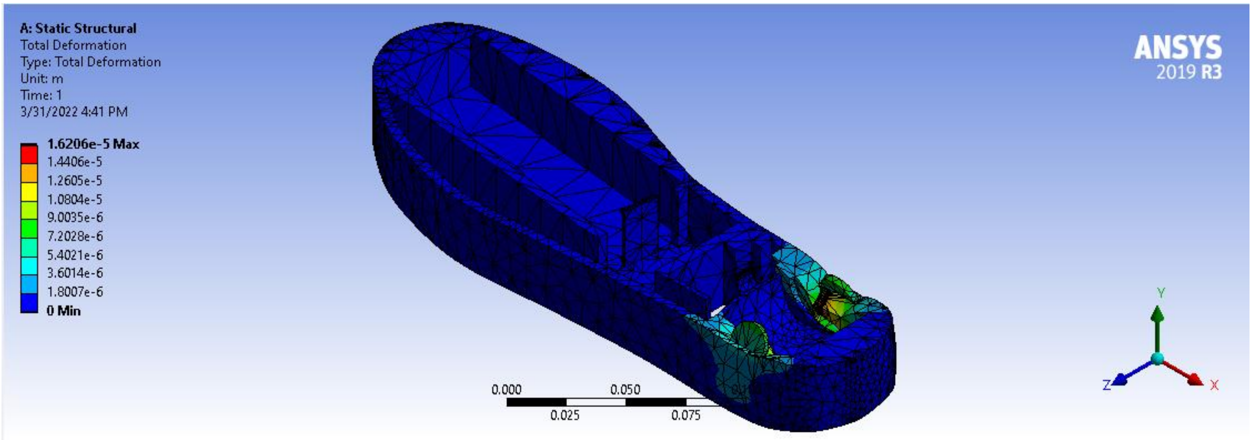


Figure 32

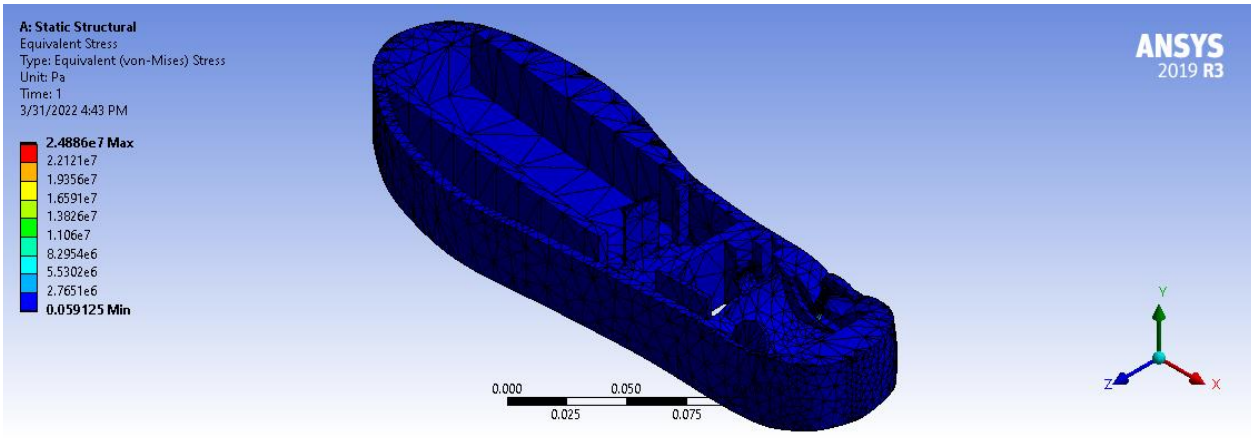


Figure 33

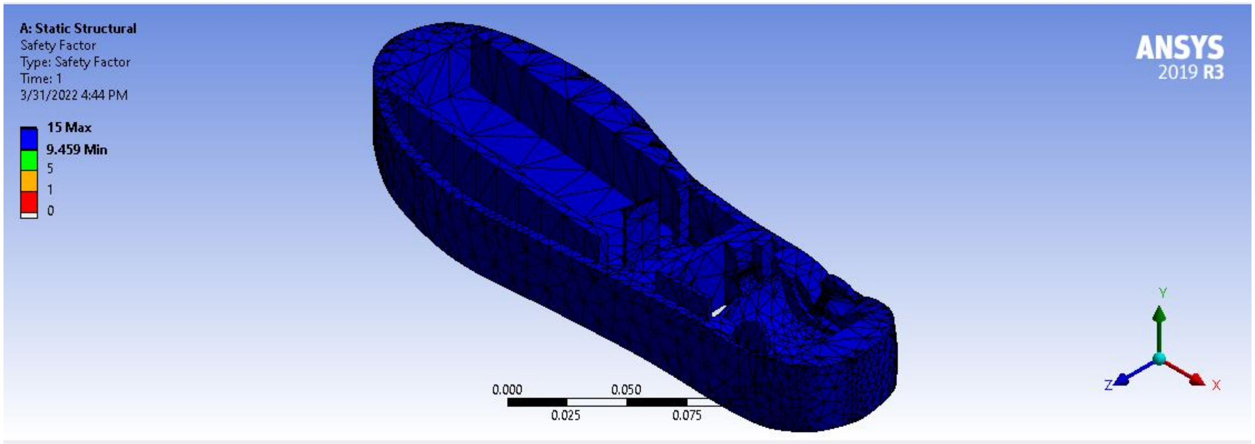


Figure 34

3.1.2 Drive Axle Simulation

For the drive axles FEA only one assumption was needed that wasn't already encompassed with the chassis' assumptions. This assumption was that the torque being applied to the drive axle was minimal enough to be omitted from its analysis. Such that this analysis was only for the drive axle under vertical load. Furthermore, it should be noted this is in a single-footed driving stance, in which the entire weight of the rider is on a single axle. The results for this analysis were satisfactory and are shown below in *Table 11*. It should also be noted that all deformations are visually exaggerated.

Drive Shaft FEA Results		**Image Reference**
Deformation	2.91*10^-6 m	*Figure 35*
Stress	3.44*10^7 Pa	*Figure 36*
Factor of Safety	>15	*Figure 37*

Table 11

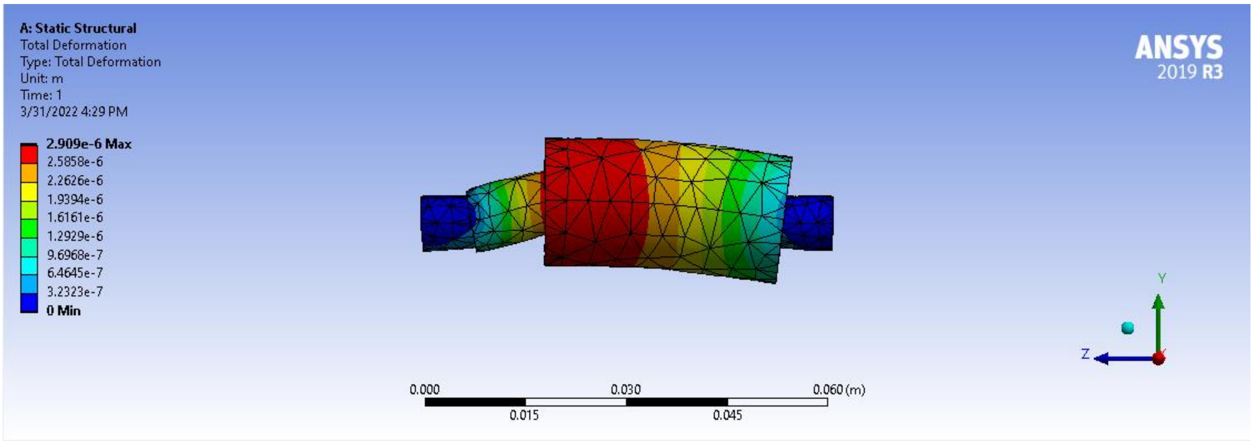


Figure 35

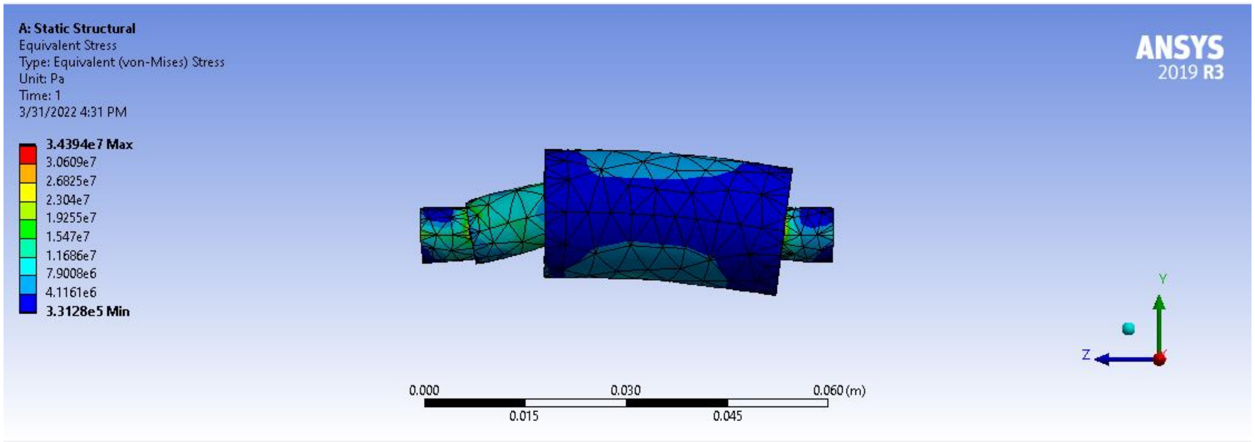


Figure 36

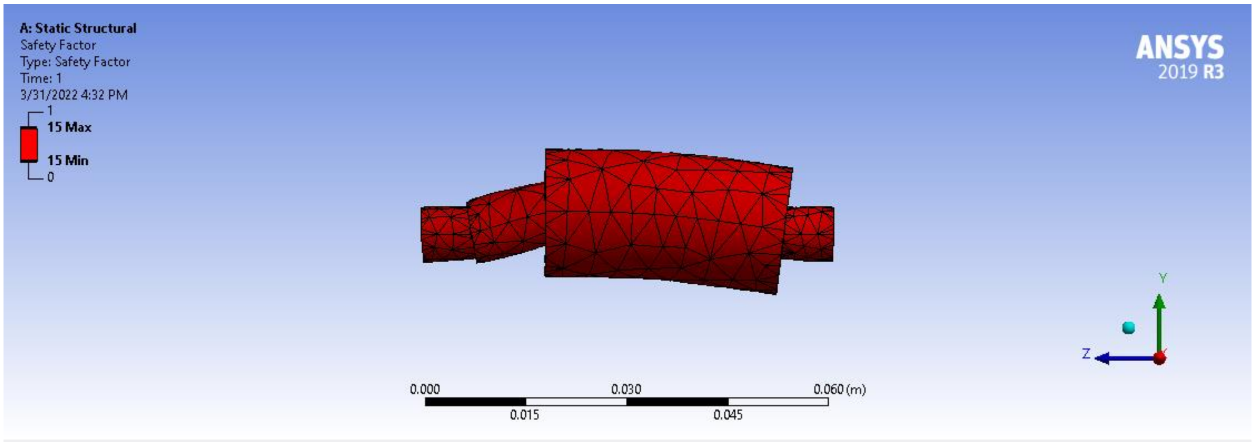


Figure 37

3.2 Real World Testing

Having successfully performed FEA for custom components for Zip Shoes, it was time to perform real world tests. These tests would be used to determine if the shoes met the criteria laid out for them within the metrics of success. Unfortunately, it should be noted that during real world testing the shoes were unable to successfully function to perform necessary tests to verify top speed and run time. This is discussed further in the "Testing Failures" subsection of this report. Despite this, however, some testing could be performed. Particularly, the weight rating, size, added weight, charge time, and comfort were all tested.

For the weight rating, the shoes were worn by an individual of the max weight capacity. They were then walked around in and used as they would be by an end consumer. As anticipated from the FEA analysis, the chassis and drive axel both withstood this test.

For the size, no special test was needed. The chassis was able to fit fully assembled into the sole of the shoe. Thus, this metric of success was met.

For the added weight, we were able to take the weights of each individual component and add them together to form a final added weight. The motor weighed 1.83 oz (Amazon, n.d.), the ESC weighed 1.44 oz (Amazon, n.d.), the receiver weighed 0.352 oz (Amazon, n.d.), the battery weighed 11.3 oz (Amazon, n.d.), the drive shaft weighed 3.23 oz (AmesWeb, n.d.) and the chassis weighed 14.2 oz as calculated in the "Production Ramp Up" section of this report. Furthermore, we considered the weight of the gears and chain along with the removed material from the shoes negligible. This gave us a total added weight of 2.02 lbs, which is less than our metric of 3lbs, so this result is considered a success.

For the charge time, two batteries for the shoes were depleted completely. Then, these batteries were charged to full power and timed. This yielded an average result of 1:30:49, within 1 minute of the desired charge time of 1:30:00. Because of this extremely close result, and the general flexibleness of the metrics of success, this result was considered a success.

For the metric of comfort, it was difficult to empirically test, as the experience of comfort varies person to person. Such that, to test this, three individuals were observed walking around in the shoes. They were able to walk semi-normally, but not completely normally. Thus, this metric for success was not achieved.

Overall, despite limits in testing capabilities, five of the seven metrics of success that warranted real world testing were able to be tested. Of these five, four were successful. Thus, leaving room for improvement while also being an overall desirable result.

3.2.1 Testing Failures

The gears purchased for the shoe used a pressure fit to adhere to the drive shaft and wheel. This was achieved by them being designed with an interference fit for the select diameters. Unfortunately, this fit did not provide enough strength to properly adhere the gearing to the motors drive shaft. Such that when attempting to use the shoes, the gearing slipped on the shaft and was unable to provide enough usable torque to propel the user forward. This regrettably resulted in the inability to test the shoes top speed and run time performance metrics. However, this issue could be solved a variety of ways. The gear could be glued to the drive shaft, the connection could have a keyway added, or the connection could have a set screw added. All three of these options would provide an adequate means to solve this key issue.

Furthermore, because of this initial failure and a lack of time to remanufacture the design with one of the given solutions, it is not currently apparent whether other failure modes exist for Zip Shoes. Thus, future testing is required.

4. Production Ramp Up

“Production Ramp-up is when the manufacturing operations begins to make and assemble the product using the intended production system.” (Budynas & Nisbett, 2020) As such this section will focus on what considerations need to be made for a future production ramp up. Furthermore, it should be noted, a key area of consideration in this section is costs. This is because of the immense impact it has on future production.

4.1 Parts Costs

As mentioned previously, Zip Shoes are made from a combination of custom and procured components. Some changes to components would be made before Zip Shoes are produced, which will impact cost. Thus, cost considerations for both the prototype and a production model are discussed here. This is regarding both the procured and custom components. First the retail cost of the procured components will be listed for the prototype. Those include the cost for the remote, base footwear, receiver, ESC, battery, motor, chain, pinion gear, spur gear, tax, shipping, and handling where applicable.

Next the cost associated with the custom designed components will be discussed. Those costs are associated with the bar stock, PLA for the chassis prototypes, and labor from producing the drive axle and chassis.

When making considerations for bulk purchasing, the company Alibaba’s prices were referenced. Some assumptions had to be made since a comparable product could not always be found in bulk on Alibaba. For parts without a comparable product from Alibaba, it is assumed the bulk purchase price is 50 percent of the retail price. This 50 percent of retail cost assumption was made on the base footwear, remote, receiver, chain, pinion gear, and spur gear. Sales tax, 6.75 percent in Ohio, has been added into the “Actual Cost” column as well.

4.1.1 Prototype

The cost of the procured parts is much higher on the prototype since components were purchased at retail price instead of at their bulk purchase price. This can be seen in *Table 12*. Furthermore, it should be noted that the chassis cost was calculated by multiplying the chassis weight by a weight correlated cost. For this case the chassis uses 14.2 ounces of PLA per shoe, at a cost of $8.80 per chassis when using PLA filament (Matweb, n.d.). Overall, the prototype parts costs $584.99.

4.1.2 Production

When moving from a prototype to a production model, some of the procured components would be eliminated from the design. The adapters would be removed since the wiring would be redesigned to remove the unnecessarily long wires on the components. The battery would have contacts instead of a plug and wires. The chassis manufacturing process would be changed to injection molding instead of 3D printing. The drive axle would be redesigned since it is excessively strong, with a factor of safety greater than 15. A different remote system would be used such that one remote could control both shoes. Such that the production cost would be much lower than the prototype cost since bulk pricing would be used, excess wiring and adapters removed, and more cost-effective manufacturing processes would be implemented. These changes would bring the production cost down to only $183.96 for the parts to put together a pair of Zip Shoes as shown in *Table 12*.

Parts Costs				
Part	**Manufacturer**	**Retail Cost ($)**	**Bulk Purchase Cost ($)**	**Actual Cost ($)**
Base Footwear	Heelys	$55.00	$27.50	$58.71
Remote	Traxxas	$59.95	$29.98	$65.00
Receiver	Traxxas	$29.95	$14.98	$64.06
ESC	RC Electric Parts	$16.99	$9.70	$36.27
Battery	Zeeee	$30.79	$19.00	$197.21
Motor	Flash Hobby	$16.99	$8.80	$36.27
Chain	ServoCity	$14.99/ft	$7.50/ft	$32.00
Pinion Gear	ServoCity	$1.99	$1.00	$4.25
Spur Gear	ServoCity	$3.89	$1.95	$8.31
Bar Stock		$11.99/ft	$1.00/ft	$12.80
Bearings	PGN	$0.98	$0.03	$10.66
Adapters	Fly RC	$23.14	NA	$24.70
PLA	Amazon Basics	$0.61/oz	$0.00043/oz	$8.66
Shipping and Handling	NA	NA	NA	$26.09
Total			**$183.96**	**$584.99**

Table 12 (Alibaba, n.d.) (Amazon, n.d.) (McMaster Carr, n.d.) (Matweb, n.d.)

4.2 Labor Costs

There is labor cost involved in both design and production. These affect both the prototype and production model, as detailed in these next sections.

4.2.1 Prototype

For the prototype most of the labor cost is associated with the design of the prototype. In calculating labor cost, it is assumed that an entry level mechanical engineer would be making $65,000 a year, which is $31.25 an hour. The hourly mean wage in Ohio for machinist is $21.42 an hour (U.S. Bureau of Labor Statistics, 2021). These values will be used to calculate the total labor cost for prototype development. On average each engineer spent 6 hours per week, for 30 weeks, designing the prototype, with two engineers working on the design. Resulting in a total of 360 engineering man hours. The machinist spent eight hours manufacturing the chassis prototypes and the drive axles for the prototype. Thus, the total machinist man hours are eight. These values are compiled, with a final cost estimate shown in *Table 13*.

Prototype Labor Costs			
Labor Type	**Cost Per Hour**	**Hours Spent**	**Total Cost**
Engineering	$31.25	360	$11,250
Machining	$21.42	8	$171.36
Total	NA	NA	$11,421.36

Table 13 (U.S. Bureau of Labor Statistics, 2021)

4.2.2 Production

The labor costs for production are much lower than they are for prototyping. For example, the average wage in China for production is $6.50 per hour, while it is $4.82 per hour in Mexico, and $2.99 per hour in Vietnam. (Statista, 2021)Those are much lower than the average manufacturing wage in America, which is $24.68 per hour. (Trading Economics, n.d.)For this reason, it is assumed Zip Shoes in Vietnam to take advantage of the $2.99 per hour average wage there. Since Zip Shoes are designed to be assembled using snap in components, instead of screws, nuts, and bolts, it is estimated that each pair of Zip Shoes will need 15 minutes of assembly time. Using $2.99 per hour in Vietnam, each pair of Zip Shoes will have an assembly labor cost of $0.75. This is much more cost effective than assembling Zip Shoes in America, if they were assembled in America each pair would have a labor cost of $6.17.

4.3 Total Costs

Encapsulated in this section is a discussion on the total cost of both the Prototype and Production model of Zip Shoes.

4.3.1 Prototype

The total prototype costs include the labor cost of the engineers, $11,250, the labor cost of the machinist, $171.36, and the parts costs from the prototype, $584.99. Which yields, a total prototype cost of $12,006.35. This prototype cost will be amortized into the cost of each pair of Zip Shoes produced.

4.3.2 Production

There are many components that go into making a pair of Zip Shoes. When all the components and the labor to assemble a pair of Zip Shoes is included, the total cost per pair of shoes is $184.71. This could be higher than the actual cost due to the assumptions made with bulk pricing of some of the components. Since the total cost per pair of Zip Shoes is $184.71, not including overhead costs and shipping costs, the retail price of a pair of Zip Shoes will be $300. That would leave a gross profit of $115.29 per pair of Zip Shoes. Even though a retail price of $200 was not possible due to material and assembly costs, Zip Shoes are still cost competitive at $300 per pair because they include a pair of shoes. The Razor Turbo Jetts, Segway Ninebot Drift W1, and Voyager Space Shoes that were the baseline for this metric do not. Even considering this, Zip Shoes are still cheaper than the Segway Ninebot Drift W1, which are priced at $469.99. (Amazon, n.d.) Furthermore, it should be noted that Zip Shoes offer a much more compact form of transportation than all three of the closest competitors. Such that buyers may be willing to pay a premium for that convenience.

4.4 Codes and Standards

Throughout this project the goal was to continually be looking ahead. As such, codes and standards that would be needed in the final production of the project were considered. Several codes and standards were investigated, with one primary set of standards standing out. This set of standards is that of the American National Standards Institute (ANSI) and Society of the Plastics Industry (SPI) standards towards horizontal injection molding, B151.1. These standards encompass safety requirements, care, and use of horizontal injection molding machines. (U.S. Department of Labor, n.d.) They are even cited by the Occupational Safety and Health Administration (OSHA) as standards by which one should abide. (U.S. Department of Labor, n.d.) These standards would need to be referenced in the manufacturing of the Zip Shoe chassis in mass, as they are designed to be an injection molded plastic part.

5. Conclusion

In conclusion, as previously stated, Zip Shoes are designed to be self-propelled footwear on wheels, based off the brand Heelys. They operate using two small electric drivetrains, each supported in a plastic chassis. These drive trains provide power to two heel mounted wheels, each sitting on a custom drive shaft. This is done so that the end user can be propelled forward.

This basic design is at the center of this entire project, and as such it is what shall be analyzed within the final section of this report. Specifically, there will be a focus on the accomplishments of this design, uncertainties of this design, ethical considerations of this design, and the future work that needs to be done to this design.

5.1 Accomplishments

Although Zip Shoes did not work as intended, that is not to say there weren't any accomplishments made in their testing. Primarily, when looking back to the original metrics of success, there are many that were accomplished during physical testing. These include the weight rating, size, added weight, and charge time.

Furthermore, two more of our metrics for success were mathematically verified but unfortunately unable to be tested in the real world. These included the top speed and run time. In fact, only two metrics were not able to truly be achieved. These included cost and comfort. Although this is unfortunate, these metrics were still close to their desired results. Such that overall, there was more success than failure in the creation of Zip Shoes.

Finally, it should be noted that more information on the specific numerical values of these metrics is available in the appendix of this document.

5.2 Uncertainties

As referenced prior, during the creation of Zip Shoes there was one key issue. This issue, the slipping of a gear on the motors drive shaft, prevented full intensive real-world testing of Zip Shoes. This has led to several uncertainties. Primarily that the top speed and run time were unable to be verified. Also, because the shoes were unable to be truly ridden under these conditions, other failure methods couldn't be observed. Thus, the top speed, run time, and other failure methods remain uncertain.

5.3 Ethical considerations

Throughout the creation of Zip Shoes there were many ethical considerations. However, if it could be simplified, then they could be grouped into two categories. These categories are safety in manufacturing and safety in end use. For safety in manufacturing, it was noted in the "Codes and Standards" section of this report that ANSI/SPI standard B151.1 would be used for the manufacturing of the shoe's chassis. For safety in end use, it was noted in the "Product use safety considerations" section of this report that an in-depth user safety guide would be created. Finally, it should be noted that ethics are always adapting and changing. Such that if there is any way safety can be improved for Zip Shoes in the future, action will be taken such that it will be.

5.4 Future work

Zip Shoes, although in a completed prototype phase, still have a long way to go. If it is decided that they are to be manufactured, there is still much work to be done. This section intends to describe the next steps that would be taken regarding the future of Zip Shoes. It describes this through discussion on the physical refinements and business steps needed.

First and foremost, Zip Shoes design would be physically refined. The problem previously mentioned of gear slippage would be the first thing fixed. Next, considerations for final materials would be made. Some materials, like the steel used for the drive shaft, are far too strong for the task they need to perform. While other materials, like the plastic gearing, may need to be strengthened. Additional chassis materials would need to be researched as well. A flexible chassis would be ideal since it would more accurately reflect a shoe sole that way. Finally, the snap in system for the wheel would be lowered into the shoe allowing for more comfort.

Secondly, Zip shoes would need discussion on the business aspects of the product. This would include things such as branding, licensing, and preparations for manufacturing. Being that Zip shoes still only exist as a prototype; these steps would be far larger than those needed for physical refinement.

Overall, despite the work that has been done, there is still plenty to be done. Although it is not yet decided what the future of Zip Shoes will be, one can still hope to imagine what they can become.

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Appendix Metrics of Success and Verifications Table

	Metric of Success	**Achieved Value**	**Report Location**	**Pass / Fail**	**Notes**
Top Speed	6 mph	6.66 mph	2.3.4.1	Pass	Only mathematically verified
Run Time	20 min	20.52 min	2.3.6.1	Pass	Only mathematically verified
Cost	$200.00	$300.00	4.3.2	Fail	
Weight Rating	225 lbs.	225 lbs.	3.1.1	Pass	Achieved value doesn’t include safety factor
Size	Fit within footprint	Fit within footprint	2.3.1	Pass	
Added Weight	3 lbs. per unit	2.02	3.2	Pass	
Charge Time	1:30:00	1:30:49	3.2	Pass	
Comfort	Walk normally	Walk semi-normally	3.2	Fail	