THE UNIVERSITY OF QUEENSLAND

Bachelor of Engineering Thesis

The design, manufacturing and testing of a Tracked Electric Mountain Board

Student Name: Lachlan STEWART (42935773)

Course Code: MECH4500

Supervisor: Professor Hal Gurgenci

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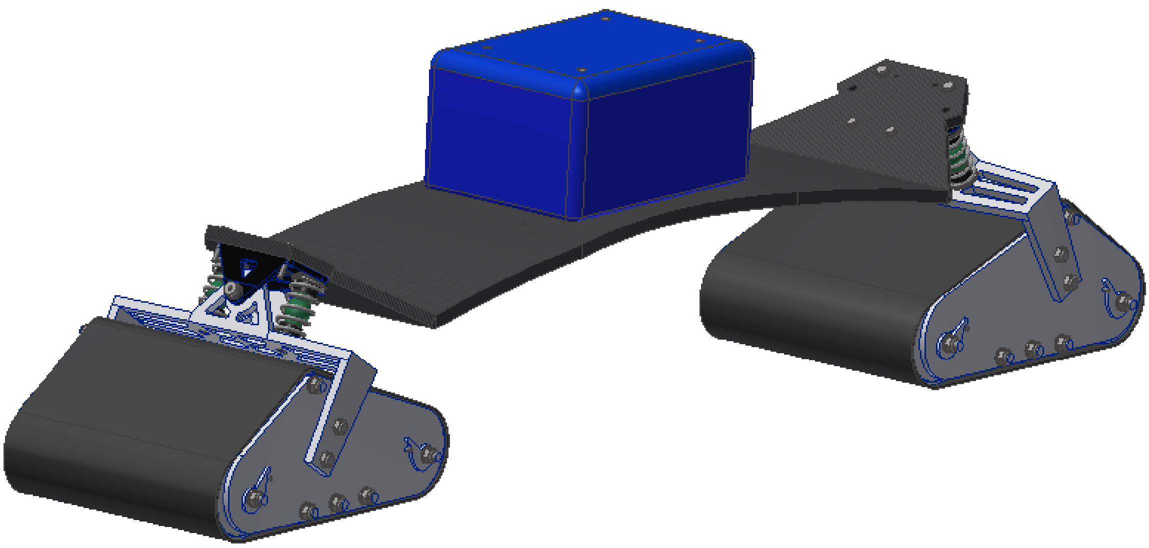
UQ Engineering

Faculty of Engineering, Architecture and Information Technology

ABSTRACT

Board sports such as surfing, snowboarding and skateboarding have been around for decades however each activity is very limited to specific terrains and conditions. This report details the design, manufacturing and testing of a tracked electric mountain board intended to provide riders with a more versatile product. The board has been designed to allow transition over a multitude of terrains including bitumen, dirt, gravel, grass, sand and snow with the ability to reach a maximum speed of 35km/hr.

After manufacturing and assembly of the prototype board, tests were conducted which found that there was inadequate friction between the drive roller and tread to consistently transfer the power to the board and allow it to accelerate. The suggested solution to this is to introduce a roller and inside tread pattern that incorporates lugs to allow constant force transfer. While most of the boards performance requirements could not be met due to this problem, general manoeuvrability was still able to be tested by riding downhill using gravity as the accelerating force. The total weight of the physical board prototype was 15.8kg and cost a total of $1924.



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1. INTRODUCTION

Board sports, including snowboarding, skateboarding and surfing have been around for many years and are considered popular recreational activities. Each case involves a rider standing on top of a board and steering via positioning their feet and transferring their bodyweight onto their heels or toes depending on which way they wish to turn. Movement is primarily driven by gravity and all three activities rely on a low friction interface between the board and contact surface. Therefore, the application of these boards is partially restricted as they can only be ridden under particular environmental conditions and certain circumstances.

One thing that could be used to improve this problem would be providing the boards with a power source, such as a small combustion engine or electric motor, greatly expands the conditions in which the board can be ridden as assistance from gravity is no longer required.

While snowboards are used in the snow, skateboards are used on concrete and asphalt and surfboards are used in the ocean, attempts have been made to construct a more versatile board that can be ridden over a wider variety of terrains. The mountain board is one such attempt which essentially involves a heavy duty skateboard with much larger wheels enabling it to roll over uneven and rougher ground. While these boards work effectively over various on land surfaces, transiting soft ground such as sand dunes and snow can cause the wheels to become bogged down.

To improve this problem, a motorised front and rear track assembly mounted to a mountain board truck and deck is proposed.

1.1 Project Aim

The aim of this project is to design and develop an off-road motorised board capable of traversing a variety of terrains including bitumen, dirt, gravel, grass, sand and snow at a cost of under $2000. The board is to be designed using the deck of a mountain board as the frame with the standard pneumatic tyres replaced with dual tracks and an external power source added to increase the boards versatility. After completion of the design, a prototype board is to be manufactured and assembled before conducting tests to determine the boards overall performance and practicality.

This report details the design process, component selection, part procurement, manufacturing procedure of custom components, board assembly, project outcomes and future recommendations to improve further upon the prototype design.

2. DESIGN REQUIREMENTS

To ensure the board is both functional and marketable, it must meet certain specifications. Table 1 outlines the criteria and target requirements of the prototype board.

Table 1: Target Design Requirements of Tracked Electric Mountain Board

Criteria	Target Requirements
Dimensions and Weight	Total board dimensions must not exceed 1400mm long x 350mm wide x 400mm high when fully assembled (board + tracks+ electrical enclosure).
	Distance between the ground surface and foot bed to be within the range of 120 – 210mm.
	Total weight of board including all components to be < 15kg.
Performance Requirements	Provide traction on bitumen, dirt, gravel, grass, sand and snow.
	Able to accelerate to reach a speed of 30km/hr.
	Able to travel up a 30° incline from standstill.
	Have a minimum run time of 45mins or 15km. (will vary depending on terrain and rider weight)
Reliability and Maintenance	Be durable enough to withstand moderate impacts when travelling at 30km/hr.
	Electrical components sealed from water, snow mud and the elements. Can be washed down afterwards.
Ergonomic Design	Have a maximum capacity to allow riders of up to 110kg.
	Be adjustable for different sized riders.
	Turn via rider weight transfer.
	Incorporate an ergonomic carry method.
	Have a maximum battery charge time from completely discharged to fully charged of < 5hrs.
Safety	Be programmable to allow the speed and performance to be set.
	Incorporate a breaking system.
Price	Total cost of components including manufacturing to be < $2000.00.

3. BREAKDOWN OF BOARD COMPONENTS

3.1 What is a Mountain Board?

A mountain board is essentially a heavy duty skateboard developed for rolling down grass and dirt mountain slopes. Very similar to the longboard in terms of deck length and manoeuvrability they have become increasingly popular with board enthusiasts looking to extend the areas and seasons in which they can ride.

Steering is achieved the same way as skateboarding by transitioning of bodyweight over the board and movement is either gravity driven or by means of ‘pumping’ (having one foot on the board and the other used to push along the ground).

Mountain boards generally consists of a deck, trucks and suspension and large 8” rubber tyres with some models offering hydraulic handbrake systems. A large range of sizes are available to cater for different rider weight and skill level. A typical mountain board set up can be seen in Figure 1.

Figure 1: Prodigy 90 Mountain Board (Surfconnect.com, c2013)

3.2 Motor

While mountain boards are primarily used on downhill trails over dirt and grass propelled by the force of gravity, adding a motor as a means of propulsion would allow them to travel over a much greater diversity of terrains and multitude of situations.

3.2.1 Engine Types and Selection

Three motor types that would be feasible options for a motorised mountain board include small 2- stroke and 4-stroke internal combustion engines as well as a small electric motor. Each of these types of engines have previously been added to skateboards however electric skateboards are by far the most common type available for a number of reasons including the following:

- full torque available from outset;
- compact sizing;
- high efficiency;
- wide range of operating speeds;
- no local pollution;
- vastly reduced noise pollution and;
- require less maintenance than small internal combustion engines.

Due to these advantages, an electrical motor setup will be used in the design of the prototype mountain board.

3.2.2 Electrical Motor Components

Along with the motor itself, a number of components need to be considered when selecting a suitable electric motor setup including the battery pack and charger, electronic speed controller (ESC) and a hand controller to regulate the motor output at a given time.

3.2.2.1 Electric Motor

The most common type of electric motor used in electric skateboard applications are brushless outrunner motors. These motors are compact, light-weight, highly efficient (over 85%), have a long service life due and quiet operation due to lack of brushes and have high power outputs (Neisa, c2016).

Most providers of brushless outrunner motors provide the following specifications:

- **Turns**: The turns of a brushless outrunner motor refer to the number of times the copper wire is wound around each pole of the armature. Generally, more turns results in higher motor torque and power, lower RPM and therefore lower velocity and a longer battery life.
- **Voltage**: The voltage specification is commonly given in terms of the maximum voltage LiPo battery that the motor can handle.
- **RPM/V**: The KV rating (RPM/V) of a brushless electric motor refers to the number of revolutions per minute (RPM) that the motor will turn with an applied voltage of 1V and no load on the motor (Pine, 2010). Motors with low KV ratings have more volts at less amps providing increased torque over motors with higher KV ratings which have more amps with less volts resulting in a higher top speed. Skateboard companies commonly use a motor with a KV rating between 150 and 250 for their electric boards.
- **Internal Resistance**: Also known as the winding resistance, the internal resistance of the motor is measured in Ohms. The greater the value of internal resistance, the less efficient the motor is.
- **Max Loading**: The max loading current is measured in Amps and is the maximum amount of current the motor can safely handle. Some motors also specify the continuous current rating, meaning the maximum number of Amps that the motor can safely draw over a long time period.

- **Max Power**: The max power rating is measured in Watts and is the power that can be safely produced by the motor. Running the motor over this rating, especially for extended periods of time is likely to cause damage to the motor.
- **Dimensions**: Motor dimensions are given in millimetres with the shaft diameter, motor length and diameter, bolt hole spacing and bolt thread measurements given.
- **Weight**: The total motor weight is specified and given in grams.
- **Motor Plug**: Different motors can use different electrical connectors. The motor plug specification outlines the connectors used on that motor. It is important to ensure that the motor plugs are the correct size and able to connect to the ESC.

Two Turnigy Aerodrive SK3– 245KV brushless outrunner motors will be used for the board prototype, with one motor driving the front track and the other driving the rear track. This will allow maximum traction over all terrains. $\frac{2\pi}{60}$

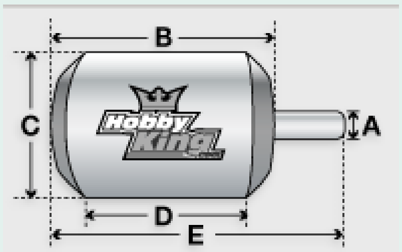
Table 2 and 3 give the specifications and dimensions of the Turnigy Aerodrive SK3– 245KV motor respectively.

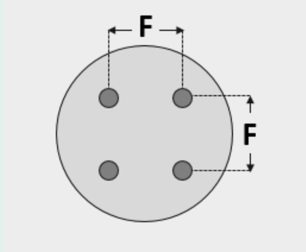
Table 2: Motor Specifications (HobbyKing.com, c2016)

Price	$96.77
Turns	14T
Voltage	37V (10S LiPoly)
RPM/V	245KV
Internal Resistance	0.018 Ω
Max Loading	70A
Max Power	2700W
Weight	718g
Motor Plug	4mm Bullet

Table 3: Motor Dimensions (HobbyKing.com, c2016)

Diameter A	8mm
Length B	72mm
Diameter C	59mm
Length D	52mm
Length E	103mm
Length F	32mm
Bolt Thread	M4





3.2.2.2 Battery Pack and Charger

For optimal board performance and ergonomics, a high energy dense, rechargeable battery with a high discharge rate is required. There are a wide variety of different rechargeable batteries available, with some common types and their properties shown in Table 4.

Table 4: Properties of common rechargeable battery types (adapted from Batteryuniversity.com, c2016)

Properties	Rechargeable Battery Types				
	Lead Acid	**NiCd**	**NiMH**	**Li-ion**	**LiPo**
Energy Density (Wh/kg)	30 – 50	45 – 80	60 – 120	90 – 120	100 – 130
Cycle Life (80% DoD)	200 – 300	1000	300 – 500	1000 – 2000	300 – 500
Charge Time (hrs)	8-16	1	2 – 4	2 – 4	2 – 4
Cell Voltage (V)	2.1	1.25	1.25	3.7	3.6
Operating Temp Range (°C)	-20 – 50	-20 – 65	-20 – 65	-20 – 60	0 – 60
Maintenance Required (days)	90 – 180	90	90	None	None
Cost	Low	Moderate	Moderate	High	High

Li-ion and LiPo (lithium polymer) rechargeable batteries have the most optimal combination of properties with no maintenance required, high cycle life, high cell voltage and very high energy densities meaning a more compact and lightweight battery is achievable. Due to the availability of Li-Po batteries, they will be used for this prototype.

Li-Po batteries packs generally have a maximum sustained discharge rate, maximum charging rate, battery cell count, voltage and capacity written on them or provided on the associated battery specifications sheet. The maximum discharge rate determines how fast the battery can be safely discharged while the maximum charging rate is the safe maximum current at which the battery can be charged at. Often LiPo battery cells are connected in series, with the number of series followed by the letter 'S' indicated on the pack. Each LiPo battery cell has a voltage of 3.7V and connecting the cells in series increases the voltage output of the battery pack. The capacity, measured in milliamp hours (mAH) indicates how much energy the battery pack can hold. Joining battery packs in parallel will increase the capacity while keeping the voltage the same.

For an electric board, a battery which is set up to the highest voltage that the motor can safely operate at is ideal as a higher voltage allows more power, torque and top end speed. The motor used for the board prototype has a voltage rating of 37V, therefore a 10S (10x 3.7V LiPo batteries connected in series) battery pack set up is optimal. To achieve this, four Zippy Compact 5000mAh 5S LiPo batteries will be used for the board prototype. The specifications and dimensions of a single Zippy Compact battery are shown in Table 5.

Table 5: Battery Specifications (HobbyKing.com, c2016)

Price	$81.23
Capacity	5000mAh
Voltage	18.5V (5S 1P / 5 Cell)
Discharge	25C Constant / 35C Burst
Max Charge Rate	5C
Balance Plug	JST-XH
Discharge Plug	5.5mm Bullet
Weight	590g
Dimensions	163 x 38 x 46mm

By connecting the batteries in both series and parallel, the combined 10S 2P pack will deliver 37V with a 10000mAh (370Wh) capacity. The maximum discharge the batteries are able to handle is 175A which is greater than the combined maximum loading of 140A that the motor can handle. With this set up the motor will be able to run at maximum capacity for short bursts if required.

The voltage of a LiPo battery should be between the range of 3-4.2V per cell at all times (Maxamps.com, c2016). Overcharging or letting the battery fall below this value can result in battery damage and compromises safety. Batteries should also be stored between 40-50% state of charge (Batteryuniversity.com 2016).

To ensure safe and efficient charging a charger specifically designed for LiPo batteries is required. The Turnigy Reaktor 300W 6S balance charger will be used to charge the Zippy Compact batteries. The charger specifications are listed in Table 6.

Table 6: Battery Charger Specifications (Hobbyking.com, c2016)

Price	$90.00
Input Voltage	11 – 28V DC
Charge and Discharge Current	0.1 – 20A
Max Charge Capacity	300W
Max Discharge Capacity	20W
Current Drain for Balancing LiPo	350mAH/cell
LiPo Battery Cell Count	1 – 6S
Intelligent Temperature Control	Yes
Weight	350g
Dimensions	140 x 95 x 27mm

This battery charger is microprocessor controlled and capable of individual cell balancing and cyclic charge and discharge.

3.2.2.3 Electronic Speed Controller (ESC)

An electronic speed controller (ESC) is an electrical circuit capable of varying an electric motors speed. The ESC is connected to the battery pack at one end and the motor via three wires at the other end. Motor output is controlled by the certain voltage pulses in particular patterns that the ESC creates and sends through the three wires.

ESCs used in skateboarding applications generally incorporate regenerative braking, allowing the operator to slow down and stop when riding. Motor performance can also be adjusted and is customizable by programming the ESC using computer software.

It is important to select an ESC with a current rating higher than the motor current rating as in extreme conditions the motor may draw more current than it’s rated to. While the motor may be able to handle this extra current for short time periods, the ESC is likely to break. It is also essential that the ESC has a voltage rating of at least that of the motor or batteries.

The ESC selected for use on the prototype board is the 150A 2-12S Car ESC with twin separate input signals from Alien Power Systems. As it is a dual configuration it allows both motors to be connected, neglecting the need for a second ESC.

The chosen ESC has the following specifications shown in Table 7.

Table 7: 150A Twin ESC Features and Specifications (alienpowersystem.com, c2016)

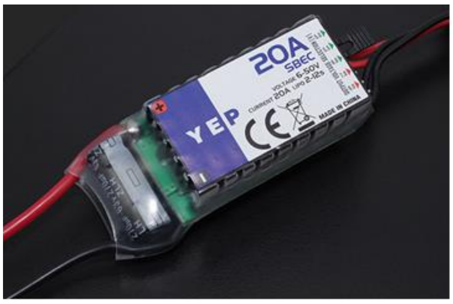
Price	$324.48
Continuous Current	150A
Voltage	(2S-12S LiPo)
Size	115 x 90 x 20mm
Weight	350g
Open source hardware and software	
Automatically upgraded firmware	
Adjustable Timing Settings	
3 types of throttle curve	
3 types of acceleration control	
Motor rotation programmable	
Automatic power cut off within 3 seconds in case of signal loss	
ABS Breaking percentage control	

Due to the high voltages that will pass through the ESC a separate battery eliminator circuit (BEC) is required. This reduces the 37V supplied by the batteries to 5V which is the required voltage for the wireless receiver. The receiver from the wireless hand controller can be connected to both the BEC and ESC allowing speed control while riding.

The Hobbyking YEP 20A HV SBEC is rated for up to 12S Lipo batteries and will be used for the prototype board. The following specifications are provided in Table 8.

Table 8: 20A HV SBEC Features and Specifications (Hobbyking.com, c2016)

Price	$18.69
Max Continuous Current	20A
Voltage	(2S-12S LiPo)
Size	57 x 26mm
Weight	42g
Switching BEC (SBEC)	
Selectable voltage output (5V-9V)	
Integrated heatsink	
Dual output leads offer power redundancy	



3.2.2.4 Electrical Housing

To protect and secure the battery and ESC while riding and transporting the board, a protective housing is needed. The Performance Diver Dry Box will be used for this purpose. The box will be located in the middle of the board on the top side and bolted in place. Rubber washers will be placed between the box and deck to help dampen the movement created when the board flexes. The box can be opened via the two clips allowing easy access to the batteries for charging purposes.

The wires that run outside of the box to each track, connecting the ESCs with the motors, will be wrapped in Flexo PET braided sleeving to keep them together and provide protection from the elements.

Table 9: Electrical Housing Features and Specifications (DiveImportscom, c2007), (Techflexcomau, c2015)

Dry Box		**Braided Wire Sleeve**	
Price	$25.00	Price	$1.43
Dimensions	225 x 200 x 115mm	Monofilament Thickness	0.010mm
Water resistant O-Ring seal		Wall Thickness	0.025mm
Rigid plastic construction		Temperature Range	-70 - 125°C
		Chemical, UV damage and rot resistant	
		Tight woven construction	
		Medium abrasion resistance	
		Range of nominal sizes	
			

3.2.2.5 Wireless Hand Controller

To enable the operator to accelerate and break while riding the board, a hand controller is needed. The large majority of electric skateboards available on the market today use some type of wireless hand controller that sends signals to the ESC. While an electrical cable joined to the ESC could also be used, when riding on trails it would be likely to catch onto something and tangle up and could potentially lead rider falling off the board and sustaining injuries. Therefore, a wireless hand controller will be used.

The Torqueboards 2.4Ghz mini remote is a reasonably priced durable and vibration proof controller that works with any standard ESC. Its compact size trigger type control makes it ideal for electric skateboard applications. It comes with a receiver which connects to ESC allowing wireless communication. Pulling the trigger inwards causes the board to accelerate and pushing the trigger outwards causes the breaks to come on. Table 10 outlines the controller specifications.

Table 10: Wireless Controller Features and Specifications (DIY Electric Skateboards, c2016)

Price	$60.00	
Dimensions	129 x 44mm	
Powerful 2.4Ghz transmitter		
Multiple channels		
Vibration resistant		
Single solid state component		
Completely silent		
Includes receiver		
Takes 2x AA Batteries		

3.3 Trucks and Suspension

Skateboard trucks mount onto the underside of the skateboard and connect the deck to the wheels. The truck is designed to allow turns to be made while riding a skateboard by transfer of bodyweight weight.

Mountain boards regularly incorporate suspension as part of the trucks for a more comfortable ride experience. This suspension is often able to be adjusted to suit specific riding styles and different rider sizes.

3.3.1 Mountain Board Truck Components and Geometry

There are two main types of suspension design currently used on mountain boards; channel truck designs and independent suspension designs. Independent suspension allows each wheel to move independently of the other however as this design only incorporates one wheel at the nose and tail of the board the following information focuses solely on mountain board channel truck designs.

3.3.1.1 Truck Components

Figure 2 shows the components of a standard mountain board channel truck.

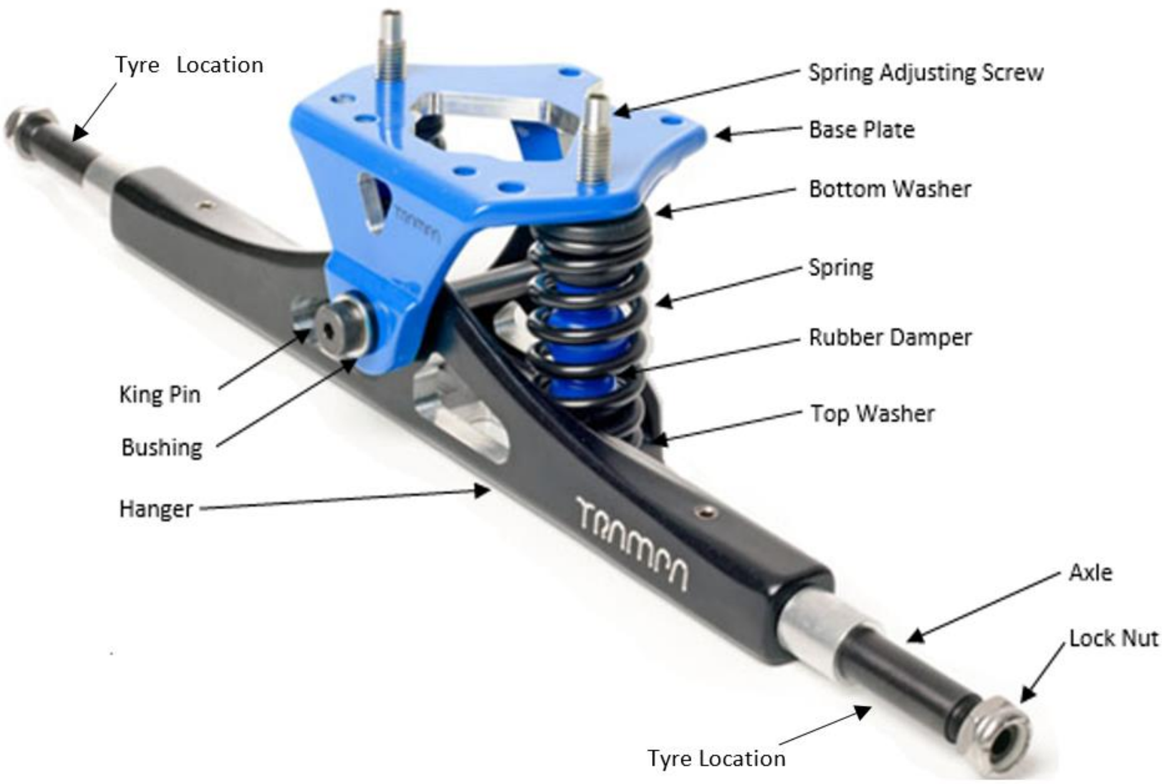


Figure 2: Mountain Board Truck Components (Boardologycouk, c2016)

The main components of mountain board trucks are as follows:

- Baseplate – the section that connects the truck to the mountain board deck,
- Axle – the long pin that runs through the length of the hanger attaching to the wheels,
- Hanger – triangular section providing support to the axle,
- King Pin – the bolt that holds the parts of the skateboard trucks together,
- Springs – provide suspension and allow the board to pivot and turn smoothly.

3.3.1.2 Truck Geometry

Truck baseplate angle determines how much a truck turns in respect to the amount of board lean. The larger the angle, the less lean required to turn the same amount as trucks with a small angle. A larger baseplate angle will also give more deck clearance but provide less stability as the centre of gravity is shifted upwards.

Often mountain board trucks have no baseplate angle, however the trucks are mounted onto the deck where the nose and tail end of the board are kicked upwards, essentially causing a baseplate angle effect.

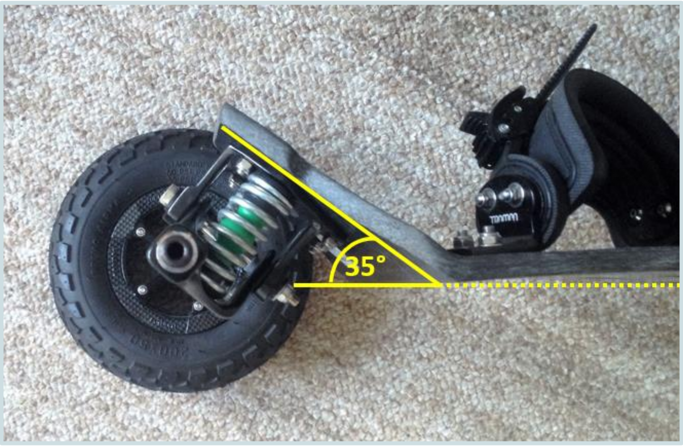


Figure 3: 35° Baseplate angle effect

For optimal performance the width of the hanger and axle should generally be as close to that of the deck as possible as this aligns the trucks and wheels to the leverage points on the board deck. Wider hangers provide more stability and are therefore often used on mountain boards but are less responsive than narrow hangers.

The direction in which the kingpin faces also effects the ride of the board. Having the kingpins facing towards each other has been the traditional or standard kingpin setup and are most commonly used on small boards designed to do tricks as the kingpin is shielded by the hanger and doesn’t interfere when grinding. Kingpins facing outwards are known as reverse kingpins and are more commonly used on longer boards. They offer more control and stability at high speeds whilst still being responsive at slower speeds.

The spring constant and pre-tensioning of the springs will determine the ease at which the board turns and the amount of turn possible. The more force required to compress a spring the more stabile the board will be at higher speeds but the less easy it will be to turn at lower velocities.

As the springs are located between the baseplate and hanger, they have no effect on the boards flex, as both sides cannot be compressed at the same time due to the king pin (i.e as the rider leans to the left, the left spring will compress and the right side spring will lengthen).

Some truck manufactures incorporate specially designed shocks within the springs which add steering resistance. These vary in stiffness and are interchangeable allowing riders to choose whether they want a firmer or more soft feeling ride. In general, the heavier a rider is, the stiffer the shock used.

3.3.2 Truck Selection and Design

There are a variety of companies offering mountain board channel spring trucks including MBS, Trampa, Scrubs and NoSno to name a few. Higher priced trucks are generally stronger, lighter and made to higher tolerance levels than cheaper alternatives.

For the prototype board trucks, a mix of prefabricated components and custom designed parts will be integrated. Using commercially made components where possible that have been tried and tested will limit the likelihood of the board underperforming as quality manufacturing can be achieved at a lower price due to mass production.

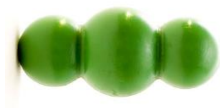
As mountain board trucks currently available on the market are designed to accommodate wheels, modifications will need to be made for tracks to be fitted. To achieve this, the truck hanger and axle will be removed and replaced with a custom designed hanger.

3.3.2.1 Prefabricated Truck Components

Trampa Boards Ltd was established in 2002 and manufacture very high quality mountain board products used by novice and professional mountain boarders alike. Trampas Vertigo Truck is a high performance, lightweight channel style truck and components from this will be used for the prototype board.

Table 11 shows the prefabricated components that will be used for the prototype. All components listed are made and distributed by Trampa Boards Ltd.

Table 11: Prefabricated Truck Components (Trampaboards, c2016)

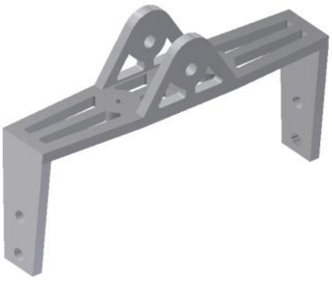
Prefabricated Components	Description
Vertigo Baseplate (x2) 	Attaches to the deck of the mountain board. - Hydraulically extruded 6061 aircraft grade aluminium. - T6 heat treated to increase molecular strength. - High quality bead polished. - Anodised for protection from the elements. - CNC precision milled.
Ultimate Kingpin (x2) 	Fixes the baseplate to the hanger whilst still allowing pivoting. - M8 x 90mm kingpin. - Made from titanium for weight reduction.
Kingpin Bushings (x8) 	Kingpin bushing allow the kingpin to move freely. Wear out so need to be checked periodically. - Made from high standard plastic.
Washer (x2) 	Helps support kingpin bushing. - M8 form B A2 grade flat washer - Marine grade stainless steel for rust protection.
Polished Spring (x4) 	Fits between the base plate and hanger. Provides resistance for responsive turning. - Coiled steel. - Precision coiled - Nickel plated.
Spring Adjuster (x4) 	Allows the springs to be tightened for different ride performance - Marine grade stainless steel for rust protection.
Spring Retainer (x8) 	Holds Trampa Dampa in place for precision steering. - Injection moulded from Dupont Materials - Reinforced by marine grade stainless steel insert. - Embossed with Trampa logo around rim.
Dampa (x4) 	Adds steering resistance and reduces speed wobble. Different shore ratings (rubber hardness) available depending on rider weight and experience level (green dampa chosen for bodyweight between 70-85kg). - Urethane elastomer - Stacked design
Countersunk Spring Retainer Bolt (x4) 	Secures spring retainer to the hanger. Countersunk head ensures flush fit with bottom of hanger. Blue paste dipped to ensure it does not undo. - M5 x 12mm - A4 Marine Grade Stainless Steel for rust resistance

3.3.2.2 Custom Designed Components

As the electric mountain board will have tracks instead of wheels, a custom made hanger and axle is required. The following hanger/axle combination has been designed to integrate in with the Trampa Infinity base plate and springs and will be joined like a regular hanger with the use of a kingpin. This will give the board a very similar feel to a normal mountain board when riding using the same use of weight transfer to steer and make turns.

The height of the hanger and where it attaches to the tracks is also of importance to ensure the tracks don't come into contact with the board deck. Table 12 lists the components of the custom hanger/axle combination.

Table 12: Custom Truck Components

Custom Components	Description
Hanger/axle (x2) 	Connects to the base plate via the kingpin and spring retainer bolts. Attaches to the tracks. - 6061 aluminium. - Welded.
Countersunk Bolt (x8) 	Secures hanger to track side plate. Countersunk head ensures flush fit with side of hanger. - M10 x 18mm. - A4 Marine Grade Stainless Steel for rust resistance.
Washer (x16) 	Helps support kingpin bushing and lock nut. - M10 A2 grade flat washer - Stainless steel for rust protection.
Lock Nut (x8) 	Screws onto countersunk bolt. Nylon thread ensures nut doesn't come loose. - M10 - Stainless steel for rust protection - Nylon insert

The maximum expected force the hanger should experience during use would occur when a 110kg rider is strapped into the board and drops from a height of 1m. This would cause a force of approximately 1225N. To determine whether the custom hanger is strong enough for general riding, a basic stress analysis was conducted using Autodesk Inventor software.

Figure 4 shows the Von Mises stress on the hanger when a vertical force of 1225N is placed inside each hole that holds the king pin (giving twice the expected force the hanger is ever expected to encounter). In this case the holes where the side plates are bolted to are constrained.

As the maximum stress due to the applied force is 122.9MPa which is much less than the minimum 241MPa yield strength of 6061 T6 aluminium, the proposed hanger design will have adequate strength (Caltechedu, 2002).

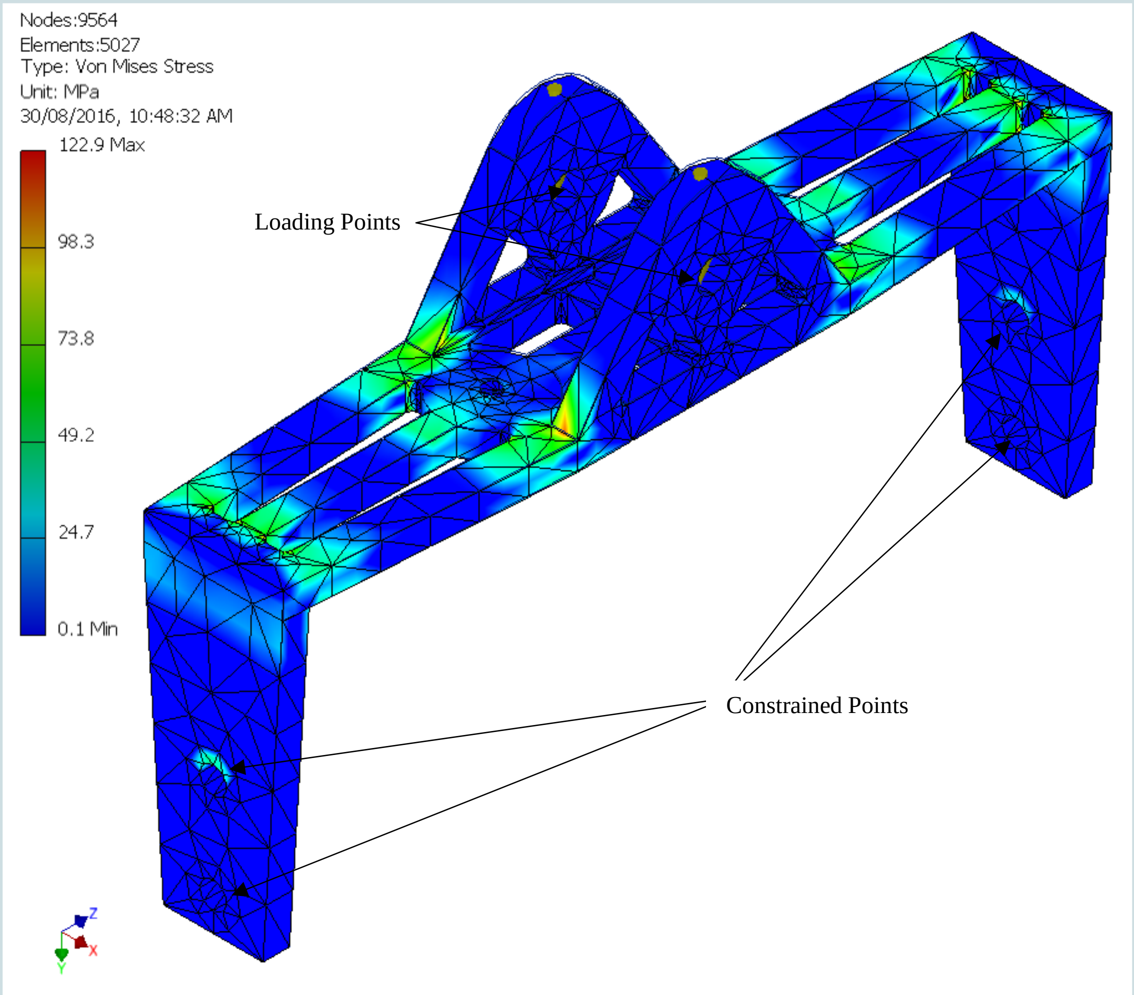


Figure 4: Von Mises Stress Analysis on Hanger

3.4 Tracks

Mountain boards make use of large rubber tyred wheels to allow them to traverse over a variety of different terrain including concrete, grass, gravel and dirt. However, when riding over softer surfaces such as sand or snow the wheels tend to get bogged down. One way to ameliorate this problem is to replace the wheels with a set of tracks. This provides a much larger total surface area being in contact with the ground and therefore reduces the chance of the board being bogged down in soft ground.

3.4.1 Optimal Dimensions and Shape

A large track will allow more surface area to touch the ground at any given time giving it greater traction and floatability. However, this comes at the price of extra weight and cost. Longer tracks will also increase the total board length, making it bulkier and harder to transport.

The width of the hanger also determines how wide the track can be. As the hanger is 250 mm wide and made from 8mm thick aluminium, the maximum track width is 234mm. Compared to the standard Trampa Vertigo hanger and axle width of 355 mm, the tracked design should achieve a smaller turning circle, meaning a more manoeuvrable board (Trampaboards, c2016). This will also give it a much lower total board width allowing it to fit more easily between trees and other obstacles encountered while riding.

The total height of the track directly effects the distance between the board deck and ground surface. A deck that is close to the ground provides good stability, however the less clearance it has for travelling over rough terrain. As the track is to be fitted with the electric motor within it, a minimum track height of 80mm is required.

Common tracks such as those used on tanks and industrial machinery such as bobcats are generally oval shaped. This is due to the pulleys or wheels at each end which the tread runs over. A slight deviation to this shape with a more triangular figuration as shown in Figure 5.b will allow the motor to fit within the tracks whilst still being protected without adding unnecessary material. For this reason, it will be incorporated into the track design.

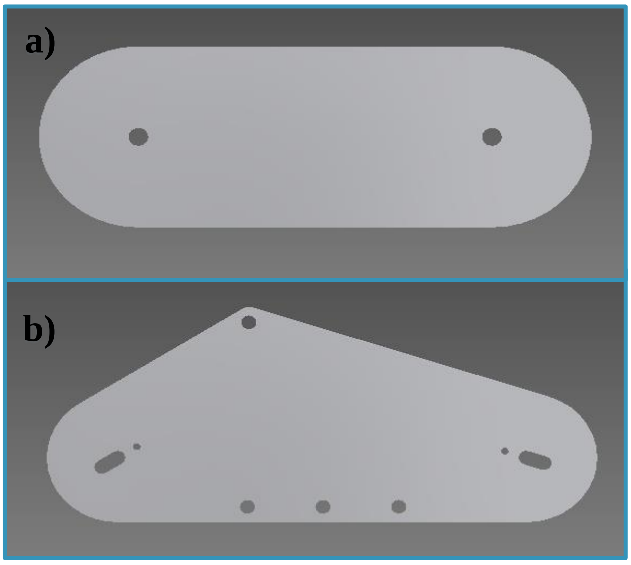


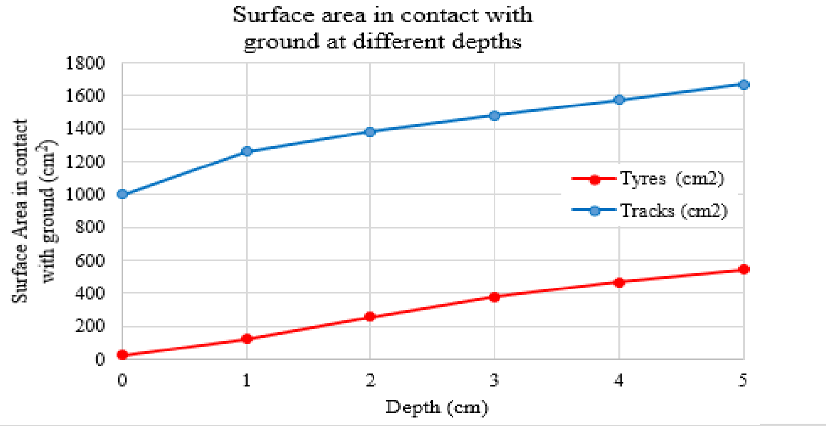
Figure 5: a) Common Track Shape, b) Modified Track Shape

As the board is to be rated to carry a 110kg rider the tracks must have a large enough surface area to prevent the board from getting bogged down in soft sand and snow when under this load. The pressure that snow can support varies greatly depending on the conditions and if it is soft powder or packed down and icy.

If the surface on which the rider traverses is soft such as snow, mud or sand the board will sink down. The following table compares the approximate total surface area that makes contacts with the ground at different depths between the four standard off road 8” tyres that come on many mountain boards and the two tracks used in this design (refer to Appendix 2 for calculations).

Table 13: Surface Area Contact Comparison

Depth (cm)	Tyres (cm^2)	Tracks (cm^2)
0	25.13	1002.24
1	125.76	1262.38
2	257.92	1379.90
3	379.72	1478.78
4	468.52	1572.02
5	545.16	1667.14



From this it can be seen that the tracks provide a much greater surface area, especially at reduced depths allowing softer terrain to be traversed much more easily. It is important to note however that at a depth of over 3.5cm and depending on the type of terrain, the tracks may experience a negative effect due to the triangular shape, potentially digging the board further into the ground. This would occur later for the off road tyres at a depth of 10cm, at which stage the board would also begin to bottom out.

3.4.1.1 Track Components

Minimising the number of parts used to create the tracks will result in a lower cost, complexity and potentially lighter weight design, however it is important that the tracks be durable enough to withstand rough use and work efficiently. Table 14 lists the components that will be used in the manufacturing of the board tracks.

Table 14: Components used to create two custom electric mountain board tracks

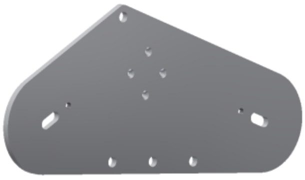
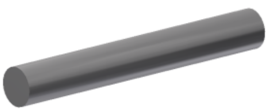
Components	Description
Side Plate (x4) 	Has holes for axles, hanger bolts, motor and adjustments. Provides protection from the side for internal track components. - Aluminium plate. - 5mm thick.
Tread (x2) 	Modification of car tyre. In contact with the ground. Tread cut-out pattern for increased grip. - Extruded Rubber compound
Small Pulley (x2) 	Connects to the electric motor drive shaft. - Steel construction. - 15 teeth. - 5 mm pitch. - 8mm bore, 12mm width.
Large Pulley (x2) 	Connected to the drive axle. Allows a gear reduction of motor rpm to increase power and torque. - Glass fibre reinforced nylon construction. - 36 teeth. - 5 mm pitch. - 8mm bore, 12mm width.
Timing Belt (x2) 	Transfers torque and power produced by the motor from the small to large pulley. - 12mm width. - 5mm pitch. - 75 teeth.
Adjuster (x4) 	Allows adjustments of the large rollers to tighten the tread and the timing belt. - Aluminium plate. - 3mm thick.
Rod (x8) 	Connects the large pulley to the large rollers. - Solid aluminium rod - 4mm diameter
Axle A (x8) 	Hold track components together, provides support for small rollers. - Aluminium. - 12mm diameter, 254mm long solid rod. - M8 Threaded ends.

Table 14 continued.

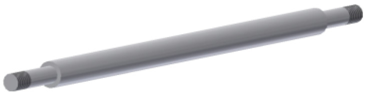
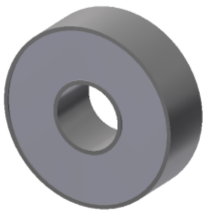
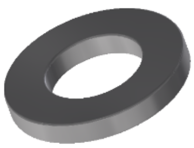
Axle B (x2) 	Hold track components together, provides support for large rollers. - Aluminium. - 12mm diameter, 264mm long solid rod. - M8 Threaded ends.
Axle B Male (x2) 	Hold track components together, provides support for large drive rollers. Inserts into Axle B Female. - Aluminium. - 12mm diameter, 147mm long solid rod. - M8 Threaded end. - 4mm end.
Axle B Female (x2) 	Hold track components together, provides support for large drive rollers. Joins Axle B Male. - Aluminium. - 12mm diameter, 132mm long solid rod. - M8 Threaded end. - 4mm drilled end.
Bearing (x26) 	Bearings allow cylinders to turn freely about axles. - 8mm core, 22mm OD, 7mm width. - Steel construction. - ABEC 5 rating
Speed Washer (x24) 	Fits onto axle between side wall and first bearing. Allows bearing to spin without friction from side wall. - M8 2mm thick speed washer. - Stainless steel for rust protection.
Large Washer (x24) 	Custom made washer that fits over bearing and within large roller. - Cut from aluminium plate. - 22mm ID, 69mm OD, 5mm thick.
Large Roller A (x2) 	Rotates about an axle. Supports tread. - Aluminium tube - 69mm ID, 75mm OD, 222mm length.
Large Roller B (x4) 	Rotates about the driven axle. Supports and drives tread. - Aluminium tube - 69mm ID, 75mm OD, 101mm length.

Table 14 continued.

Small Roller (x8) 	Rotates about axle on bearings. - Aluminium tube - 22mm ID, 25mm OD, 222mm length.
Lock Nut (x24) 	Screws onto ends of axle to hold track together. Nylon thread ensures nut doesn't come loose. - M8 nyloc nut. - Stainless steel for rust protection. - Nylon insert
Countersunk Bolt (x16) 	Secures motor housing to side plate. Countersunk head ensures flush fit with side plate. - M4 x 12mm - Stainless steel for rust protection.
Small Lock Nut (x16) 	Screws onto countersunk bolt for motor housing. Nylon thread ensures nut doesn't come loose. - M4 nyloc nut. - Stainless steel for rust protection. - Nylon insert.

The pulleys are used to gear the motor to produce less rpm but more power and torque. Using the components in Table 14, for the SK3 motor with a 15 tooth pulley connected to the motor drive shaft and 36 tooth pulley as the track drive axle, a theoretical top speed of 42.7km/hr can be calculated (Refer to Appendix 2 for calculations). As the motor will be under load whilst operating, due to rider and board weight, the actual top speed will be significantly less. Using a 12mm wide belt and pulley system will ensure adequate motor torque transfer is achieved. The two end axle has been designed so they are able to slide horizontally along the side plate for 10mm. This will allow the belt to be tensioned correctly so it does not slip on the pulleys during operation.

A hard wearing tread with lugs is required to ensure optimal traction is achievable on the large variety of terrains that the board is expected to operate over. A rubber based material such as that used on car and motorbike tyres is ideal as it is long lasting and does not destroy the ground surface like a hard plastic or steel would. Rubber should also provide some shock absorption when travelling over hard objects which should increase the life of the internal track components.

Figure 6 shows the partial set-up of a single track with all the components listed in Table 14 assembled with the addition of the electric motor and excluding the timing belt, tread and wiring.

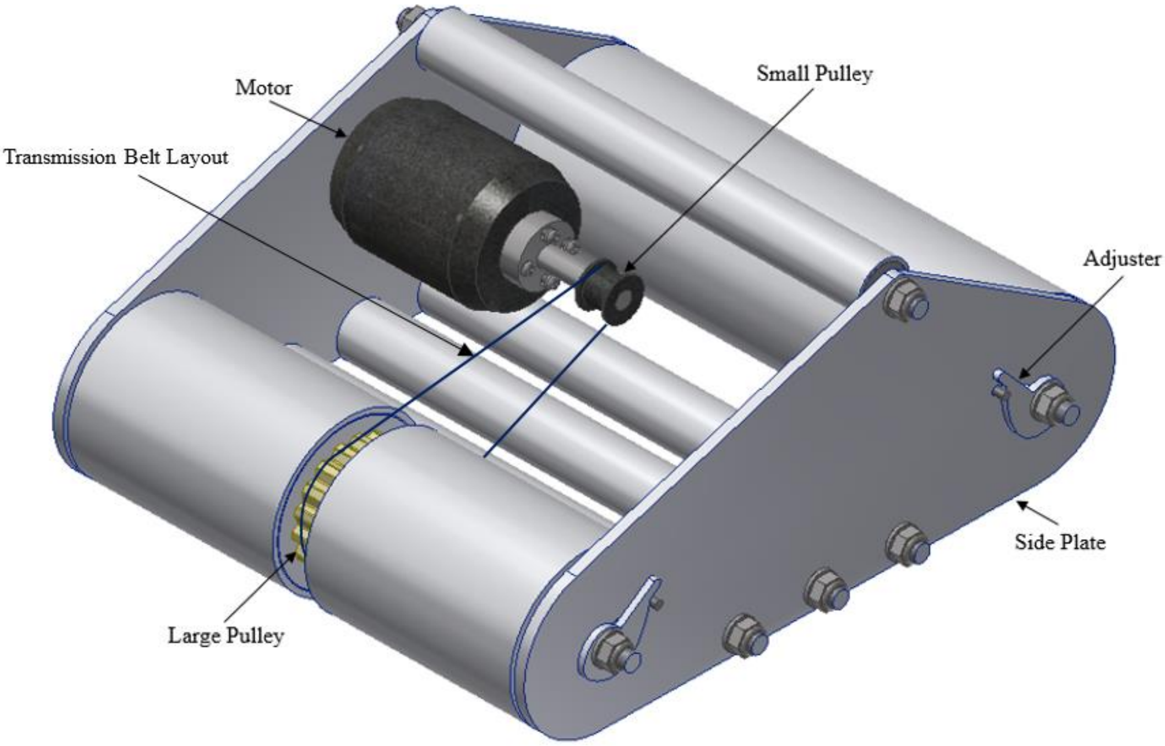


Figure 6: Partial Track Structure

3.5 Deck

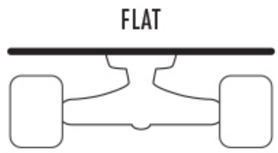
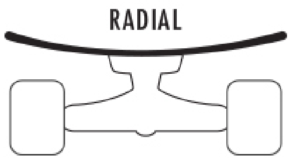
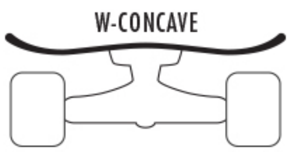
The deck of a mountain board is the platform on which you stand when riding. Mountain board decks have traditionally been made from wood and glue, however as materials and manufacturing methods have advanced boards made from composites, aluminium and other materials are now also being produced (Storeyourboardcom, 2016). A good deck needs to be strong so that it does not break under the load produced by the weight of the rider and also light and slightly flexible so that manoeuvres can be more easily performed.

3.5.1 Common Deck Shapes and Dimensions

3.5.1.1 Deck Shapes

The shape of the deck can directly impact board performance. There are a variety of different concave shapes with some of the main designs shown in Table 15.

Table 15: Concave Deck Design (Warehouseskateboards, c2016)

Concave Design	Description
	Many mountain boards that use foot straps have flat decks as standing on a flat surface feels the most natural. Having your feet securely strapped in place allows lots of lean to still make turns easily.
	The radial deck shape is the most commonly used, allowing secure footing.
	Similar to the radial deck shape, the progressive deck features steep side walls and is flat in the centre giving you good foot grip with the side walls still allowing rapid shifts in energy to make sharp turns.
	The W-concave deck design features steep sidewalls and a convex centre making it very responsive and precise to shifts in energy rom heel to toe. This shape is generally only seen at the tail end of the board mellowing out to a more progressive design at the front.

The lateral deck curve also determines how the board feels especially regarding board flex and comfort. Neutral, camber and rocker shaped decks are three main design options to consider.

Neutral decks have been around since skateboards where first made and essentially have not lateral curve.

Decks that are raised in the middle are known as camber decks and due to the higher centre of gravity, they provide much more flex.

A deck that sags in the middle is known as a rocker deck, providing a lower centre of gravity and therefore are more stable and flex less. However, because they have less clearance they are rarely used on mountain boards.

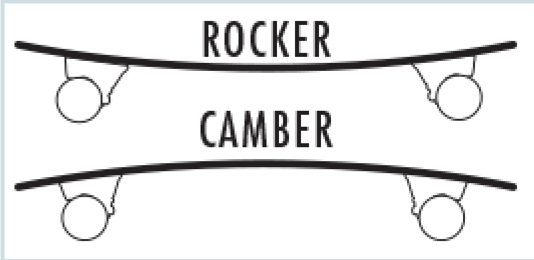


Figure 7: Rocker and Camber Deck Curves (Warehouseskateboards, c2016)

Even very slight lateral curves can make a large impact on the flex of the board.

Another design component seen on the majority decks is what is known as a kicktail or riser. A kicktail is usually seen at both ends of the board and is the part of the deck that curves upwards. Many mountain boards have the truck connected to the kicktail.

3.5.1.2 Deck Dimensions

Mountain board decks come in a variety of different sizes and designs influenced by the type and style of boarding the rider intends to do. Figure 8 show the basic skateboard dimensions.

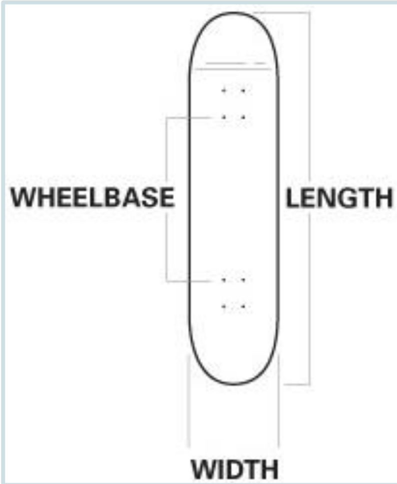


Figure 8: Basic Skateboard Dimensions (Warehouseskateboards, c2016)

Deck width is the main determinant when choosing a board and depends largely on rider height, shoe size and personal preference. The average deck width is between 190 – 220mm (Tactics, c2016). A deck that is too wide requires more effort to manoeuvre and a deck that is too narrow provides less stability.

Wheelbase is another very important design consideration. It is the distance between the truck mounting points and determines how far the front and back wheels are spaced apart.

Length also plays a role in deck design with shorter style boards, 700 - 820mm in length generally shaped and designed for the user to perform tricks and get air (Warehouseskateboards, c2016). Longer style boards, 820+mm are more commonly used in the mountain board world due to the additional stability.

3.5.2 Mountain Board Deck Selection

There is a large range of mountain board decks available, with many different sizes, styles and materials used. Trampa Boards Ltd have some of the strongest mountain board decks available and come with an unbreakable lifetime guarantee. Made from a reinforced glass and plastic thermos composite which allows the decks to be customised with holes and cut outs without compromising board strength. This ability to drill holes in the deck is significant as the prototype board design involves a battery box which will be bolted into the centre of the deck.

The 35° Holy Pro mountain board deck from Trampa will be used for the prototype, with the board, foot strap and binding specifications and features listed in Table 16.

Table 16: Deck and foot strap components (Trampaboards, c2016)

Prefabricated Components	Description
Deck (x1) 	The deck is concave and has a large camber for flexibility. 35° riser angle at each end of the board with holes drilled to accommodate vertigo truck. Foot beds contain grip tape and hole cut outs to reduce total deck weight. - Reinforced glass and plastic thermos composite. - 16 Ply, 2740grams. - 910mm total deck length. - 230mm deck width. - 35mm riser height.
Foam Footstraps (x2) 	Ribbed foam padded underside for extra grip. - Foam construction with plastic cover for structural integrity.
Ladder Straps (x2) 	Lightweight and durable. Fit to L brackets and tightened over the foam straps via the ratchet buckle. Reinforced base for added strength. - Plastic and foam construction.
L Bracket (x4) 	Bolts to the skateboard deck and holds one end of the ladder straps and one end of the foam foot straps. - Extruded Aluminium. - T6 heat treated to increase molecular strength. - Anodised.
Ratchet (x2) 	Ratcheting mechanism used to tighten ladder straps over feet, to keep rider securely attached to board. Incorporates quick release clip. - Anodised aluminium construction. - Plastic lever.
Star Fasteners (x2) 	Fixes the ratchet to the ladder straps. - Marine grade stainless steel for rust protection.

Table 16 continued.

Countersunk Bolt (x2) 	Secures ratchets to ladder straps. Screws into star fasteners. Countersunk head ensures flush fit with bottom of hanger. Blue paste dipped to ensure it does not undo. - M5 x 8mm. - A4 Marine Grade Stainless Steel for rust resistance.
Dome Bolt (x8) 	Connects the ladder strap and foam foot straps to the L bracket. Extra wide dome head for foot comfort. Blue paste dipped to ensure it does not undo. - M5 x 20mm. - Marine grade stainless steel for rust protection.
Washer (x8) 	Adds extra support to dome bolt connection with L bracket. - M5 form B A2 grade flat washer. - Marine grade stainless steel for rust protection.
Nylock Nut (x8) 	Screw onto dome bolts. Nylon thread ensures nut doesn't come loose. - M5 A4 grade nyloc nut. - Marine grade stainless steel for rust protection. - Nylon insert.
U Bolt (x2) 	Bolts onto nose and tail of board providing point for strap to clip to. - Stainless Steel
Shoulder Strap (x1) 	Padded and adjustable for comfort. Helps rider carry the board. Removable for when riding. - Made from nylon webbing. - Neoprene rubber padding.

As the board is on tracks, pumping will be much harder than if it had a typical wheel set-up and therefore if the board run out of battery while out riding it may need to be carried. As the board is significantly heavy, an adjustable padded shoulder strap can be connected to the nose and tail end of the board via U bolts. Figure 9 shows an example of this carry method with a standard mountain board.

Figure 9: Mountain board carry method

4. PROTOPTYPE BOARD PART PROCUREMENT AND MANUFACTURE

4.1 Part Procurement

The prototype board contains a large number of different parts which had to be sourced from a wide variety of manufactures. Procurement of parts began after the major design plans for the board were completed on the 5th of May 2016 with the purchase of the Trampa deck and hanger. The remaining components were then ordered over the following 14 weeks with the final order of parts complete on the 17th of August 2016.

Due to many items being ordered from overseas manufactures shipping times were often lengthy. The entirety of parts required for the completion of the board were not received until the 15th of September 2016. The large time duration between the ordering and acquiring of all the parts needed was due to a number of reasons including slight design changes, items out of stock or on backorder, long shipping times, incorrect items being sent and financial circumstances.

The total cost of the parts required for the prototype tracked electric mountain board came to approximately $1925.

Table 17 shows the parts used to build the tracked electric mountain board prototype along with a short description and the associated costs.

Table 17: List of Components and Suppliers

Part Name	Description	Parts Included	Supplier	Number Required	Cost/part (AUD)	Total Cost (AUD)
Trampa Holy Pro 35° Deck	16ply GRP MTB Deck with 35° Risers (includes truck bolt kit, binding bolt kit)	1 x 16ply 35° Holy Pro Blank Deck 2 x 9 Inch Squares of Jessop Grip Tape 2 x M5 X 25mm Skate Truck Bolt Kit 8 x M6 X 25mm Countersunk Bolt - Marine Grade SS 8 x M6 Nut - Marine Grade SS Nylon Nut 8 x M6 Washer - Marine Grade SS	Trampa Boards LTD	1	$291.67	$291.67
Vertigo Baseplate	6061 Aircraft aluminium. T6 Heat Treated	1 x Vertigo Baseplate	Trampa Boards LTD	2	$33.34	$66.68
Springs	Powdercoated sprung steel springs with dampas	4 x Trampa Dampa (Green) 4 x Spring Adjusters 4 x Springs - Powder Coated Steel 8 x Spring Retainers	Trampa Boards LTD	1	$96.66	$96.66
Ratchet Bindings	Pair of adjustable ratchet bindings for secure connection of rider to deck	1 x Ratchet Binding Footstraps (Pair) 1 x Ladder Strap (Pair) 4 x L Bracket - Anodised Silver 2 x Ratchet Buckle - Anodised Silver 2 x M5 Star Nut Fastener 8 x M5 X 8mm Countersunk Bolt - Marine Grade SS 8 x M5 x 20mm Extra Wide Dome Head Bolt - Marine Grade SS 8 x M5 Washer - Marine Grade SS 8 x M5 Nut - Marine Grade SS Nyloc Nut	Trampa Boards LTD	1	$91.67	$91.67

Table 17 continued.

High Discharge Li-Po Battery	Capacity: 5000mAh, Voltage: 6S1P 22.2V, Discharge: 25C	1 x Zippy compact 5000mAh 6S 25C LiPo Pack	HobbyKing.com	4	$81.23	$324.92
245kv Brushless Outrunner Motor	Turns: 14T, Voltage: 10S LiPoly, RPM: 245kV, Max Load: 70A, Max Power: 2700W	1 x Turnigy Aerodrive SK3 - 6364 - 245kv Brushless Outrunner Motor	HobbyKing.com	2	$96.77	$193.54
ESC Motor Controller	Open source hardware and software. Regenerative Breaking. 8V-60V (2S to 12S LiPo). 150A	1 x Dual ESC HV Twin Motor Controller	Alien Power System	1	$324.48	$324.48
BEC	SBEC, voltage reducer. 6V-50V (2S to 12S LiPo). 20A	1 x Hobbyking YEP HV SBEC	HobbyKing.com	1	$18.69	$18.69
Tracks	5mm Aluminium Plate	1 x Aluminium Plate - Mill Finish (1200x2400x5mm)	Rose Valley Steelworks	0.2	$280.00	$56.00
	3mm Aluminium Plate	1 x Aluminium Plate - Mill Finish (1200x2400x3mm)	Rose Valley Steelworks	0.02	$180.00	$3.60
	10mm Aluminium Rod	1 x Aluminium Rod (10x4000mm)	Rose Valley Steelworks	1	$11.15	$11.15
	75mm Aluminium Tube	1 x Aluminium CHS (75mm OD, 69mm ID, 4000mm)	Rose Valley Steelworks	0.8	$122.95	$98.36
	25mm Aluminium Tube	1 x Aluminium CHS (25mm OD, 19mm ID, 4000mm)	Rose Valley Steelworks	0.46	$26.85	$12.35
	Bearings	1 x Abec 5 Longboard Bearings (22mm OD, 8mm ID)	DIY Electric Skateboard	28	$1.12	$31.36

Table 17 continued.

Tracks	Nuts	1 x M8 Nut - Marine Grade SS Nylon Nut	AccuGroup	24	$0.18	$4.32
	Tread	1 x Pyramid Rubber Matting (4.5mm x 1000mm x 1000mm)	Clarke Rubber	0.3	$79.95	$23.99
	Small Pulley	1 x 15T 12mm Steel Pulley (12mm width, 8mm shaft)	Enertion Boards	2	$19.95	$39.90
	Large Pulley	1 x 36T Nylon Wheel Pulley (12mm wide)	Enertion Boards	2	$19.95	$39.90
	Belts	2 x HTD5 12mm Timing Belts (100T)	UXCell	1	$19.95	$19.95
Hanger	8mm Aluminium Plate	1 x Aluminium Plate - Mill Finish (1200x2400x8mm)	Rose Valley Steelworks	0.02	$340.00	$6.80
	Bolts	1 x M10 SS Countersunk Bolt		8	$0.20	$1.60
	Washer	1 x M10 SS Washer		8	$0.15	$1.20
	Bearings	1 x Abec 5 Longboard Bearings (22mm OD, 8mm ID)	DIY Electric Skateboard	4	$1.12	$4.48
	Nuts	1 x M8 Nut - Marine Grade SS Nylon Nut	AccuGroup	4	$0.18	$0.72
Charger	DC LiPo Charger	1 x Turnigy Reaktor 300W 20A 6S Balance Charger	HobbyKing.com	1	$90.00	$90.00
Electrical Box	Waterproof Box to secure and protect batteries and ESC	1 x Water Resistant Plastic Dry Box (225x200x115mm)	Dive Imports	1	$25.00	$25.00
Wireless Hand Controller	Wireless 2.4ghz hand controller transmitter and receiver	1 x Torqueboards 2.4GZ Mini Remote Controller	DIY Electric Skateboard	1	$60.00	$60.00
Electrical Components	Heat Shrink to cover solder points	1 x Heat Shrink Tube (8mm x 30mm)	HobbyKing.com	1	$1.00	$1.00
	Solder Wire for electrical connections	1 x Solder Wire		1	$1.00	$1.00
	Braided Cable Sleeve	1 x Techflex Flexo PET Expandable Tube (10mm*5m)	Techflex Australia	0.25	$5.70	$1.43
	Motor Connections	1 x 4mm Female Bullet Connectors	HobbyKing.com	6	$0.20	$1.20
	Anti-Spark Connector	1 x XT90-S Anti-Spark Connector	HobbyKing.com	1	$2.73	$2.73
TOTAL COST						$1,923.17

4.2 Manufacturing Process

While the majority of the components for the tracked electric mountain board prototype where bought pre-fabricated, some components required custom manufacturing. This included the truck hanger, track and various electrical components.

4.2.1 Truck Hanger and Track Manufacture

The truck hanger and track where firstly designed using Autodesk Inventor. Special care was taken in the design of the hanger to ensure it would connect seamlessly to both the Trampa trucks and track baseplate and springs. Once the designs where finalised and the parts procured fabrication for the custom components began. This involved cutting, grinding, drilling, welding and lathe work to get the desired shape and size from stock aluminium sheets and tubing. While the majority of the work was completed by myself, the aluminium welding was outsourced and done by an accredited boilermaker.

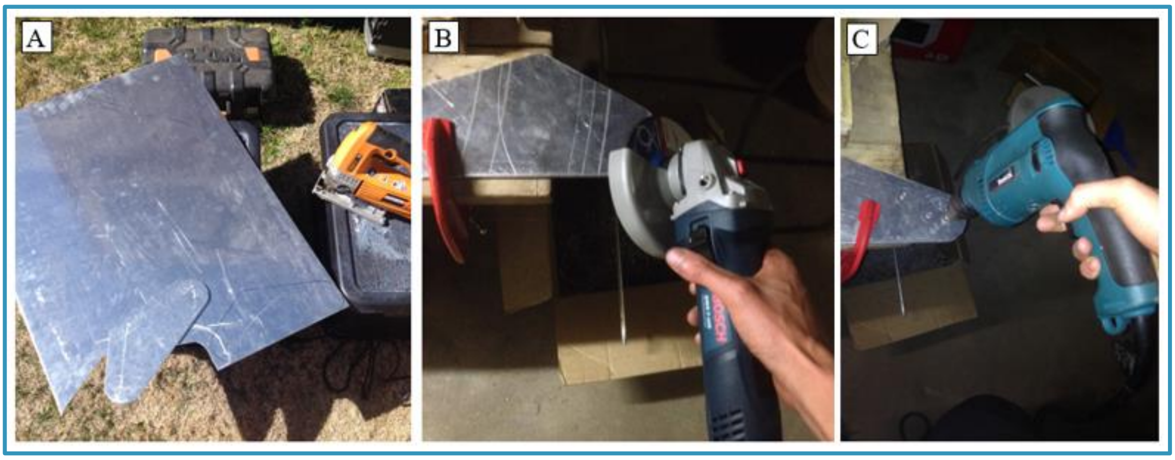


Figure 10: A) Cutting out side plates, B) Grinding side plates, C) Drilling side plates

The side plates where cut from the 5mm aluminium plate using a jigsaw and grinder. The pieces were then clamped together and the edges ground with a grinder to ensure they were the same size and shape. Holes were then drilled through the side plate for the axles and motor mounts.

The hanger was manufactured in a similar manner being cut from 5mm aluminium plate, ground and drilled. They were then taken to a boilermaker for welding.

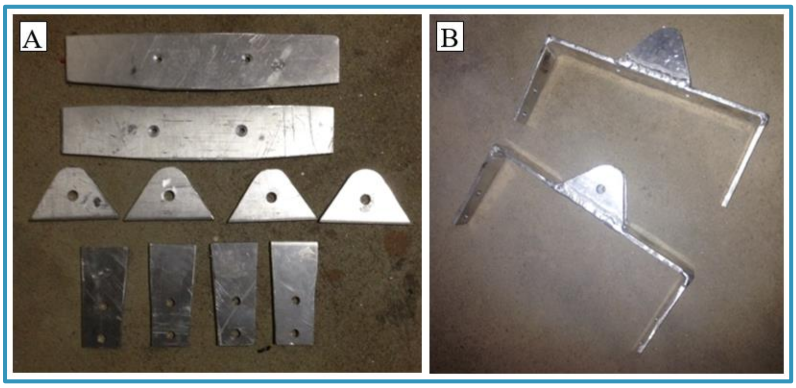


Figure 11: A) Separate hanger sections pre-welding, B) Welded hangers

The small and large rollers where cut from 25mm and 75mm diameter aluminium tubing to specified lengths using a grinder and hacksaw. Large washers were drilled from 5mm aluminium plate using hole saw drill bits. To enable the bearings and large washers to fit tightly within the rollers, the ends of each cylindrical tube were drilled out.

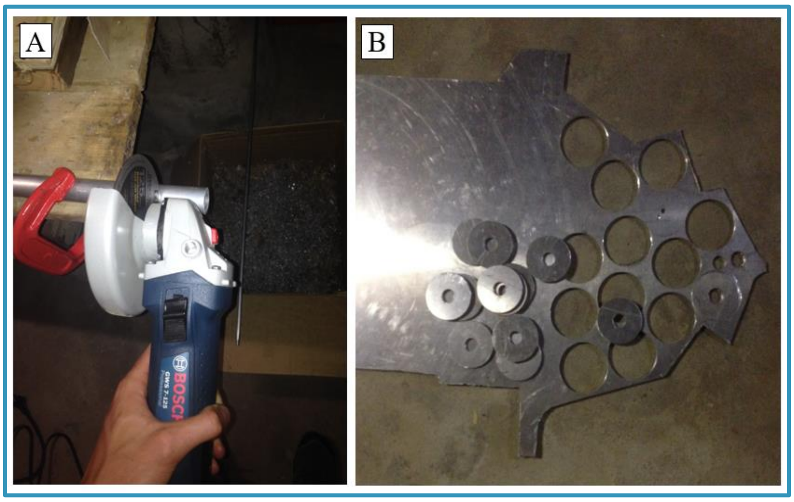


Figure 12: A) Cutting lengths of tube, B) Large washers drilled from plate

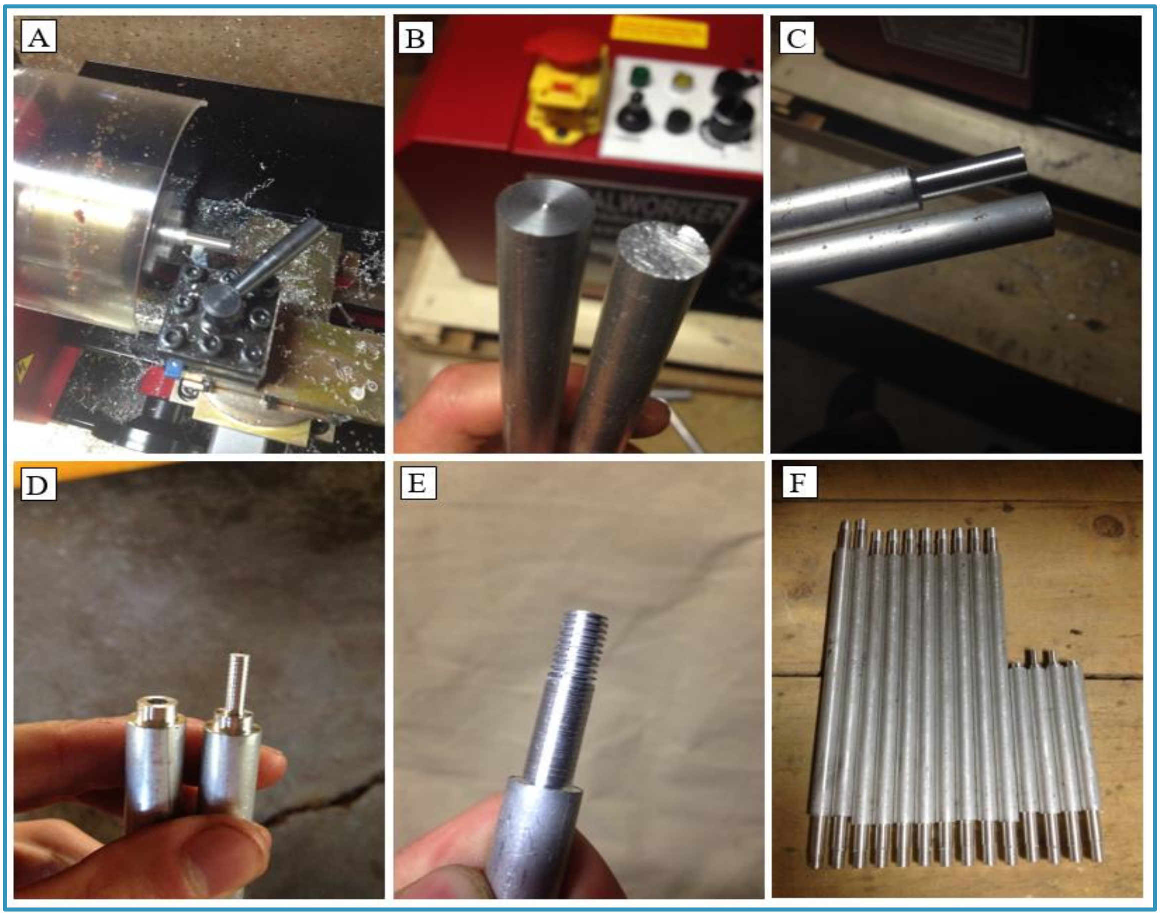


Figure 13: A) Reducing axle end thickness on lathe, B) Comparison of faced edge, C) Lathed axle end, D) Drive axle centre join structure, E) Threaded axle end, F) All completed axles

To produce the axles, measured lengths of solid 12mm aluminium rod where cut with a hacksaw. Each end was then faced on the lathe to get more accurate lengths and a smooth finish. The diameters of ends where then reduced from the original 12mm to 8mm to allow the bearings to fit onto the rods up to the thicker section which acts as a bearing stopper. Each drive axle required extra attention as they are designed as two piece sections that connect in the middle and involved drilling the female end and further diameter reduction on the male end to allow the pieces to slot together. The ends of all the axles were then threaded using a M8 1.25 die to allow nyloc nuts to screw on which hold the track together.

All the rollers were then assembled using the axles, bearings, cylindrical tubing, large washers and large cogs.

The male and female axles used for the drive rollers required minor adjustments on the lathe to ensure the correct spacing for the large cogs. Secure fittings were achieved by using Loctite 680 retaining compound.

Figure 14: Different rollers manufactured

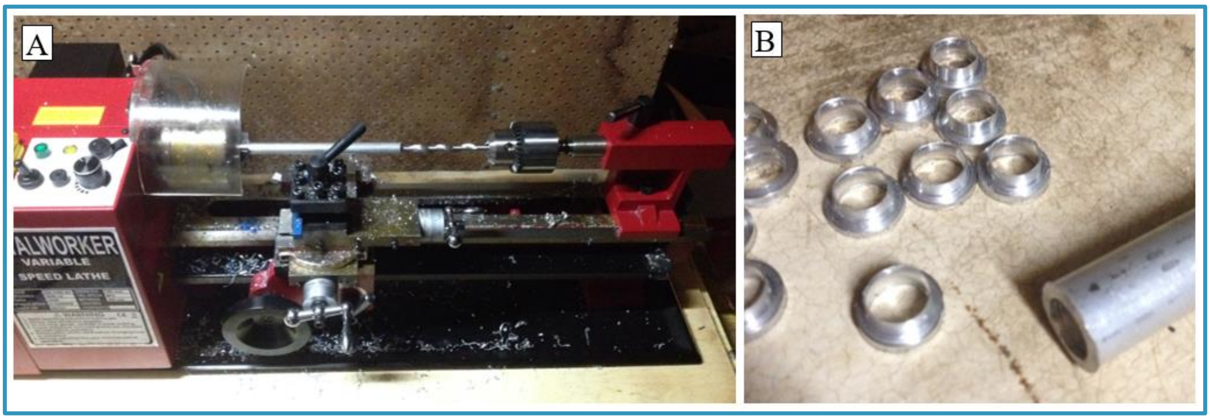


Figure 15: A) Drilling hole in aluminium rod, B) Completed spacers

Small spacers to be fitted between the rollers and side plate to allow the bearing to rotate freely without pushing up against the side plate were created by drilling a 8mm hole through the middle of some 12mm aluminium rod and then making cuts on the lathe every 2mm.

To allow the small pulley to connect to the motor, the first 18mm of the aluminium shaft that bolts to the motor was reduced from 12mm to 8mm on the lathe.

The required tread was measured and cut from both pyramid rubber matting and standard rubber matting using a Stanley knife. Methylated spirits were then used to clean and prepare the rubber, effectively removing

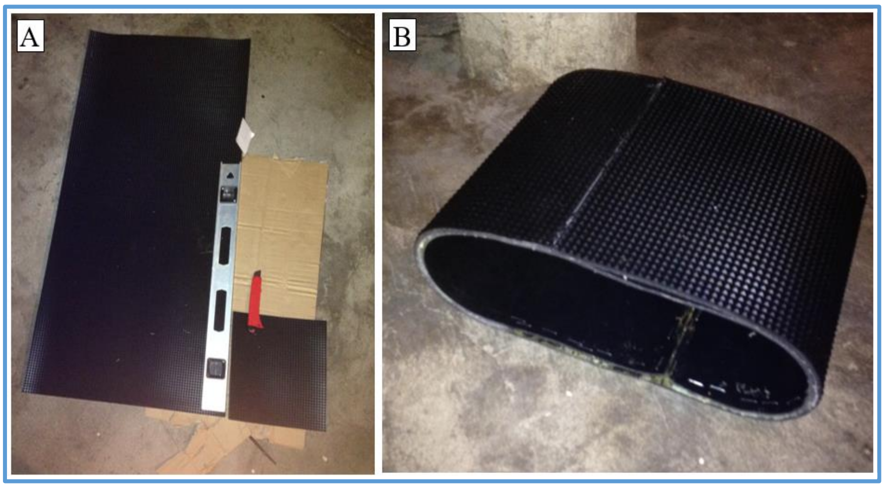


Figure 16: A) Cutting out rubber, B) Single tread bonded together

any dirt or contaminants. The rubber was then connected by joining two layers together using contact bond cement with the ends joined at different locations and the rubber clamped together for 12hrs until the bonding agents were fully cured. Due to the large surface area a strong yet flexible bond could be formed. To ensure the edges would not start peeling up after use, the outside edges were also sewn together with wire braid.

Other minor components that required minor modification included the deck and dry box. Holes were drilled through the base of the drybox and through the deck to enable the box to be securely held in place. An additional hole was drilled through both sides of the dry box to allow the motor wires to protrude.

The manufacturing of custom mechanical components was a very lengthy process, due partly to my fairly limited skill and experience and also because of the general tools and machines I was working with. An estimated 55hrs was spent measuring and manufacturing the required components over the course of four weeks, however with more adequate experience and industrial tools this process would be greatly reduced.

4.2.2 Custom Electrical Components

To properly fit and connect all the electrical parts some components needed modifying.

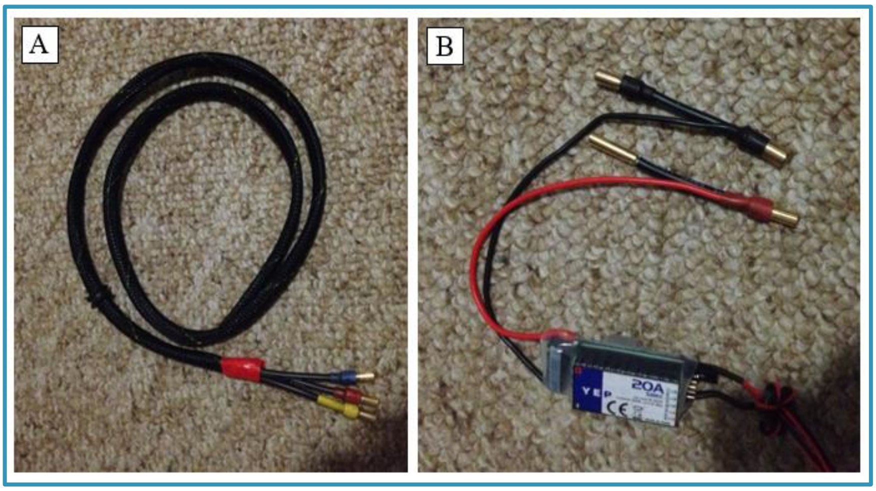


Figure 17: A) One end of wire lengths for motor complete, B) BEC wire connection

Due to the motors being located within the tracks and the batteries and ESC being positioned in the middle of the deck, the motor wires each needed to be lengthened to cover this distance. This involved six 950mm lengths of wire to which bullet connectors where soldered to each end. Heat shrink was then melted over the connectors and joins to ensure the bare metal surfaces where adequately covered to prevent unwanted sparks. Coloured heat shrink was used to match where it was to be connected to. To keep the sets of wires together they were guided within braided sleeve which then had its ends melted and taped to prevent fraying. This braided sleeve also acts as a protective layer reducing the risk of anything cutting or grazing the wires that protrude from the battery box and run over the foot straps and into the tracks.

The positive and negative wires running from the BEC were soldered to two small wire lengths in a similar manner to the motor wires with bullet connectors on each end and using coloured coded heat shrink to protect the connectors.

The time spent completing the electrical components once everything was attained was approximately 2hrs.

5. BOARD ASSEMBLY

5.1 Parts List

The following table shows an extract of the parts list. Included is the item number, part code, part description, material the part is made from and the quantity of parts required for the complete build of the tracked electric mountain board. For the complete set of tables refer to Appendix A.

Table 18: Track Parts List

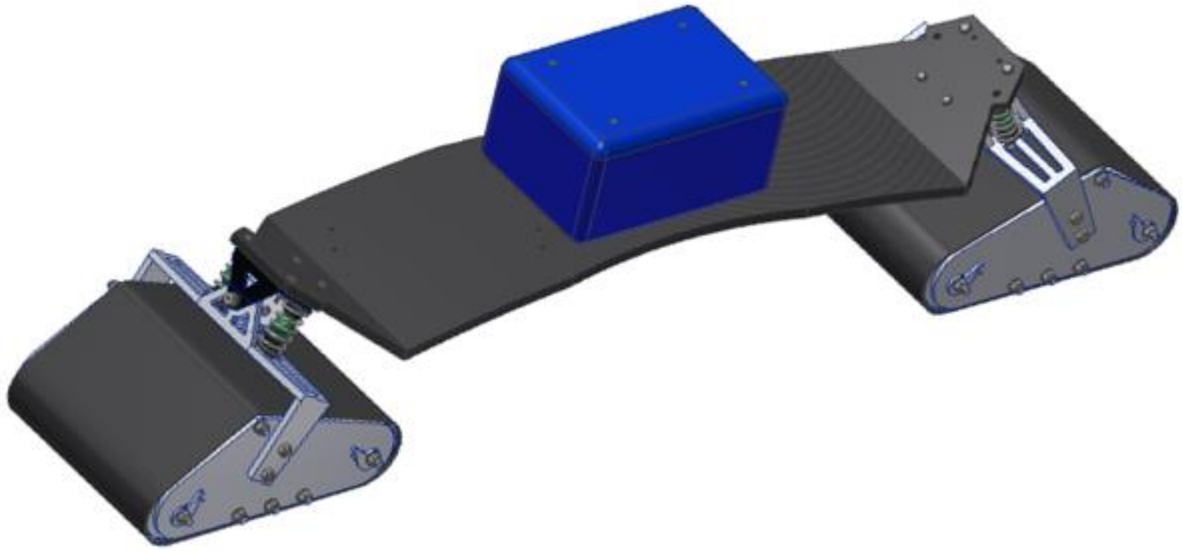
TRACK PARTS LIST				
ITEM NO.	**PART NO.**	**DESCRIPTION**	**MATERIAL**	**QTY.**
1	SPLA1	SIDE PLATE, CUSTOM, T5	ALUM	2
2	SPLA2	SIDE PLATE, CUSTOM, EXTRA HOLES, T5	ALUM	2
3	AXLE1	AXLE, SOLID, CUSTOM, D12, L254	ALUM	8
4	AXLE2	AXLE, SOLID, CUSTOM, D12, L264	ALUM	2
5	AXLE3	AXLE, SOLID, CUSTOM, MALE, D12, L147	ALUM	2
6	AXLE4	AXLE, SOLID, CUSTOM, FEMALE, D12, L132	ALUM	2
7	ROLL1	ROLLER, HOLLOW, CUSTOM, OD25, ID19, L218	ALUM	8
8	ROLL2	ROLLER, HOLLOW, CUSTOM, OD75, ID69, L218	ALUM	2
9	ROLL3	ROLLER, HOLLOW, CUSTOM, OD75, ID69, L102	ALUM	2
10	ROLL4	ROLLER, HOLLOW, CUSTOM, OD75, ID69, L100	ALUM	2
11	ADJU1	ADJUSTER, CUSTOM, T3	ALUM	8
12	SPUL1	PULLEY, W12, 15T, P5, ID8	STEEL	2
13	LPUL1	PULLEY, CUSTOM, W12, 36T, P5, ID8	NYLON	2
14	BELT1	TIMING BELT, 12W, 100T, P5	RUBBER	2
15	MOTR1	BRUSHLESS OUTRUNNER MOTOR, 274KV	-	2

5.2 Mechanical System Assembly

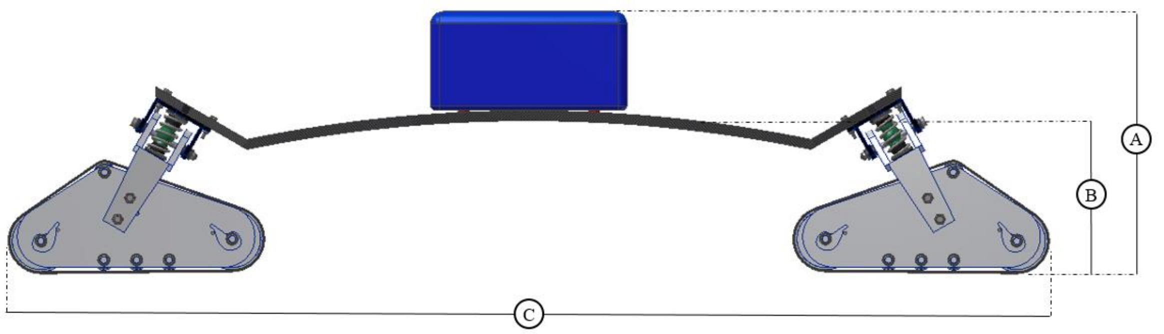
5.2.1 General Dimensions

The schematic shown in Figure 18 provides the basic overall dimensions of the tracked electric mountain board. With a maximum length, width and height of 1275mm, 264mm and 314mm respectively, the board is longer and narrower than a standard mountain board of 955mm long and 357mm wide (Trampaboards, c2016). The height of the prototype board is higher than that of a standard mountain board due to the Dry Box located on the top of the deck that houses the electrical components.

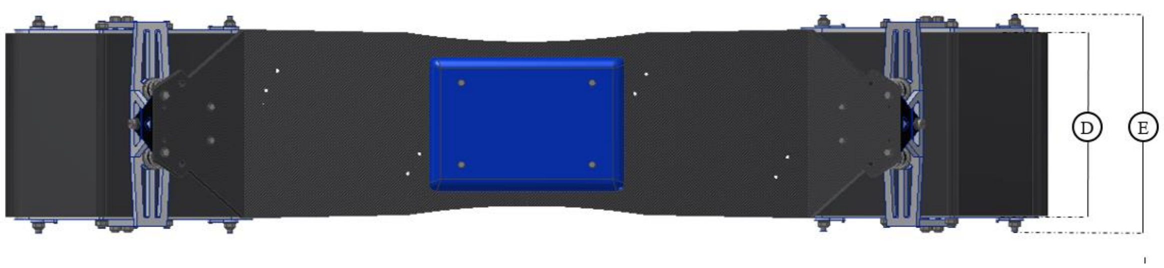
The average distance between the ground and the foot bed is 180mm when the board is unloaded. When the board is being ridden this distance will generally deviate within a range of approximately 1-5cm depending on rider weight and terrain due to the flex of the deck.



Side View



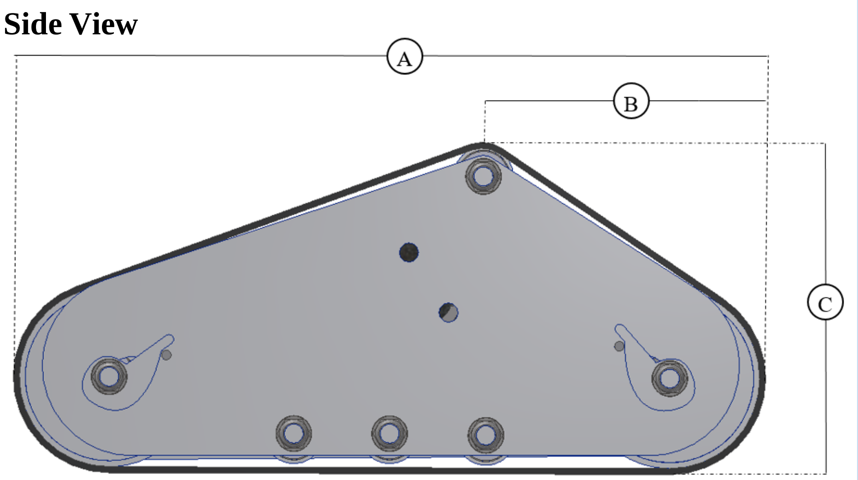
Top View



Section	A	B	C	D	E
Dimension (mm)	314	180	1275	224	264

Figure 18: Basic Dimensions of Tracked Electric Mountain Board

The general dimensions of the tracks used can be seen in Figure 19 with track width given in Figure 18 and measuring 224mm. The specific shape and size of each track allows an electric motor to fit inside, providing motor protection.



Section	A	B	C
Dimension (mm)	314	117	138

Figure 19: Basic Dimensions of Track

5.2.2 Exploded View

The deck is connected to each truck via four bolts that run through the deck and into the baseplate. Each truck is then connected to the side plates of the tracks via two bolts per side plate. This creates a fixed connection, preventing the tracks from rotating up and down and allowing the force from rider weight positioning to compress the springs and dampas and allow turns to be made. Refer to Chapter 2 for further details on stiffness of the springs required and how the truck setup allows one to turn. Figure 20 shows a general exploded view of the board.

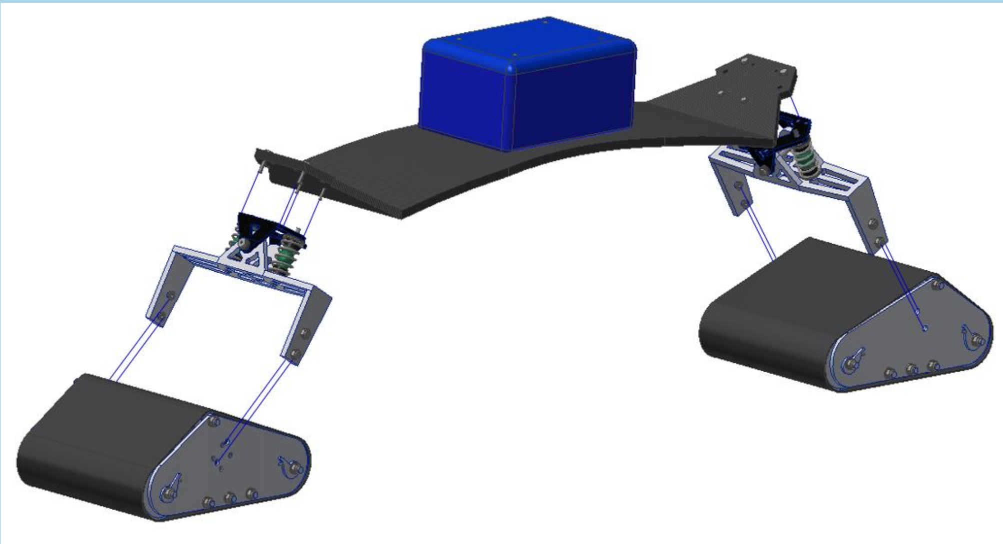


Figure 20: Exploded View of Tracked Electric MB

The following tools where used in the fully assemble the board once the manufacturing of components was complete:

- 13mm, 10mm, 8mm spanners,
- 4mm hex key,
- Phillips head screwdriver,
- Adjustable wrench,
- 2x G-clamps, and
- Combination pliers.

The full assembly of the board took approximately 2hrs initially, however after having pulled it apart and put together again a few times this process was reduced to about 1hr. Figure 21 shows the board fully assembled. For the assembly breakdowns and exploded views of minor sections refer to Appendix B.

Figure 21: Assembled Tracked Electric MB Prototype

5.3 Electrical System Assembly

5.3.1 Electrical Layout

A schematic of the electrical system set up can be seen in Figure 22.

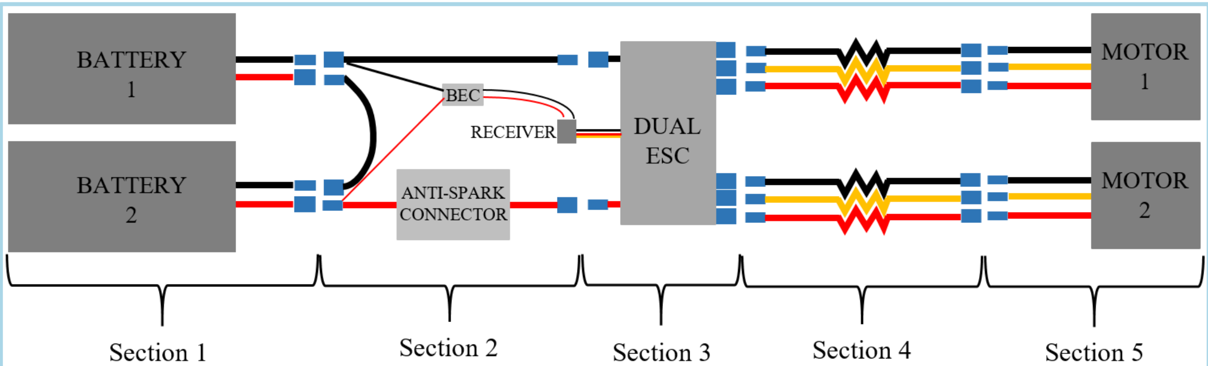


Figure 22: Electrical System Configuration

Section 1: Batteries

Identical Li-Po batteries are used that come stock with 5.5mm bullet.

Section 2: Series Connector

A series connection is made by joining the positive lead from one battery to the negative lead of the other battery. This allows the current to flow along a single path and essentially doubling the voltage output. The wires are connected to batteries and ESC using 5.5mm bullet connectors. An anti-spark connector is added to the positive wire to allow the system to be disconnected when not in use to avoid battery drainage. The anti-spark component of the connector works by slowing down the amount of current initially able to travel through the circuit via resistors which prevents a large arc from occurring which can damage the electrical components. The BEC is also connected in this section to both the positive and negative wires and then to the receiver. The BEC reduces the voltage from 37V to the 5V capacity of the receiver.

Section 3: Dual Electronic Speed Controller

An electronic speed controller (ESC) is an electrical circuit used to vary an electric motors speed, which is explained in more depth in Chapter 3. One side of the dual ESC contains a positive and negative lead with 5.5mm bullet connectors that joins to the series connector. Three small wires also come from the ESC and are plugged into the receiver to allow the transmitter to send wireless signals to the ESC to control the motors. The other side of the ESC contains six 5.5mm bullet connectors allowing the three wires from each of the motors to be connected. There are also another set of small wires protruding from the battery side of the ESC which are not shown in the diagram. These allow a connection to be made via USB to a computer for the programming of the ESC.

Section 4: Wire Lengths

As the electrical component box is in the middle of the deck and the motors are at each end of the board within the tracks, the standard length wires that come from the ESC and motors are not long enough to be connected. Therefore, an extra six lengths of wire are required. To ensure enough current can pass through the wires, 12amg wires are used which are slightly larger than those coming standard on the motors

Section 5: Motors

Two identical brushless outrunner motors are used that come stock with 4.0mm bullet connectors. These plug into the wire lengths.

5.3.2 Electrical System Installation

The majority of the electrical components are positioned within the Dry Box, with the exception of the motors, part of the motor wire lengths and the hand held controller. The Dry Box provides protection as well as holding the components in place. Figure 23 shows the layout of electrical components within the Dry Box.

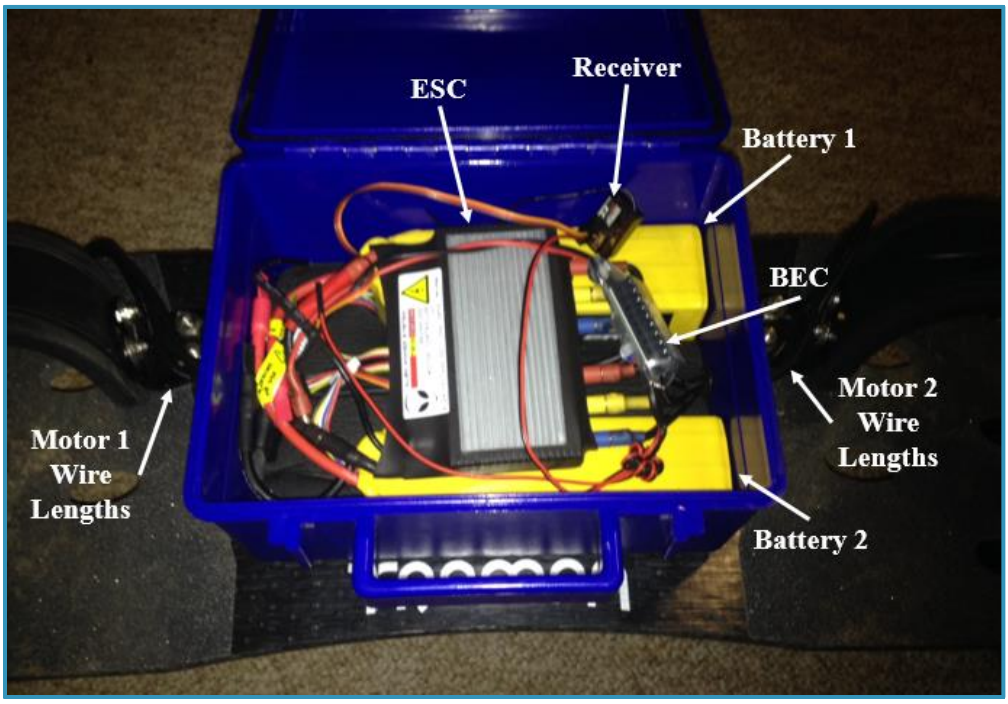


Figure 23: Electrical Layout within Dry Box

6. PROJECT OUTCOMES

6.1 Prototype Board Testing

Once the manufacturing and assembly was completed, initial board testing began. The electrical system was turned on and the Wi-Fi hand controller paired with the ESC and receiver. Once initial connection is achieved, each subsequent time the controller is turned on within range, the receiver emits a blue led light and the ESC lets out a series of 4 beeps after approximately 3 seconds when connection is established. Pulling the trigger of the controller then engaged the motors as intended transferring power along the timing belt to the large pulley. This caused the drive roller to rotate as required, however there was not adequate traction between the roller and tread for the tread to rotate around the tracks as needed. Therefore, while the motors did not stall, the board would not move.

The design incorporated four adjusters on each track for the purpose of tightening the tread as shown in Figure 24. These worked by increasing the distance between the front and rear roller, essentially increasing the area the tread was wrapped around. However, even with this system extended as far as possible the tread did not consistently grip the drive roller and slipping still occurred.

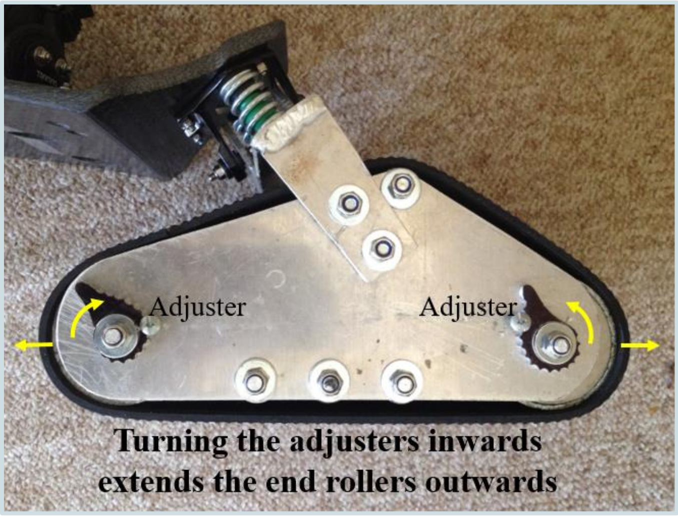


Figure 24: Tread adjustment diagram

To try to further increase friction between the drive roller and tread, the tracks where pulled apart and marine silicone was applied to the outer surface of the drive roller creating a better grip than the aluminium originally provided. This also made the roller slightly larger allowing the tread to be tightened slightly more than at first. This still did not work adequately so the tracks were again pulled apart and CRC belt grip was also applied to the drive roller and tread.

With the tread still not gaining sufficient traction, as the drive roller was continually spinning inside the track, testing the boards speed and other performance characteristics was not possible. Due to time and budget limits other solutions where not feasible, however an alternative design that would provide more traction between the rollers and tread is looked into in Chapter 7.

6.2 Target Requirements

To ensure the board would be both functional and marketable, a list of design specifications where outlined in Chapter 2. The following section discusses how well the prototype board met these specifications.

Dimensions and Weight

Overall the dimension and weight requirements where mostly met, with the exception of the total weight of the board.

The prototype board measured a total of 1275mm long, 264mm wide and 314mm high. This was well within the maximum dimensions allowed of 1400mm long, 350mm wide and 400mm high when fully assembled. These dimensions allow the prototype board to fit within the boot of the average modern car.

The distance between the ground surface and foot bed was 180mm when unloaded and 132mm when loaded with 110kg. This was within the specified range of 120-210mm designed to ensure adequate clearance over objects, whilst not being so high that balance and manoeuvrability where adversely impacted.

The board was designed to be as light as possible whilst still providing adequate strength and functionality. Using the weight specifications given for the premade components and using Autodesk Inventors material properties for the values of weight for the custom designed components, the expected weight of the prototype board was 15.4kg (refer to Appendix C5 for a breakdown of component weights). After the board had been fully assembled, it was placed on a bathroom scale and had a weight reading of 15.8kg. With a target maximum weight of 15kg, the prototype board was overweight by 0.8kg and therefore this specification was not met.

Performance Requirements

As a working prototype could not be fully completed within the timeframe, none of the performance requirements could be achieved. This included the board providing traction on a range of different surfaces, accelerating to a speed of 30km/hr, travelling up a 30° incline from standstill and having a minimum run time of 45minutes or 15km.

Reliability and Maintenance

The target requirements in this category were also not able to be achieved. Testing the board’s ability to withstand moderate impacts when travelling at 30km/hr could not be undertaken due to the prototype not fully functioning.

The maintenance requirement could be partially achieved with the board able to washed down. This was tested by turning off all electrical components, ensuring the dry box lid was shut and then spraying the board with water for a 5 minute duration to wash off any dirt. The electrical system within the dry box remained dry and worked as before the test. The two motors did get wet however they also continued to work as before. None of the mechanical components where effected by the water.

Figure 25: Spraying the board with water

Ergonomic Design

The board was designed to be able to allow riders up to 110kg. Whilst this was not able to be tested sufficiently in terms of its ability to propel the rider via its two electrical motors, the board was ridden downhill by a 93kg rider carrying a 25kg plate. With a total weight of 118kg the board did not seem to experience any structural problems. This test was only done on grass to minimise the chance of injury if the rider fell off while holding onto an additional 25kg and therefore much more testing would be required over different surfaces to properly determine the boards structural integrity.

Another requirement was that the board be adjustable for different sized riders. This was achieved through the ability to easily change the tightness of the foot straps to accommodate different shoe types and sizes. The foot straps worked the same as those used on wakeboards with a ratchet type set-up allowing fast tightening to adequately fix the riders feet in place and a quick release mechanism to loosen the foot strap to enable the feet to be removed.

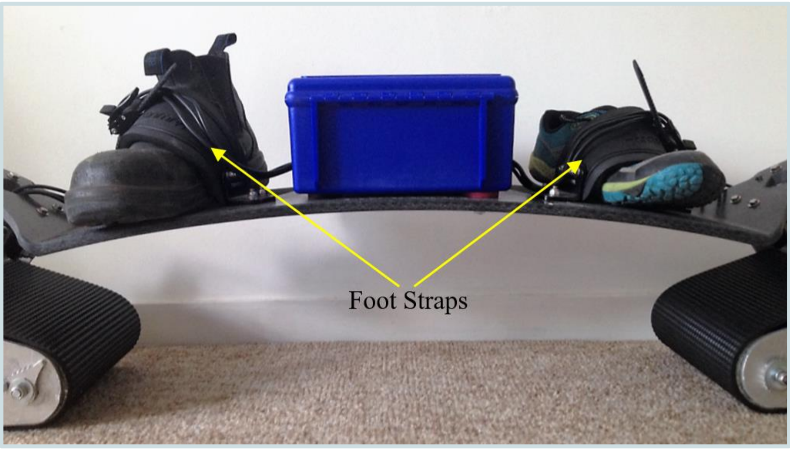


Figure 26: Foot straps can be tightened differently depending on shoe type and size

The ability to turn via weight transfer was achieved through the truck design, which was very similar to that of a regular mountain board. As the board did not accelerate as required, trial runs where done by going downhill and using gravity to propel the board, allowing the feel and manoeuvrability of the board to be tested. Due to the additional foot bed height and the tracks having less width than a traditional mountain board setup with tyres, the prototype board was less stable. This meant that you could not lean as far out as you would on a traditional board to make tight corners however reasonably sized turns could still be made with both tracks in contact with the ground. For tighter corners, the front track could be lifted and the rear track screwed however this took much more skill and also required a fair amount of strength due to the additional weight of the tracks and electrical system.

The original idea in regards to carrying the board was to attach a padded shoulder strap attached to U bolts at the nose and tail ends of the board deck. However, as the board was fairly heavy the easiest way to carry or move the board while walking was to simply grab the hanger at one end, lift the end up, and then walk along as shown in Figure 27. This negated the need to lift the full weight of the board, with the majority of the weight instead on the track in contact with the ground. This method allows the tread with ground contact to rotate around the track as it typically would when being ridden, only this time with the propulsion force coming from the rider instead of the electric motors.

Figure 27: Carry method

To ensure the batteries don’t get prematurely damaged, the ESC is programmed to shut off once each battery cell reaches 3V (30V for complete setup). The theoretical time calculated for the batteries to charge from 3V to their maximum voltage of 3.7V was 3hrs (refer to Appendix C3). To test this the batteries where discharged to 3V per cell and then charged back to 3.7V per cell. The actual test charge time of approximately 3hrs 10mins was similar to what was expected, being much less than the maximum charge time of <5hrs specified in the design requirements. Charging the batteries did require removing them from the dry box and disconnecting them from the ESC. While this was straightforward, being able to charge them without having to remove or disconnect anything would be beneficial for increased simplicity.

Figure 28: Balance charging a single LiPo 5S battery

Safety

The safety requirements of the board included the ability to program the ESC to set maximum speeds and change performance along with incorporating an adequate breaking system. Both these requirements where incorporated into the design and manufacture of the prototype board however their capabilities could not be fully tested as the board did not run as required.

The ESC was programmable through connection to a computer via a USB cord and then using APS ESC software. The software allowed a number of settings to be modified including:

- Battery type selection,
- The cut-off voltage to ensure the LiPo batteries didn't fully discharge and become damaged,
- The throttle curve (logarithmical, linear or exponential) which had a direct impact on the effect on the amount of trigger movement on the handheld controller,
- The acceleration (soft, medium or hard),
- Braking percentage (0-100%) which effected how hard the motors braked, and
- The motor timing degrees and pulse width modulation (PWM), which allowed slight performance adjustments to be made.

However, the extent to which these variables effected the motor output and overall ride could not be fully realised due to the board not being fully functional.

Price

The total cost of components and manufacturing came to $1923.17, slightly below the target maximum of $2000. This price does not include a price for labour except in cases such as the welding of the hanger which had to be outsourced and could not be completed by myself. As the board does not yet properly work, more funds would be needed to slightly change some of the components such as the drive roller.

7. FUTURE CHANGES AND RECOMMENDATIONS

7.1 Reflection on Problems Encountered

Throughout the duration of the project, many problems and complications where encountered.

During the initial stages of design, a small 2-stroke combustion engine was planned as the means of powering the board. This was going to involve a pair of telescopic drive shafts with universal joints connected at each end to drive the tracks. However, this idea fell through after a considerable amount of time was spent trying to source a motor that would be suitable and coming up with nothing. An electrical power system was eventually deemed a better choice due to significant advantages in terms of noise and local pollution.

After the design stages of the board had been completed and it was time to begin ordering components to build the board it was discovered that the VESC which had been intended for use was out of stock and on a 4-month backorder. This was due to a massive increase in DIY skateboard enthusiasts within the last year and the VESC being a fairly recent design specifically tailored to electric skateboards and only available from two manufactures worldwide. Before the introduction of the VESC, DIY electric skateboard builders had been mainly using high amperage model car ESC's which was eventually chosen for the project. Although these work, they require more programming than the VESC to be 'skateboard ready' and thus more time than expected went into the coding of the ESC.

As the majority of parts where sourced from overseas manufactures due to reduced prices and supply, shipping times where often extensive and in some cases longer than expected. One such instance that involved a very lengthy turnaround was for the two timing belts that connect the motor and drive pulleys. Due to the unavailability in Australia of the specific size and dimensions required for the belts to fit seamlessly with the pre-purchased pulleys the belts where ordered online from a company in Hong Kong. Shipping was three weeks which had been factored for however when the belts arrived they were not to the measurements ordered. Therefore, emails where sent to the company explaining this mishap and the company acknowledged their mistake and sent the right sized belts through. This however required another three weeks of postage time ultimately delaying the completion and testing of the board by a few weeks. To prevent the problems related around shipping, items should have been ordered well in advance.

Aluminium supplies for the custom track and hanger components were purchased locally over the mid-year university holidays. While most of the stock tubing and plate required for the build were available, the 8mm thick aluminium plate that was to be used for the hanger was not in stock anywhere in Armidale where the majority of the board was built. This reduced the options to using either 5mm plate or 10mm plate. In the end the 5mm plate was decided on due to it being much cheaper, lighter and a lot easier to cut and shape.

Once the board was completed, testing showed that there wasn't adequate friction between the drive roller and tread. While different methods to try and fix this essential issue where tried, they were not sufficient. This resulted in the board being unable to be powered by the motors which limited testing to strictly downhill runs where gravity provided the acceleration force.

7.2 Suggested Improvements for Board Performance

With the main determinant stopping the prototype board from performing as designed being the loss of traction between the drive roller and tread, modification is required. An effective way to increase friction in this area would be to incorporate lugs on the rollers as shown in Figure 29. The tread would then also need to incorporate lugs that mesh into the grooves on the drive roller (such as those on a timing belt). The other rollers would also require lugs. This would also help keep the tread aligned and synchronized, reducing stretching when making turns on the board. This design change would incur a higher cost and be much more difficult to manufacture which is why it was not adopted in my original design however is very likely to resolve the problem.

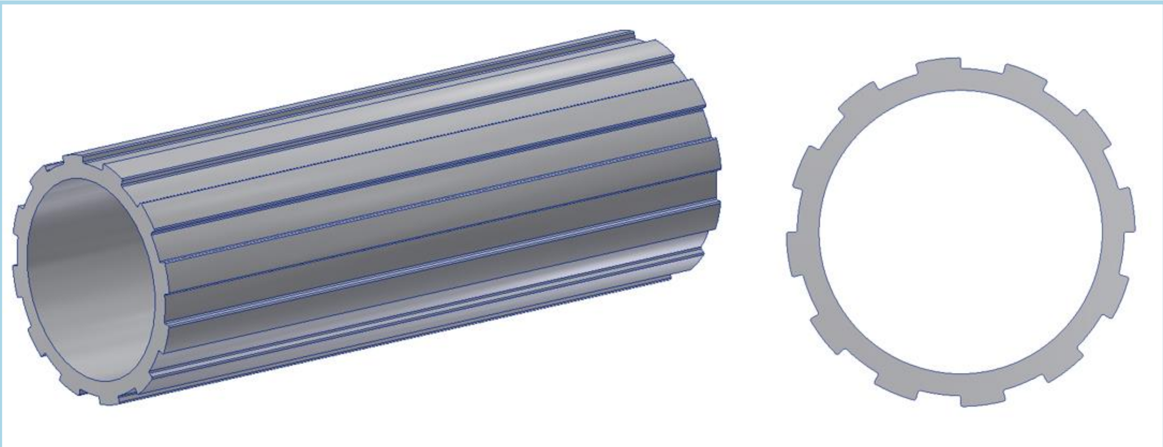


Figure 29: Roller showing lug design (orthogonal and side view)

Figure 30: Tread with lugs matching roller design (orthogonal and side view)

If the tread successfully grips the rollers as required, it is likely that other problems may be experienced as the force is then transferred to the rest of the system. The next weakest link in the chain being the timing belt.

The timing belt provides a positive drive without slippage, limited only by the tensile strength of the belt and the shear strength of the teeth. According to the specifications provided by the manufacture, the neoprene and fiberglass 12mm wide HTD5 timing belt used in the design of the board has a specified allowable working tension of 215N.

At the motors maximum speed, the motor pulley will be spinning at 9065RPM and producing a tensile force of 205N on the belt which is less than the specified working tension and therefore the belt should be adequate (for motor torque and linear force calculations refer to Appendix C4).

If the force on the timing belt is found to be greater in use than the theoretical value calculated and the belt fails, a stronger and wider HTD timing belt would need to be incorporated or GT2 synchronous belt options could be explored. Other options would be to change to either spur gears or chain drive however these alternatives would require more major modifications to be made.

There are a number of other potential design changes that could be incorporated to optimise the board feel and performance.

Figure 31: Motorbike "paddle" tyre design (Sedona tire & wheel, c2016)

While the prototype board was only tested going downhill on grass and dirt surfaces, it is likely that different tread designs would benefit the board depending on the terrain. For example, if riding in sand dunes, using a tread paddle design similar to those used on motorbikes for similar situations would provide the board with much more traction in that situation. Therefore, having different tread patterns that are easily interchangeable could be a beneficial design option.

Testing the board over different terrains using different sized tracks could also help determine the optimal track size to maximise the boards ability to traverse soft terrain whilst minimising weight and cost.

Having the base of the tracks be completely flat proved to increase the difficulty of lifting one track off the ground to make tight turns during the test run. Using a design with a slightly curved base as shown in Figure 32 would likely reduce this problem and increase ease of manoeuvrability.

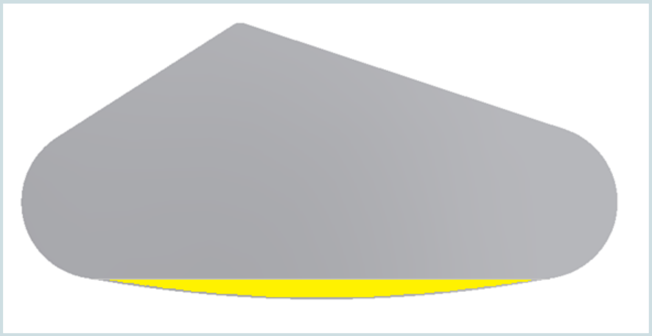


Figure 32: Sidewall showing added curved base in yellow

As the tracks are much narrower than the position of standard mountain board wheels, leaning too far out caused the tracks to lift up on one side. By using softer spring in the trucks greater lean would be possible before this occurs leading to an easier and more enjoyable ride.

For optimal performance and efficiency, the custom components would need to be built to much higher tolerances than those that were achieved during manufacture with the limited tools and experience available.

8. CONCLUSION

The design, manufacturing and testing of a prototype board have been presented and results discussed in this report. The prototype is based around a mountain board deck and incorporates dual tracks each containing a brushless electric outrunner motor. The motors are connected to a battery pack positioned in the middle of the deck and protected by a dry box.

The major design phases of the project were completed by the 5th of May 2016, with the procurement of parts beginning thereafter. Manufacturing of custom parts including the tracks, hanger and some electrical components where undertaken during the procurement stages as the necessary materials arrived. A variety of problems were encountered associated with the ordering and obtaining of the required components with some items out of stock or unavailable. This caused minor changes in the original design. A major setback of approximately three weeks was incurred when the synchronous belts which were ordered from China arrived and were the wrong size. Due to the uncommon belt width required to match the chosen pulleys, ordering from other suppliers with quicker shipping times would have been much more expensive so the belts were returned and replacement belts sent again from the same factory.

The original assembly of the prototype board was completed on the 22nd of August 2016, however initial tests found the drive roller slipping within the tread resulting in the tracks needing to be disassembled. A few methods were developed to try and overcome this problem without drastically changing the design including covering the drive roller with marine silicon to increase friction and also using CRC belt grip. These methods did not work effectively however and due to time and budget restraints a fully working prototype was not achieved. Incorporating lugs on the outside of the rollers and inside of the tread are likely to fix this problem and would be a recommended design change.

As the board was unable to be effectively powered by the motors, board manoeuvrability was tested by going downhill with the aid of gravity. It was found that while wide turns could be made, tight corners were difficult to achieve. Using softer springs and changing the track design to achieve a slightly curved bottom are likely to improve this aspect and are recommended for further prototypes.

The board had overall dimensions of 1275mm long, 264mm wide and 314mm high and a total weight of 15.8kg. The total cost of the prototype board was $1924.

It is believed if the above recommendations are implemented, a fully functional tracked electric mountain board is expected and could be a viable option in the future for riders wanting to be able to traverse a wider range of terrains whilst still having the performance characteristics and manoeuvrability of a standard mountain board.

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10. APPENDICES

Appendix A – Complete Parts List

A1. Track Parts List

TRACK PARTS LIST				
ITEM NO.	**PART NO.**	**DESCRIPTION**	**MATERIAL**	**QTY.**
1	SPLA1	SIDE PLATE, CUSTOM, T5	ALUM	2
2	SPLA2	SIDE PLATE, CUSTOM, EXTRA HOLES, T5	ALUM	2
3	AXLE1	AXLE, SOLID, CUSTOM, D12, L254	ALUM	8
4	AXLE2	AXLE, SOLID, CUSTOM, D12, L264	ALUM	2
5	AXLE3	AXLE, SOLID, CUSTOM, MALE, D12, L147	ALUM	2
6	AXLE4	AXLE, SOLID, CUSTOM, FEMALE, D12, L132	ALUM	2
7	ROLL1	ROLLER, HOLLOW, CUSTOM, OD25, ID19, L218	ALUM	8
8	ROLL2	ROLLER, HOLLOW, CUSTOM, OD75, ID69, L218	ALUM	2
9	ROLL3	ROLLER, HOLLOW, CUSTOM, OD75, ID69, L102	ALUM	2
10	ROLL4	ROLLER, HOLLOW, CUSTOM, OD75, ID69, L100	ALUM	2
11	ADJU1	ADJUSTER, CUSTOM, T3	ALUM	8
12	SPUL1	PULLEY, W12, 15T, P5, ID8	STEEL	2
13	LPUL1	PULLEY, CUSTOM, W12, 36T, P5, ID8	NYLON	2
14	BELT1	TIMING BELT, 12W, 100T, P5	RUBBER	2
15	MOTR1	BRUSHLESS OUTRUNNER MOTOR, 274KV	-	2
16	MSHA1	MOTOR SHAFT, CUSTOM	SSTEEL	2
17	MBLT1	MOTOR BOLTS, COUNTERSUNK, M4, L10	SSTEEL	8
18	BRNG1	BEARING, BALL, MTL, SEALED, OD22, ID8, W7	-	26
19	WSHR1	SPEED WASHER, OD10, ID8, T2	SSTEEL	24
20	WSHR2	WASHER, M8, OD15	SSTEEL	24
21	WSHR3	WASHER, CUSTOM, OD70, ID22, T7	ALUM	8
22	WSHR4	WASHER, CUSTOM, W/HOLES, OD70, ID22, T7	ALUM	4
23	NNUT1	NYLOC NUT, M8, 1.25	SSTEEL	24
24	DROD1	DRIVE ROD, SOLID, CUSTOM, D4, L30	ALUM	8
25	AROD1	ADJUSTMENT ROD, CUSTOM, D4, L9	SSTEEL	8
26	TRAC1	TRACK	RUBBER	2

A2. Hanger Parts List

HANGER PARTS LIST				
ITEM NO.	PART NO.	DESCRIPTION	MATERIAL	QTY.
27	HANG1	HANGER, CUSTOM, T8	ALUM	2
28	CBOL1	BOLT, COUNTERSUNK, M8, L18	SSTEEL	8
29	CBOL2	BOLT, COUNTERSUNK, M4, L12	SSTEEL	4
30	WSHR5	WASHER, M8	SSTEEL	16
31	NNUT2	NYLOC NUT, M8	SSTEEL	8
32	NNUT3	NYLOC NUT, M5	SSTEEL	2
33	SADJ1	SPRING ADJUSTER	SSTEEL	4
34	SRET1	SPRING RETAINER	PLASTIC	8
35	DAMP1	DAMPA	RUBBER	4
36	SPNG1	SPRING	SSTEEL	4
37	BPLA1	BASEPLATE	ALUM	2
38	KPIN1	KINGPIN	TITANIUM	2
39	BSHG1	BUSHING	PLASTIC	8

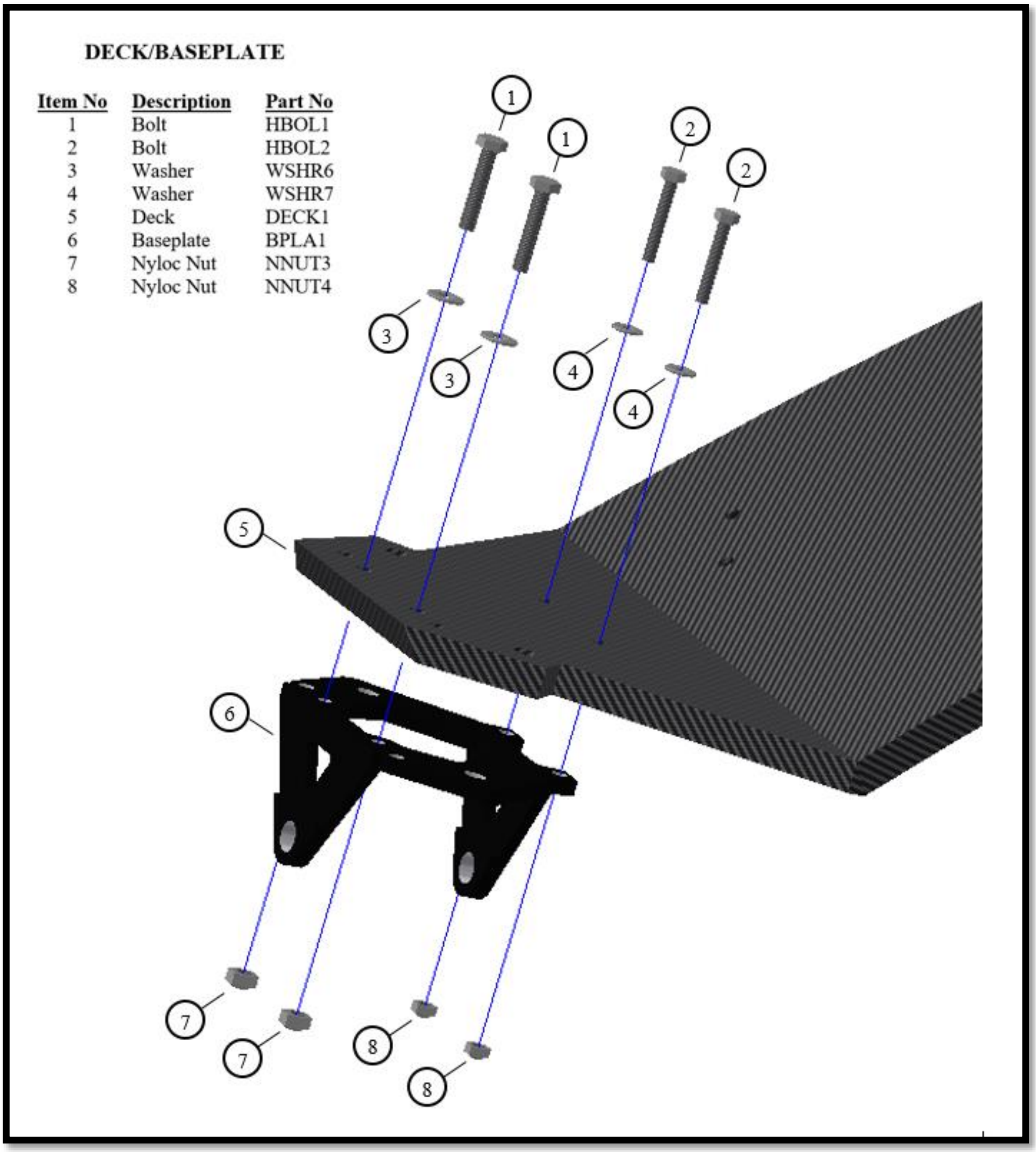
A3. Deck Parts List

DECK PARTS LIST				
ITEM NO.	PART NO.	DESCRIPTION	MATERIAL	QTY.
40	DECK1	DECK, TRAMPA HOLYPRO	GLASS/PLASTIC	1
41	FSTP1	FOOTSTRAP	FOAM	2
42	LSTP1	LADDER STRAP	PLASTIC/FOAM	2
43	LBRK1	L BRACKET	ALUM	4
44	RATC1	RATCHET	ALUM/PLASTIC	2
45	SFAS1	FASTENER, STAR	SSTEEL	2
46	CBOL3	BOLT, COUNTERSUNK, M5, L8	SSTEEL	2
47	DBOL1	BOLT, DOME, M5, L20	SSTEEL	8
48	WSHR6	WASHER, M5	SSTEEL	12
49	NNUT3	NYLOC NUT, M5	SSTEEL	12
50	HBOL1	BOLT, HEX, M5, L30	SSTEEL	4
51	HBOL2	BOLT, HEX, M4, L30	SSTEEL	4
52	NNUT4	NYLOC NUT, M4	SSTEEL	4
53	WSHR7	WASHER, M4	SSTEEL	4
54	WSH8	WASHER, M8	RUBBER	6
55	UBOL1	U BOLT	SSTEEL	2
56	STRP1	SHOULDER STAP	NYLON/NEOPRENE	1
57	DBOX1	DRY BOX	PLASTIC	1

A4. Electrical Parts List

ELECTRICAL PARTS LIST				
ITEM NO.	**PART NO.**	**DESCRIPTION**	**MATERIAL**	**QTY.**
58	LBAT1	BATTERY, LIPO, 5000MAH	-	4
59	DESC1	ESC, DUAL, 150A	-	1
60	SBEC1	SBEC, 20A	-	1
61	WCON1	CONTROLLER, WIRELESS, 2.4GHZ	-	1
62	WREC1	RECIEVER, WIRELESS, 2.4GHZ	-	1
63	WSLE1	WIRE SLEEVE, 6M	PET	1
64	ACON1	CONNECTOR, ANTI SPARK	-	1
65	BCON1	CONNECTOR, BULLET, FEMALE, 4MM	STEEL	6
66	WIRE1	WIRE, 12AWG, 1M	COPPER/PLASTIC	6
67	CHRG1	CHARGER, LIPO, DC	-	1

Appendix B – Autodesk Inventor Drawings

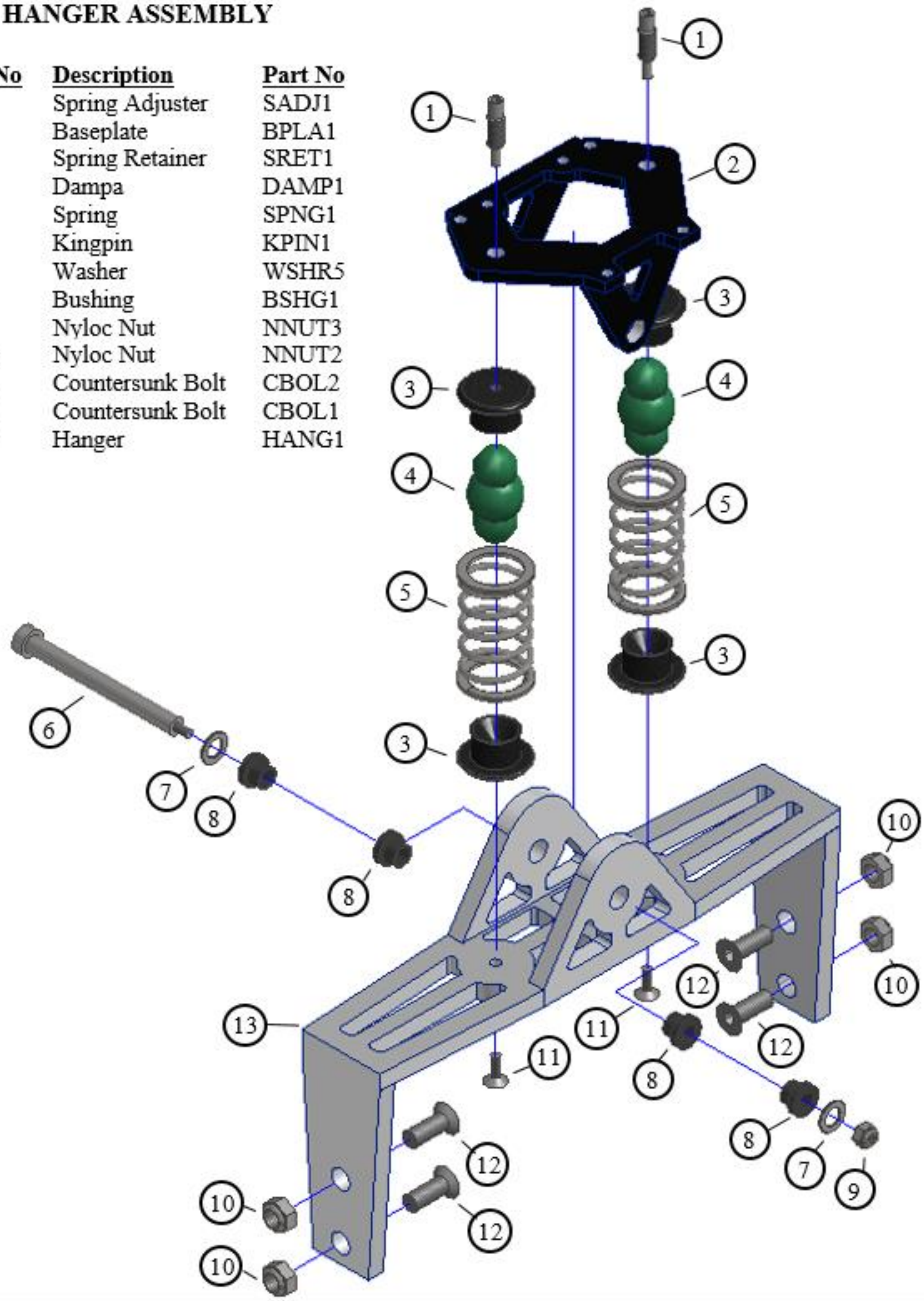


DECK/BASEPLATE

Item No	Description	Part No
1	Bolt	HBOL1
2	Bolt	HBOL2
3	Washer	WSHR6
4	Washer	WSHR7
5	Deck	DECK1
6	Baseplate	BPLA1
7	Nyloc Nut	NNUT3
8	Nyloc Nut	NNUT4

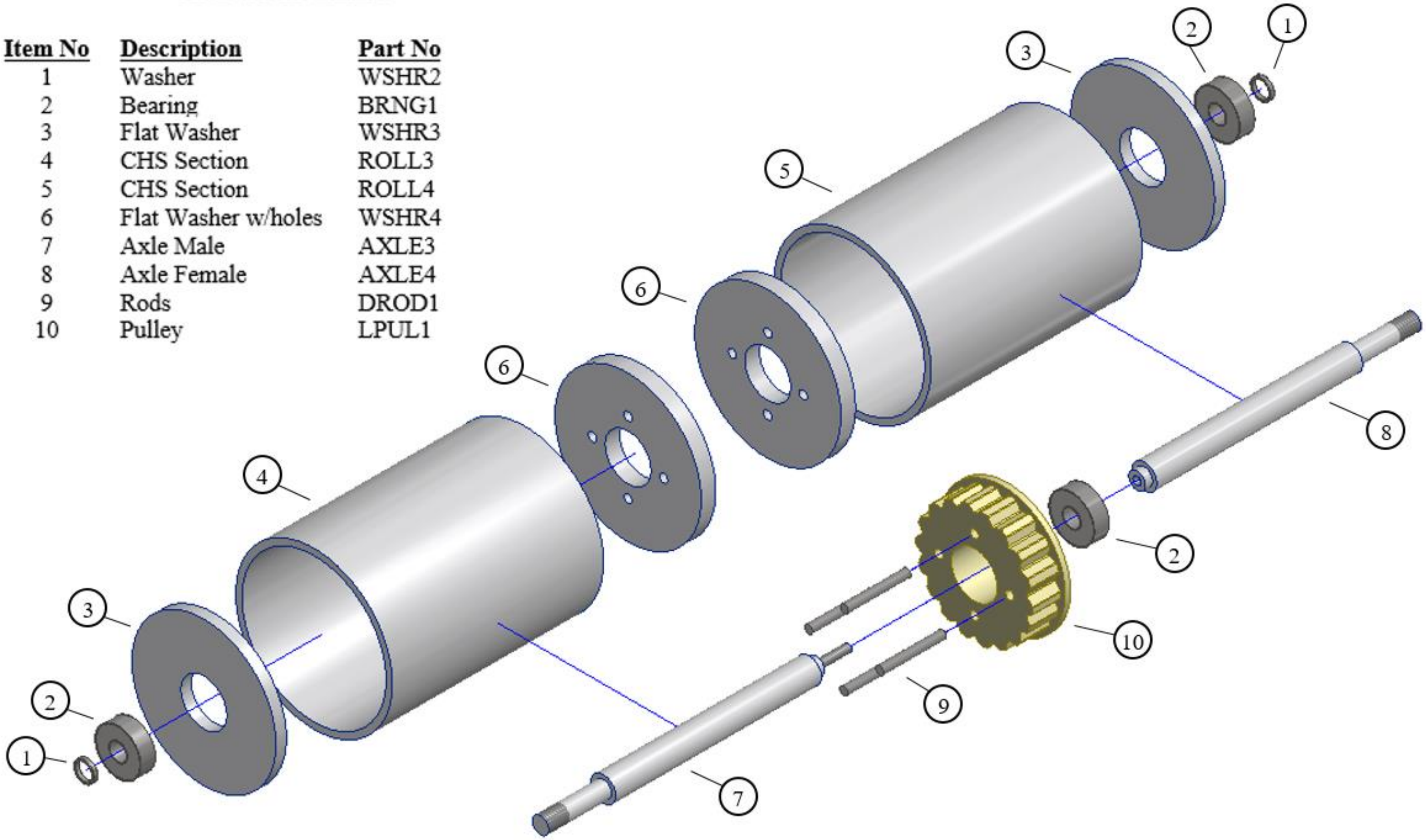
HANGER ASSEMBLY

Item No	Description	Part No
1	Spring Adjuster	SADJ1
2	Baseplate	BPLA1
3	Spring Retainer	SRET1
4	Dampa	DAMP1
5	Spring	SPNG1
6	Kingpin	KPIN1
7	Washer	WSHR5
8	Bushing	BSHG1
9	Nyloc Nut	NNUT3
10	Nyloc Nut	NNUT2
11	Countersunk Bolt	CBOL2
12	Countersunk Bolt	CBOL1
13	Hanger	HANG1



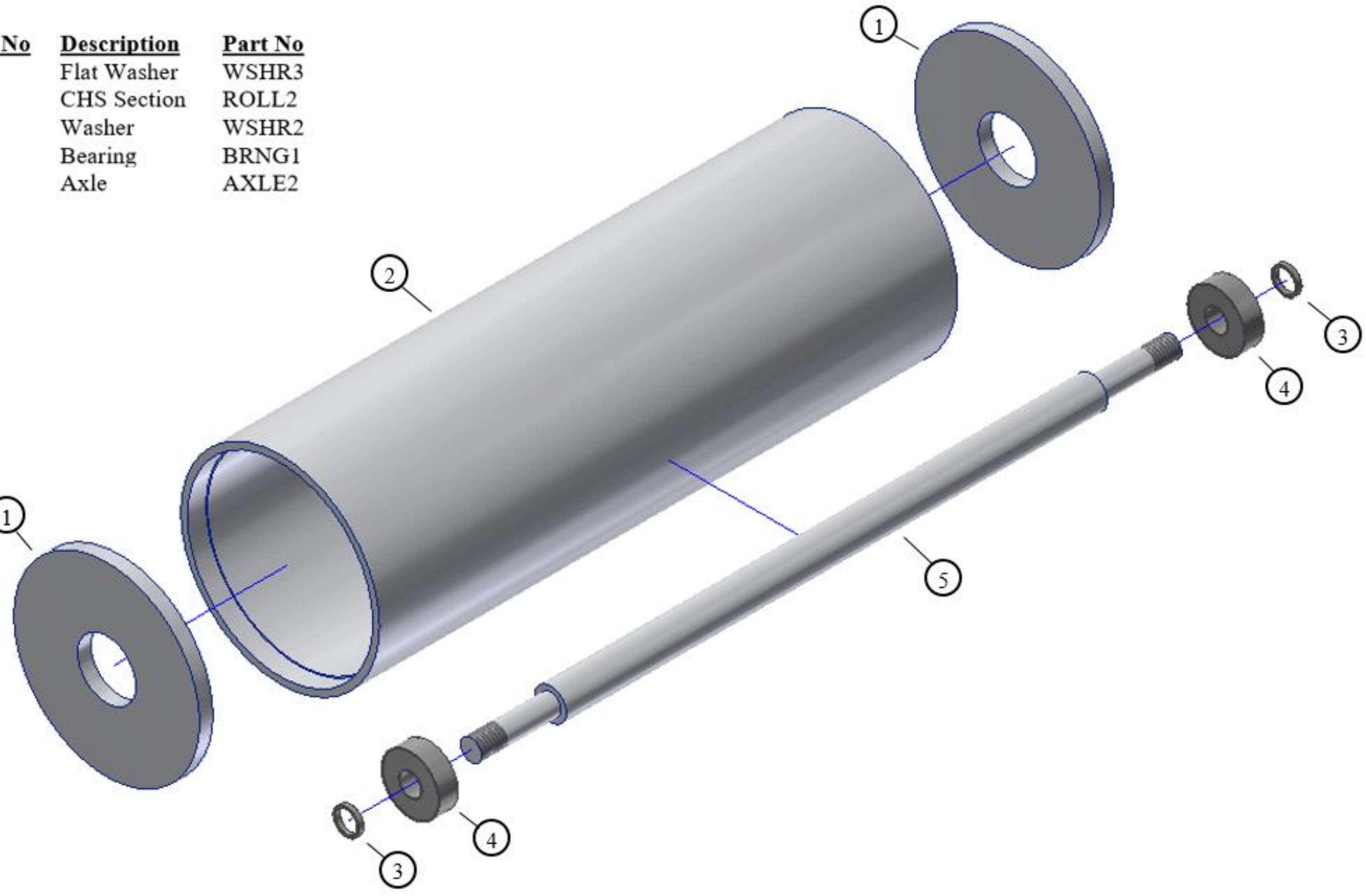
DRIVE ROLLER

Item No	Description	Part No
1	Washer	WSHR2
2	Bearing	BRNG1
3	Flat Washer	WSHR3
4	CHS Section	ROLL3
5	CHS Section	ROLL4
6	Flat Washer w/holes	WSHR4
7	Axle Male	AXLE3
8	Axle Female	AXLE4
9	Rods	DROD1
10	Pulley	LPUL1



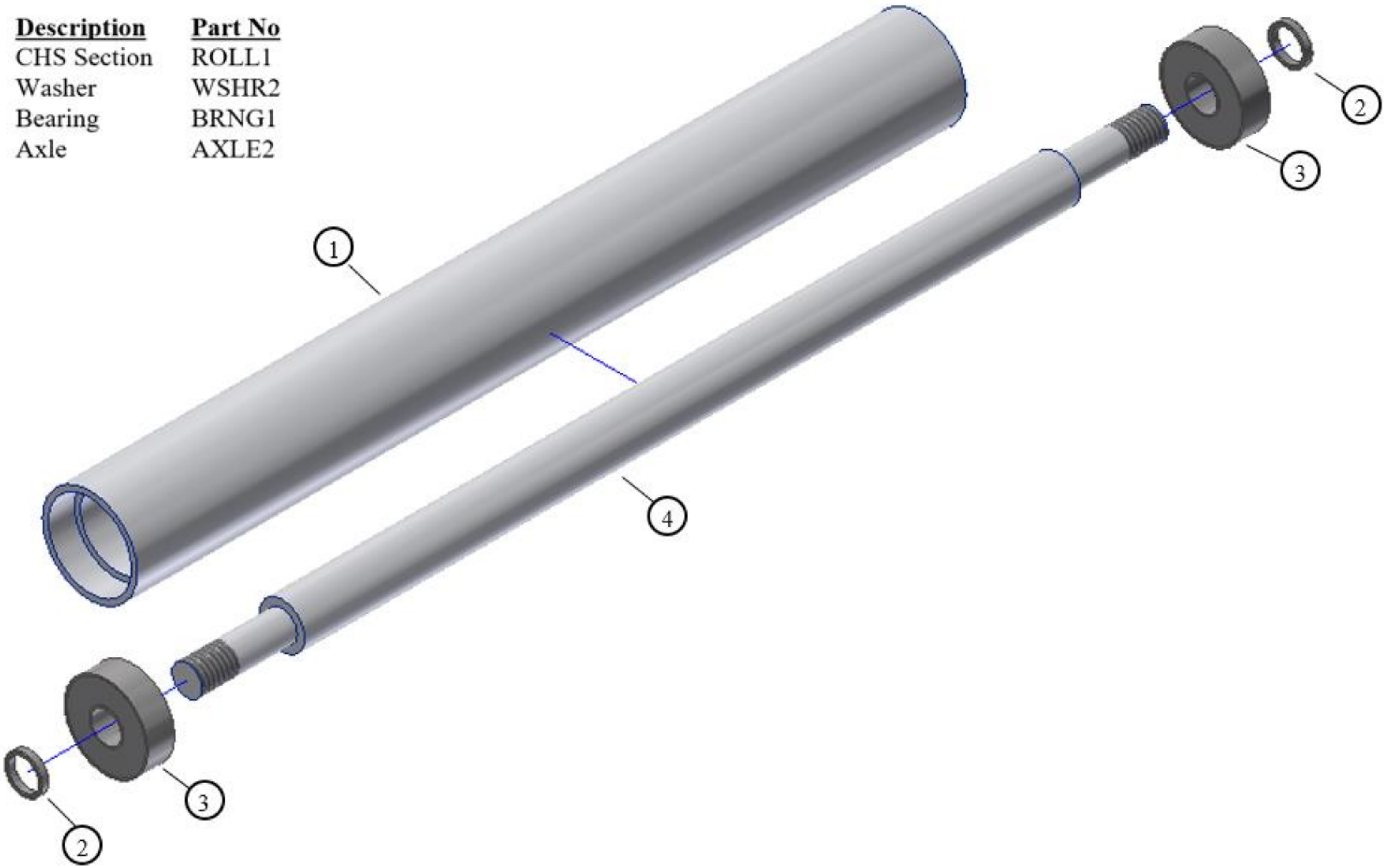
LARGE ROLLER

Item No	Description	Part No
1	Flat Washer	WSHR3
2	CHS Section	ROLL2
3	Washer	WSHR2
4	Bearing	BRNG1
5	Axle	AXLE2



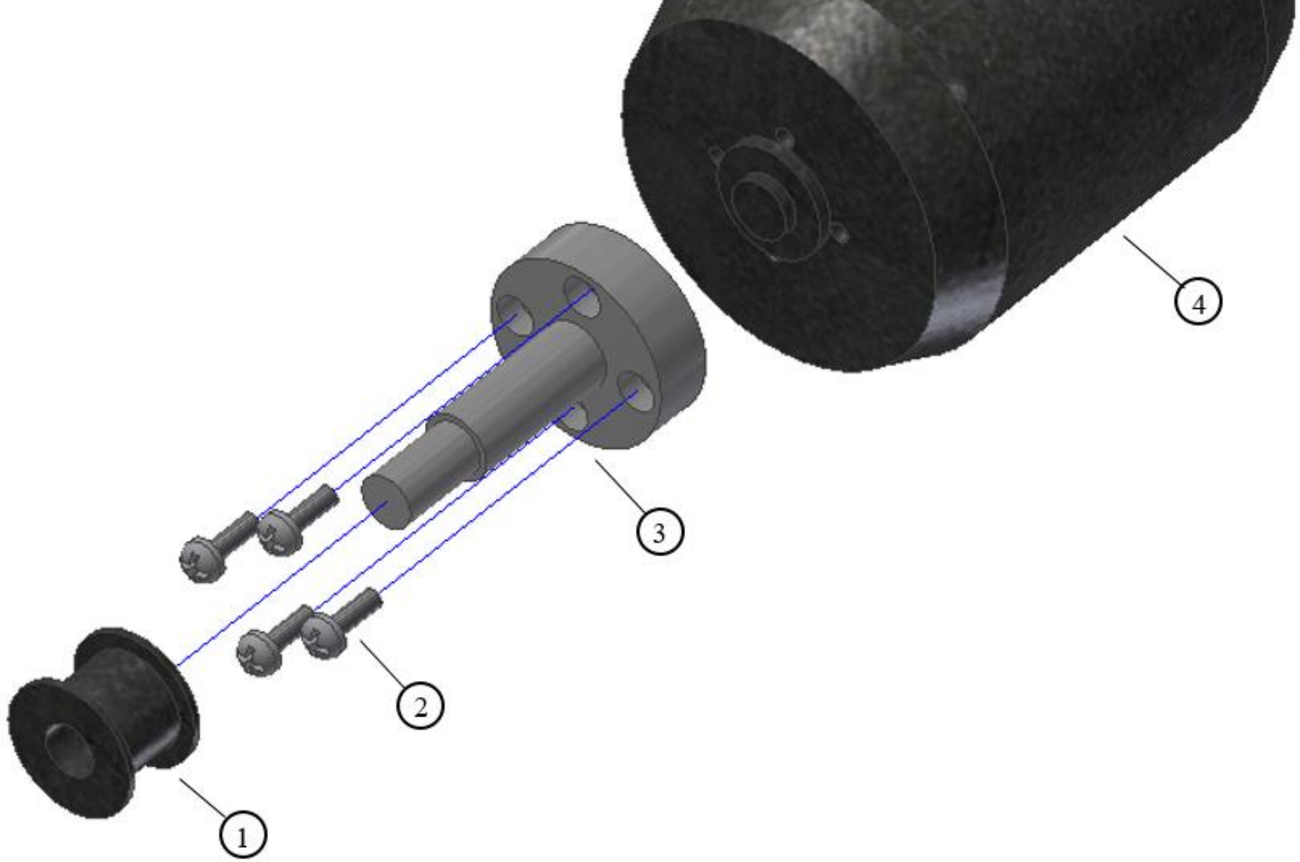
SMALL ROLLER

Item No	Description	Part No
1	CHS Section	ROLL1
2	Washer	WSHR2
3	Bearing	BRNG1
4	Axle	AXLE2



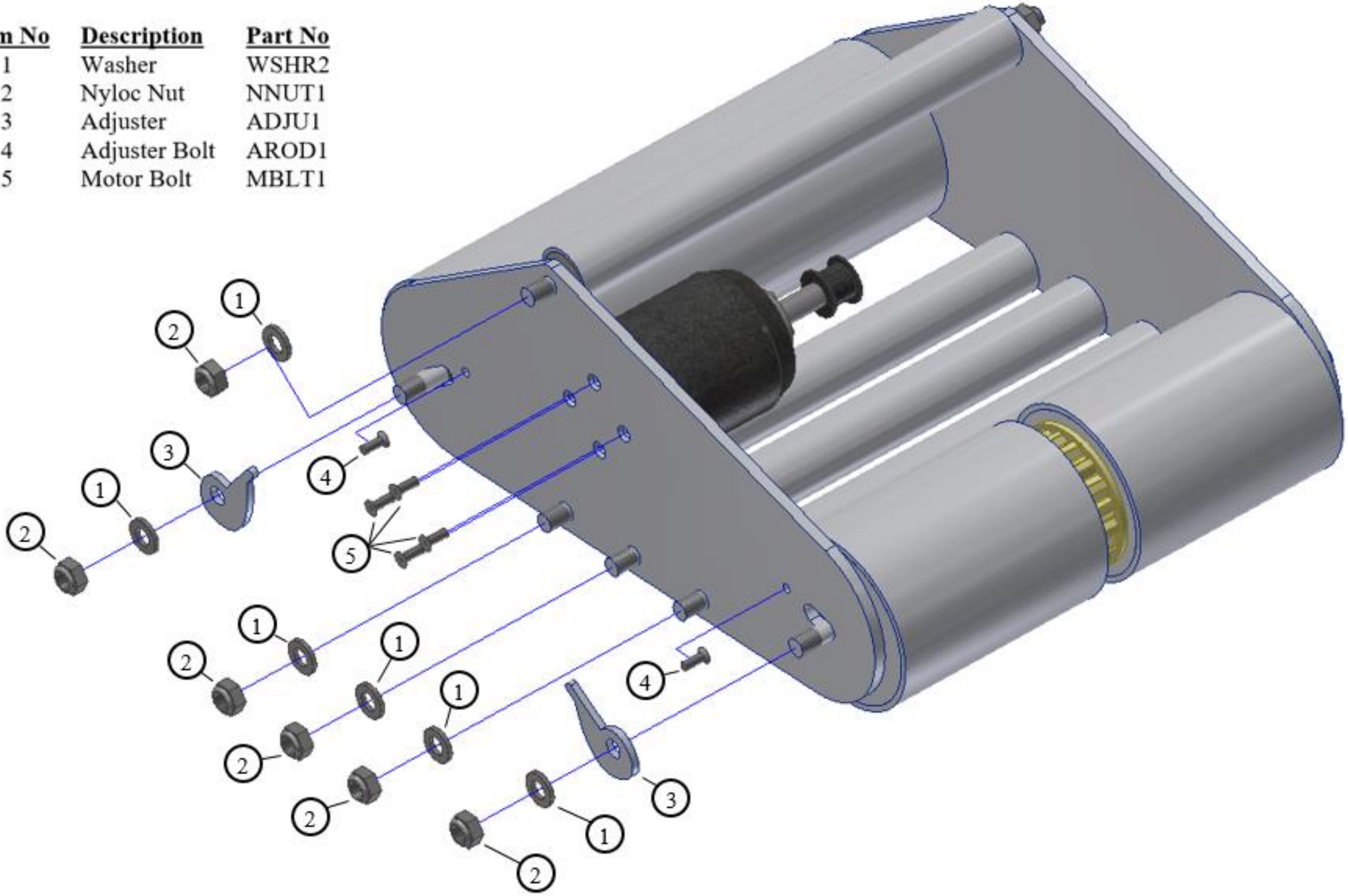
MOTOR

Item No	Description	Part No
1	Pulley	SPUL1
2	Bolts	MBLT1
3	Shaft	MSHA1
4	Motor	MOTR1



SIDEPLATE

Item No	Description	Part No
1	Washer	WSHR2
2	Nyloc Nut	NNUT1
3	Adjuster	ADJU1
4	Adjuster Bolt	AROD1
5	Motor Bolt	MBLT1



Appendix C – Calculations

C1. Theoretical Top Speed

$$Motor\ KV\ =\ 245(motor\ specs)$$

$$Battery\ Cells\ =\ 10\ (battery\ specs)$$

$$Volts\ =\ 10\ cells\ *\ 3.7V\ =\ 37V$$

$$Assumed\ Load\ Factor = 80\%$$

$$Motor\ Speed\ = 0.8 * Volts * Motor\ KV = 0.8 * 37 * 245 = 7252rpm$$

$$Big\ Pulley\ Teeth\ =\ 36$$

$$Small\ Pulley\ Teeth\ =\ 15$$

$$Drive\ Ratio\ = \frac{Small\ pulley\ teeth}{Big\ pulley\ teeth} = \frac{15}{36} = 0.417$$

$$Diameter\ of\ Large\ Roller = 0.075m$$

$$Circumference\ of\ Large\ Roller = Diameter\ of\ Large\ Roller * \pi = 0.2355m$$

$$Top\ Speed = \frac{Circumference\ of\ Large\ Roller * Drive\ Ratio * Motor\ Speed * 60}{100}$$

$$\therefore Top\ Speed = 0.0002355km * 0.417 * 7252rpm * 60 = 42.7km/hr$$

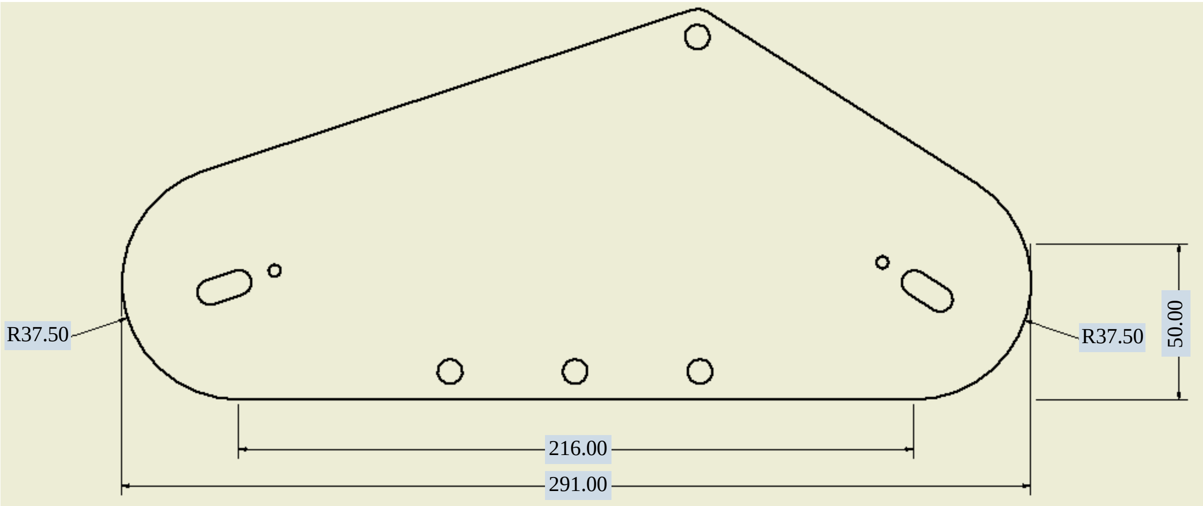
So with this set up, a theoretical maximum velocity of 42.7km/hr is achievable with no external motor load.

C2. Surface Area In Contact With Ground

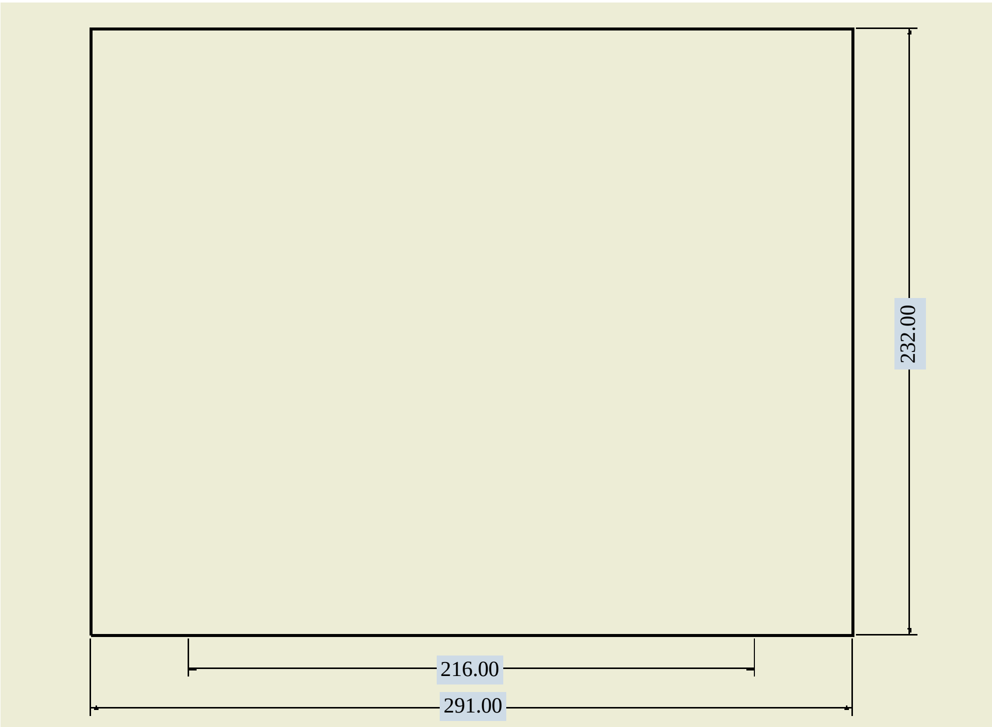
To calculate surface area in contact with ground at different depths the shape was calculated using the computer program Autodesk Inventor. For the tracks the surface area was multiplied by two to accommodate for the front and rear track. For the rubber tyres the surface area was multiplied by four to give the total surface area in contact with the ground.

Track:

Side View:



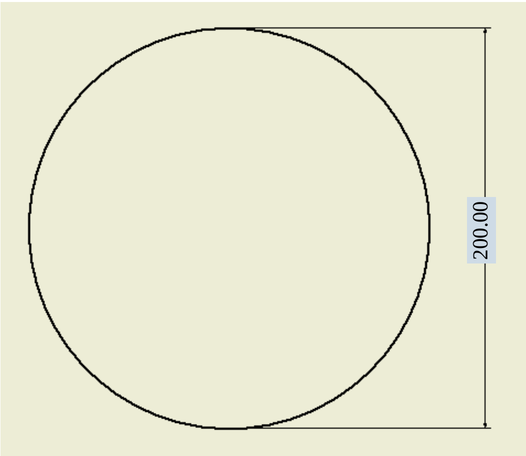
Top View:



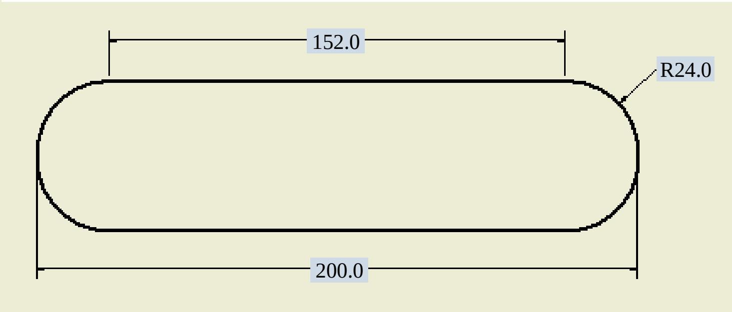
Depth (cm)	Total Surface Area (cm^2)	Notes
0	1002.24	At 4 cm tracks would begin to dig downwards as the ground surface would be slightly above the point at which the track turns backwards. Therefore, transitioning in depths of over 3.75cm would result in the board possibly becoming more ‘stuck’.
1	1262.38	
2	1379.90	
3	1478.78	
4	1572.08	
5	1667.14	

8” Rubber Tyre:

Side View:



Top View:



Depth (cm)	Total Surface Area (cm^2)	Notes
0	25.13	Theoretically there will be minimal ground contact. However, with the rider standing on the board and compressing the tyres somewhat there will be some contact with the ground. Once the depth into the ground reaches above the convex part of the tyre, the other surface area in contact with the tyres will be pushing from the side and actually hinder its ability to move. Therefore, the surface area touching the flat sides of the tyres has not been included in the calculations.
1	125.76	
2	257.92	
3	379.72	
4	468.52	
5	545.16	

C3. Charge Time

Battery specified maximum charge rate of 5C and capacitance of 5000mAH.

$$Max\ Charge\ Rate = 5C = 5 * 5000mAH = 25000mAH = 25AH$$

Charger specified maximum charge rate of 20AH.

Charging at maximum rate is not advised as it can lead to reduced battery life. Therefore, a much lower charge rate of 1.25AH (1/4C) will be used.

The batteries are connected in series and parallel giving a total maximum capacitance of 10000mAH at 37V. The charger is only able to handle a maximum one 6S battery at a time, therefore the four batteries will be charged separately. This gives a maximum capacitance of 5000mAH at 18.5V per battery.

The ESC is programmed to shut off when the voltage of the batteries combined reaches 30V to preserve battery life. This equates to 15V per battery.

At 15V, assuming capacitance decreases linearly with voltage drop, capacitance of a single battery will be:

$$\frac{5000mAH}{18.5V} * 15 = 4054.05mAH$$

The difference in capacitance between full charge and cut off is therefore:

$$5000mAH - 4045.05mAH = 954.95mAH = 0.95AH$$

At a 5AH charge rate, the time required to charge a single battery from 15V to 18.5V is:

$$\frac{0.95AH}{1.25AH} = 0.76hrs\ (\sim 45mins)$$

As there are four batteries this equates to a total charge time of approximately 3hrs (180mins).

C4. Timing Belt Selection

Motor Specifications:

Max Voltage	37V (10S LiPoly)
RPM/V	245KV
Internal Resistance	0.018 Ω
Max Loading	70A
Max Power	2700W

Torque changes with speed. Maximum torque occurs in brushless outrunner electric motors at stall.

Using Ohm's Law, which states that applied voltage is directly proportional to the current through the conductor:

$$I = \frac{V}{R} = \frac{37V}{0.018\Omega} = 2055.55A$$

However, it states that the max loading is 70A.

Power in, is given by the formula:

$$P_{in} = I * V = 70A * 37V = 2590W$$

To achieve the maximum power of 2700W stated, the motor would need over 100% efficiency. As this is impossible an 90% efficiency rating is assumed:

$$P_{out} = 0.9 * P_{in} = 2331W$$

Maximum RPM of motor shaft:

$$\frac{245rpm}{V} * 37V = 9065rpm$$

The angular speed is given by:

$$\omega = rpm * \frac{2\pi}{60} = (245 * 37) * \frac{2\pi}{60} = 949.285rad/s$$

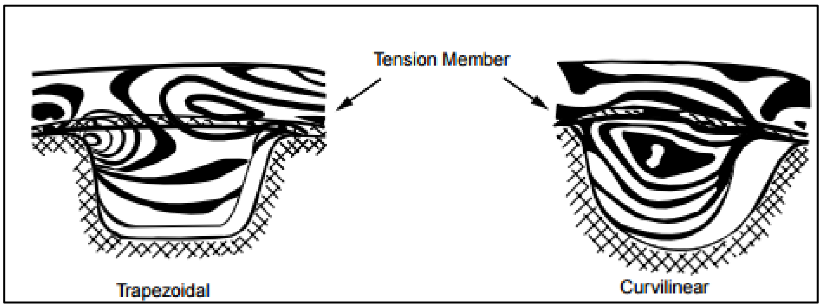
Power out, is also directly related to torque and motor speed as given by the following equation:

$$P_{out} = \omega * T$$

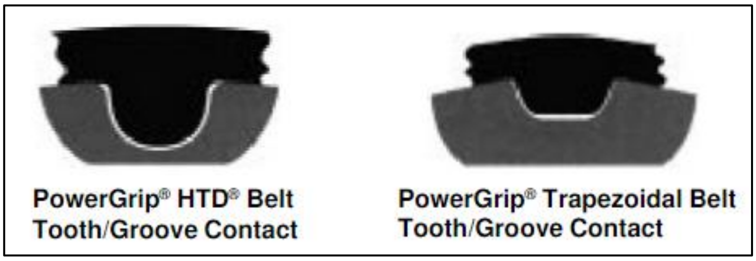
$$\therefore T = \frac{P_{out}}{\omega} = \frac{2331W}{949.285rad/s} = 2.46Nm$$

Each motor outputs 2.32Nm of torque.

Chose to use HTD synchronous belts because of their curvilinear tooth design which improves stress distribution for higher tooth strength compared to conventional trapezoidal tooth designs. The GT2 synchronous belt system is similar to the HTD design with an even greater load carrying capacity, however, they are more expensive and harder to procure than HTD belts.

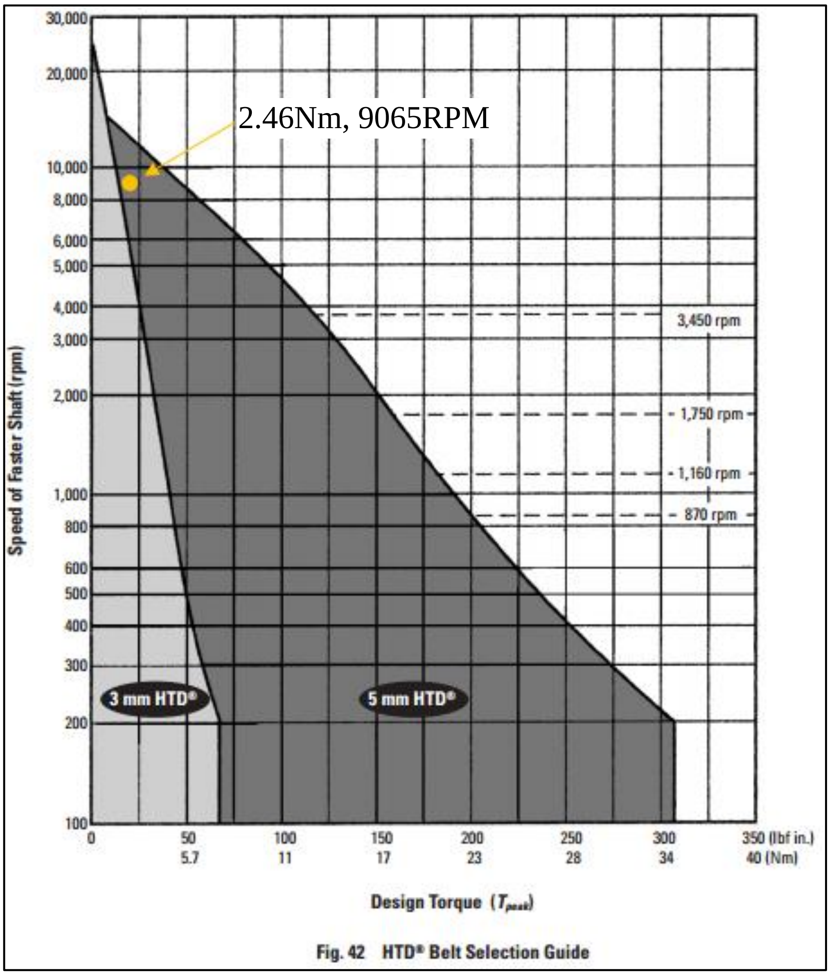


Tooth stress pattern of different designs (SDP/SI, 2016)



Different tooth profile comparison (SDP/SI, 2016)

HTD Belt Selection Guide (the 5mm HTD belt is optimal at the theoretical speed and torque calculated.)



HTD Selection Graph (SDP/SI, 2016)

Force can also be calculated from the following equation, where d is the radius of the small pulley:

$$T = F * d$$

$$\therefore F = \frac{T}{d} = \frac{2.46Nm}{0.012m} = 204.62N$$

The timing belt chosen should have a maximum tensile strength of at least 204.62N

The HTD5 synchronous belt used in the design has an allowable working tension of 454N/inch of belt width. This equates to approximately 215N for the 12mm timing belt used in the design which is greater than the maximum tension the belt should experience in use of 204.62N

C5. Theoretical Board Weight

The total expected weight of the board is 15.43kg.

BREAKDOWN OF COMPONENT WEIGHTS				
Description	**Quantity**	**Weight/Part (g)**	**Total Weight (g)**	**Material**
Trampa Holy Pro Deck	1	2740	2740	COMP
Vertigo Baseplate	2	128	256	ALUM
Springs	4	32	128	SSTEEL
Ratchet Bindings/ Footstraps	2	220	440	-
High Discharge Li-Po Battery	4	352	1408	-
245KV Brushless Motor	2	718	1436	-
Drybox	1	350	350	PLASTIC
Dual ESC	1	350	350	-
Sidewall (5mm)	4	378	1512	ALUM
Small Cylinder (FL) (3mm)	8	43	344	ALUM
Large Cylinder (FL) (3mm)	2	188	376	ALUM
Large Cylinder (HL) (3mm)	4	86	344	ALUM
Bolts for large pulley	8	4	32	ALUM
Large Washer (5mm)	8	58	464	ALUM
Large Washer (w/holes) (5mm)	4	56	224	ALUM
Small Pulley	2	20	40	STEEL
Large Pulley	2	20	40	NYLON
Timing Belt	2	18	36	RUBBER
Bearings	38	16	608	STEEL
Large Axle	2	34	68	ALUM
Small Axle	8	28	224	ALUM
Male Axle	2	18	36	ALUM
Female Axle	2	16	32	ALUM
Speed Washer	24	1	24	ALUM
Adjuster	8	10	80	ALUM
Adjuster Bolt	8	2	16	ALUM
Small Pulley Adapter	2	3	6	ALUM
Motor Bolts	8	1	8	SSTEEL
Nyloc Nuts	32	4	128	SSTEEL
Washers	40	4	160	SSTEEL
Hanger Bolt	8	11	88	SSTEEL
Hanger	2	384	768	ALUM
Tread	2	982	1964	RUBBER
Electrical (Other)	-	-	400	-
Mechanical (Other)	-	-	300	-
TOTAL WEIGHT			**15430**	