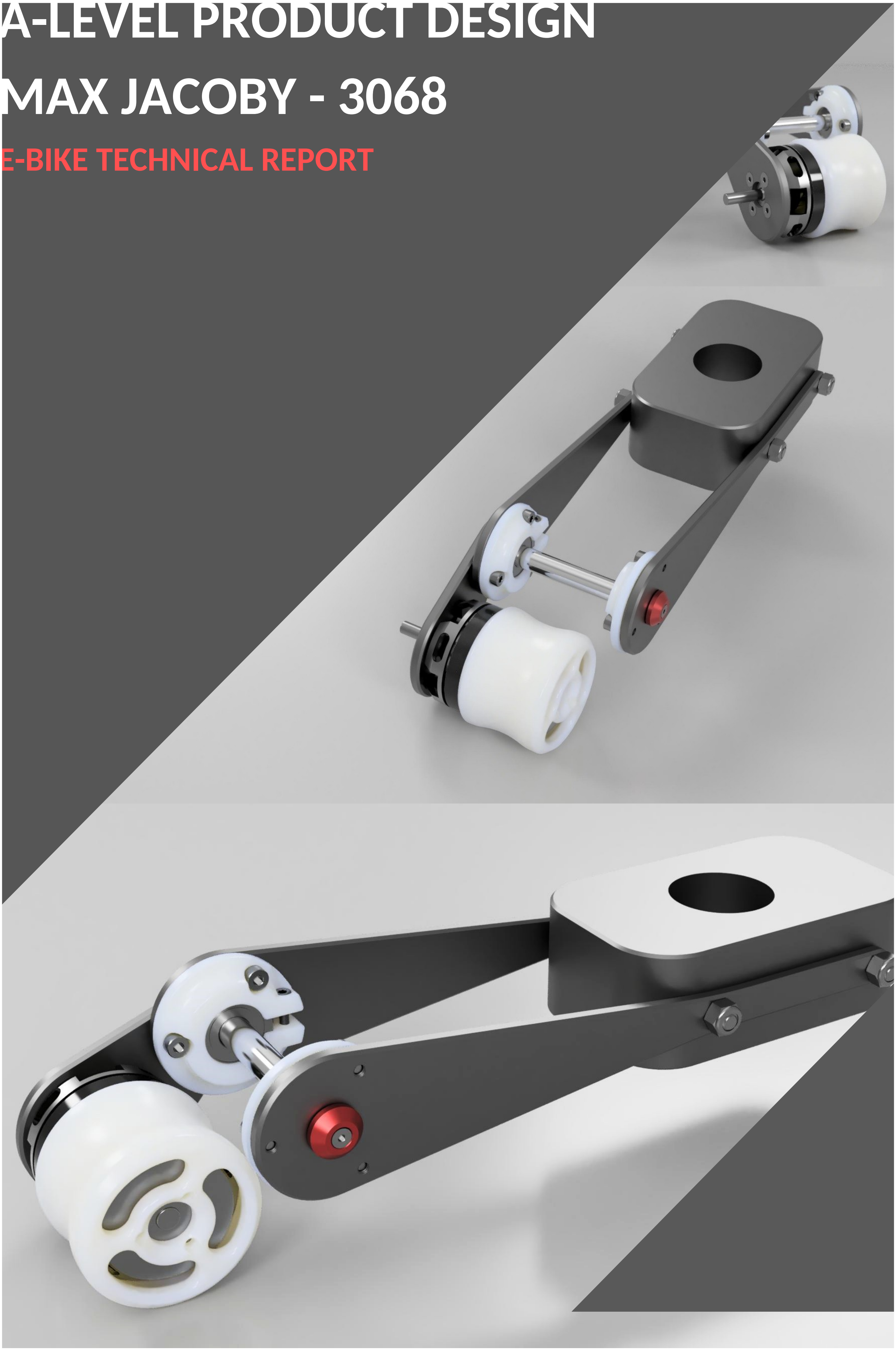
A-LEVEL PRODUCT DESIGN

MAX JACOBY - 3068

E-BIKE TECHNICAL REPORT



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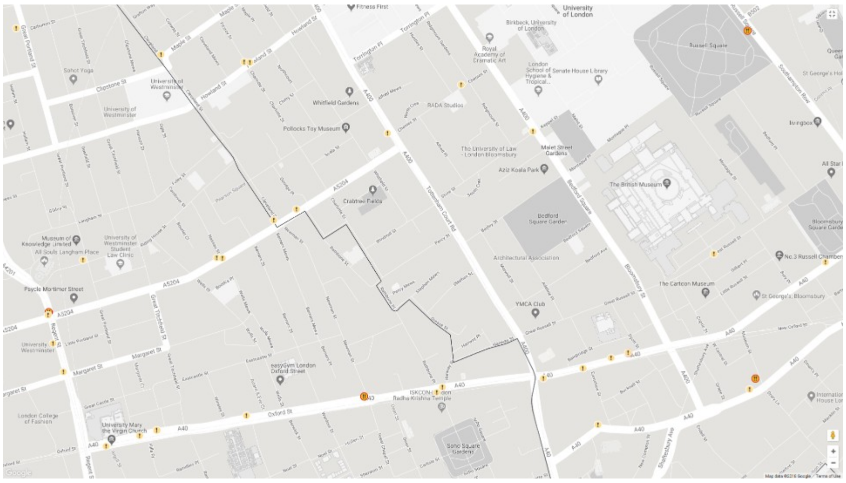
PROJECT ANALYSIS

PROBLEM

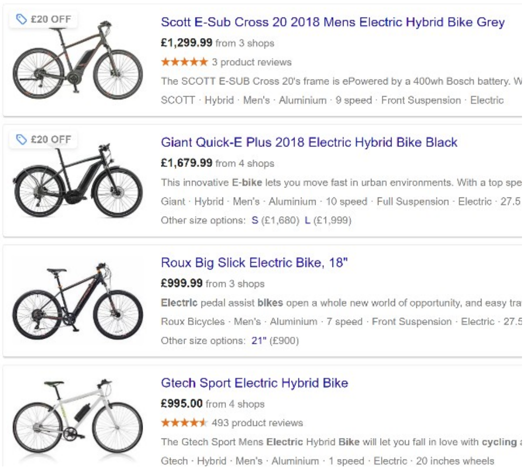
The problem I have identified is that electric bikes, or e-bikes, are expensive and do not incorporate extra features which could make riding bikes safer and more convenient. Electric bikes are most attractive to commuters who cycle to work as the bike provides help on ascents, meaning commuters can arrive at work without being too tired from their commute. At the end of the day when you are tired, an electric bike will help you get home as well. Additionally, if more people use bikes instead of taking public transport, it aids the solution of the other areas I explored as part of analysing different problems. Namely CO2 transport emissions and public transport overcrowding. Unfortunately, many of these e-bikes are in excess of £1000, which is more than people might like to spend and taking into account that most people already own a bike, this is not an attractive purchase.

Bikes and e-bikes are common in cities as it's a much more convenient way to get around – but in cities like London there are vast numbers of cycle related accidents. If I can make e-bikes more accessible, this would reduce transport traffic, and if combined with safety equipment it could make road cycling safer. Bicycles are designed for outdoor use, so the solution will have to withstand the harsh environments of city or off-road use.

Opposite, the collision map shows that accidents happen at junctions and turnings. The main problem is that drivers do not see cyclists and turn at a junction



This collision map of Tottenham Court road in London form tfl.gov.uk shows bike accidents in 2016.



The high price of e-bikes

DESIGN BRIEF

My original brief was to design and prototype a universal e-bike upgrade kit which can transform a regular bike into and electric bike without modifying the bike. After researching conversion kits I found that this market area was already saturated by solutions, and instead decided to focus on an off-road oriented conversion kit - where there is a gap in the market as most kits are tailored to light cycling on the roads and not for more challenging conditions. Therefore, my brief will be to design an e-bike conversion kit which can transform any regular bike into an electric motor assisted one. It should be able to be used off-road and on a commute, and should also incorporate safety features to help combat cycling accidents on the road.

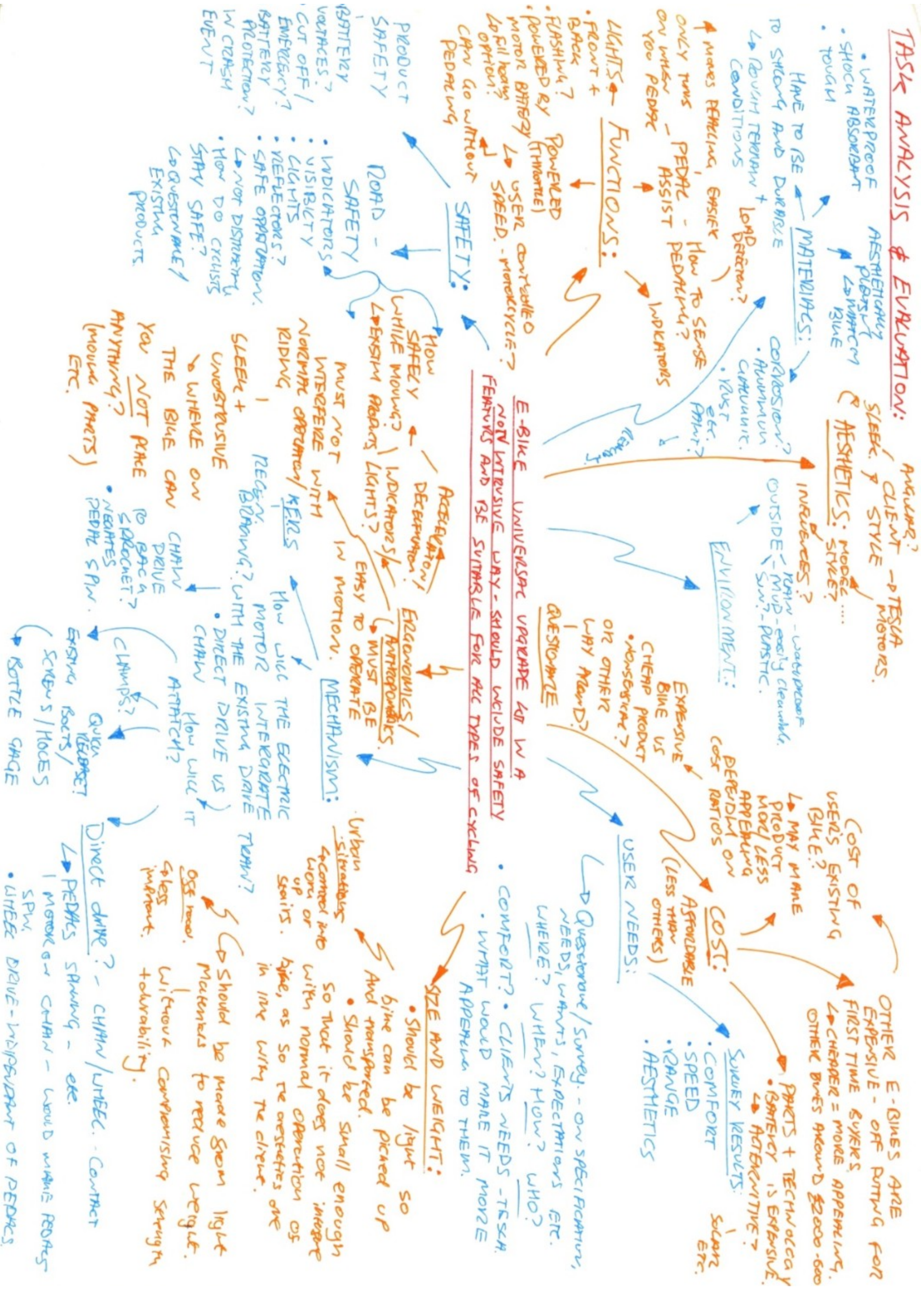
CLIENT NEEDS

A potential client could be Tesla, who design and manufacture electric cars, power banks, and solar panels. Their cars are currently in mass production due to the high demand, although my product should be batch produced, as electric motors and batteries being improved all the time. Batch production would allow each generation to be better thanks to technological improvements. Tesla's design style is sleek and minimalist, so the product should be designed to fit this style and should be high quality in keeping with Tesla's other products.

USER NEEDS / TARGET AUDIENCE

The user group is people who cycle in off road conditions. It must have a long range, be able to keep up with the cyclist, be rechargeable, be aesthetically pleasing, durable and well-built from high quality materials and be universal to fit any bike. It should be comfortable to ride and be able to be charged when the user arrives at their destination. The market for electric bikes is continuing to expand and sales are rising, so as more and more people want to buy an electric bike. My product could fill the mid-range of the market between cheap kits that don't perform well and the very expensive electric bikes, while still delivering good performance at a reasonable price. This would allow more people to access electric bikes, possibly encouraging them to cycle.

TASK ANALYSIS AND EVALUATION



From my task analysis I can see that there are lots of ways I can reach the goal of creating an upgrade kit, I just have to find out which ways are viable and which would not be possible. Additionally, I don't know what kind of features or performance the bike should have. I will have to research these quantitative aspects, so I know how to proceed in designing to meet the market standards, and also ask bike users what they would expect from such a product so that it is appealing to the customer.

RESEARCH PLAN

From my task analysis I know what I must find out to make a product which will perform and be attractive to users. By formulating a research plan I can organise what I must find out, and what I have to do to get the information I need. This will make researching information for my product much easier and allow me to structure my time more effectively

AREA FROM TASK ANALYSIS	WHAT DO I WANT TO FIND OUT?	WHERE WILL I FIND IT?	HOW WILL I USE IT?	PRIMARY / SECONDRY
Product analysis – e bikes and safety products.	How do other electric bikes work? What is a typical range? How fast do they go? How useful are different safety products?	Bike shops like Halfords or a specialist bike shop, online shopping sites,	This will determine the specifications and design of the bike to be in competition with other electric bikes, and how I design the safety side of the product to make it safe and easy to use as well as effective.	Primary & secondary
User needs – What does the user need/want?	How the user will use the bike, where, in what weather, and what features they would like to see in the bike, what users do not like about electric bikes.	Survey, interviews, questionnaires, inspirational visit	This will help me design the solution so that it is attractive to the user, and avoiding the unattractive traits of existing bikes. Also so it can perform in the needed conditions.	Primary
Ergonomics and Anthropometrics	Dimensions of hands on handlebars, how the body moves while on the bike, shape of hands,	Books on anthropometrics, first hand measuring	With this information I can design a control system which is easy and comfortable to operate while riding, and a motor and battery system which does not interfere with the rider.	Secondary
Location Visit	How my product should look and how it should perform, in which conditions	Bike trails, bike roads, Tesla garage	Will help me gain a better understanding of the problems, terrain and aesthetic style that my product will have to overcome and conform to.	Primary
Aesthetics/Styles	My client's design style (Tesla), other bike styles and designs. What would fit well with existing bikes?	Bike shops, Tesla showrooms, bike designers	This will help me design the product so that it looks natural on the bike and doesn't look out of place.	Primary & secondary
Materials	Which materials are strong enough to withstand the forces on the bike, which are durable to withstand crashes, and which are cost effective?	Books, online material databases, own testing	When I design my product, I will know what to make it out of to keep costs low while delivering a quality and durable product.	Primary & secondary
Safety	What voltages do electric bikes run at? Do they have safety features? What dangers are present? Are there any laws that my bike needs to follow?	Online research, bike stores, surveys & questionnaires, bike trails	With this I can design a safe bike which is equal or better than competitors and operate within any laws that may be applicable.	Primary & secondary
Sustainability	What is the lifetime of the parts/ product? What is the shortest lifespan component, and will it render the bike useless, meaning it has to be thrown away? How can I extend its lifetime?	Component datasheets manufactures notes/user manuals.	Will enable me to build an environmentally responsible product which will have a long lifetime.	Secondary
Environment	Where will the bike be used? Which conditions will it be subject to?	Surveys & questionnaires	Will help me design a bike which will withstand its environment.	Primary
Manufacture	How can I attach the product to the bike without changing or modifying the bike?	Focus e learning and tests in the workshop	I can design the product around modular and non-intrusive means to attach it.	Primary & secondary
Function	What features do other electric bikes have? How do they work, what kind of electric bike they are.	Bike shops, other online products.	Means I can design the bike to compete with other electric bikes on the market and will help me come up with a design which is applicable and will work.	Primary & secondary

This plan clearly lays out what I must do in order to find out what I need in order to design a product which will fit my user and client needs.

EVALUATING EXISTING PRODUCTS

HALFORDS BIKE SECTION VISIT

To gain a better understanding of electric bikes and how they work, I visited Halfords – one of the UK's biggest retailer of bikes. They had a large range of electric bikes using several different technologies which I looked at in detail in my product analysis. It also gave me an idea of ways to incorporate the technology needed to make an electric bike run. I found that by law, bikes that can be sold to use on roads must be pedal assist, among other restrictions. This means that the motor only helps you pedal but cannot power the bike for you. I found that there were two main types of electric bikes: hub drive and mid drive. These terms refer to where and how the motor transfers energy to the back wheel.

BIKE #1

The hub drive's motor is contained within the back (or front) hub of the wheel and is the one of the simplest ways of transforming a bike to electric as there are no other moving parts. This does mean one of the wheels has to be replaced with the specialist motor one. This may not be a problem for most, although as it is a specialist part there is not much choice in design or materials. For people who are particular about wheels or need a special rim to fit a specific tire, this may not appeal to them. It is also not a particularly sturdy solution – it is designed for commuting to work and other light tasks but is not very suited to off road or more rough conditions. This has the advantage of the motor being able to run and just freewheel, meaning the motor can drive the bike and the pedals do not turn. Although using it to power the bike on its own does not conform to the law, it is an interesting and useful feature which I could utilise.

Hub drive example

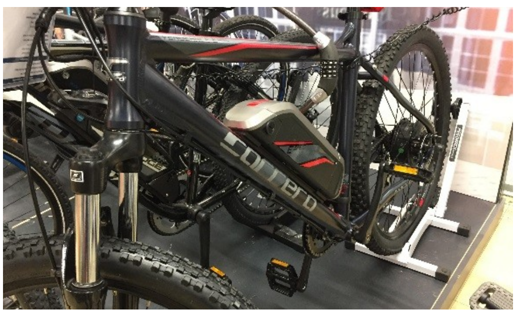
BIKE #2

Mid drive example

The second type of E-Bike I saw was mid drive. In this configuration the motor is situated in the bottom bracket of the bike (the area where the pedals are affixed). In this position the motor is integrated into the frame, so it is well protected and more suited to off road, in comparison to the hub drive. Because there is more room for the motor than in a hub they are also generally more powerful than the hub drive. The motor's power is transferred through the entire drivetrain which gives it a much more natural feel more akin to pedalling alone. The motor has a ratchet gear which also means that the motor can never pedal for you or accidently power up and throw you off. By the power being transferred through the drivetrain and gearing, the motor has effectively as many speeds as you bike gearing has. This allows the motor to have a much more reasonable specification in terms of torque and speed and relies on the user changing gear for the conditions. Again, this makes the experience like pedalling with less load. This is the more complex of the two but the most elegant and convenient solution.

Additionally, there is a third way of driving the wheel called friction drive. I did not see this on my visit, but I researched them elsewhere on Google. This is the simplest type, where a small rubber wheel connected to the motor is pressed against the tyre of the bike to transfer power. It is not a very robust solution and only works on smooth tyres and does not provide much power. This being said, it is far cheaper than the other options and much easier to set up.

The battery packs were high power Lithium Ion, with a capacity of about 15 amp hours. Some were mounted to the downtube of the bike, and others used a luggage rack on the back of the bike which housed the battery and also provided luggage space. These were more popular on the commuter style of bike, and the downtube mount was more popular on the off-road style. The downtube mount is out of the way and makes use of space which would otherwise be unused or house a water bottle. They both had the charging and



A downtube mounted battery pack

control build in to properly control and maintain the lithium battery. One battery was incorporated into the frame and was not visible at all – which was a very visually appealing option. They had battery indicators were connected via a wire to a control unit on the handlebars. This controls the level of pedal assist, on and off, and on more advanced ones also shows speed, battery level, distance and other information about the ride.

In summary my product analysis gave me a much better idea of what already exists and consequently what my product should compete with or at the very least match. It gave me rough estimates of battery capacities, power and methods of drive which I can apply to my own designs.

E-BIKE BELOW THE LINE SPECIFICATION SUMMARY

SPECIFICATION:	PENDLETON HYBRID BIKE	VODOO ZOBOP E-MOUNTAIN	CARERRA ELECTRIC HYBRID	CARERA VULCAN
PRICE	£850	£2,700	£1,400	£1,125
SPEED	15.5	15.5	15.5	15.5
RANGE	50 MILES	60 MILES	80 MILES	50 MILES
BATTERY CAPACITY	8 AH	13.4 AH	11 AH	11.45 AH
TYPE	HUB DRIVE	MID DRIVE	MID DRIVE	HUB DRIVE

Both the mid drive systems have the largest range but do not necessarily have the largest battery. In fact, the smallest battery capacity has the same range as the Vulcan, which has a much larger battery. This could be because of motor efficiency of different test conditions for each bike. However, both mid drive units have the best battery and range, suggesting that they have the most efficient motors due to the larger space available. All have a top speed of 15.5mph which is due to legal limitations. After this speed the motor must cut out otherwise it is classified as a motor vehicle and has to be taxed and insured. The Pendleton Hybrid is a folding bike and is probably lighter than the Vulcan which also explains why it has a longer range.

E-BIKE ABOVE THE LINE SUMMARY

I found that the electric bikes at Halfords were all not that aesthetically pleasing. They looked like electric bikes, with large and clunky components. The controls stuck out a long way and were also not in a particularly good position allow control while on the bike. The hub drive versions looked like they had just had the components added with no concern for how they look or the usability. The hub drive on the other hand looked much sleeker, has more thought put into the control placement and overall looked less like an e-bike and more like a normal bike. If I can make this custom fit approach of the hub drive work on my conversion kit, I can make it look purposeful and part of the bike, making it more attractive to the user. The battery pack on some is also in the frame, which is a better distribution of weight on the bike making it more stable than the ones mounted over the back wheel.

INSPIRATONAL VISIT

To get a sense of the environment the bike will be used in, I went for a ride in Epping Forest. The varied terrain and conditions will give me an idea of a range of environments that my conversion kit will have to withstand. I rode for about an hour and encountered asphalt, mud, grass, gravel and leaves / forest floor. I stopped periodically to check what kind of dirt the wheels had picked up and transferred to the frame of the bike.

By doing this I know how my product must be sealed or protected against the conditions which could affect its functionality.

At the end of the ride I found that the wheels were caked in sticky mud with stones and leaves imbedded in them. I also encountered muddy water, which was flung up my back and onto the frame. This might the biggest threat to the performance of the kit because the water is conductive and could short out the electronics.

I would like to avoid a friction drive method because I highly doubt this would work with wet or muddy tyres and would just spin, not transferring any power. Instead I might be able to drive the back wheel directly in some way.

This is a path in Epping Forest. This kind of gravel path is common in most forests and off-road areas. In dry weather it becomes dusty, but most of the time it is fairly similar to tarmac. There are sometimes large pebbles which are flung up by the tyres.

To resist this the kit would have to be protected against large stones getting into the moving components and also protected against dust.

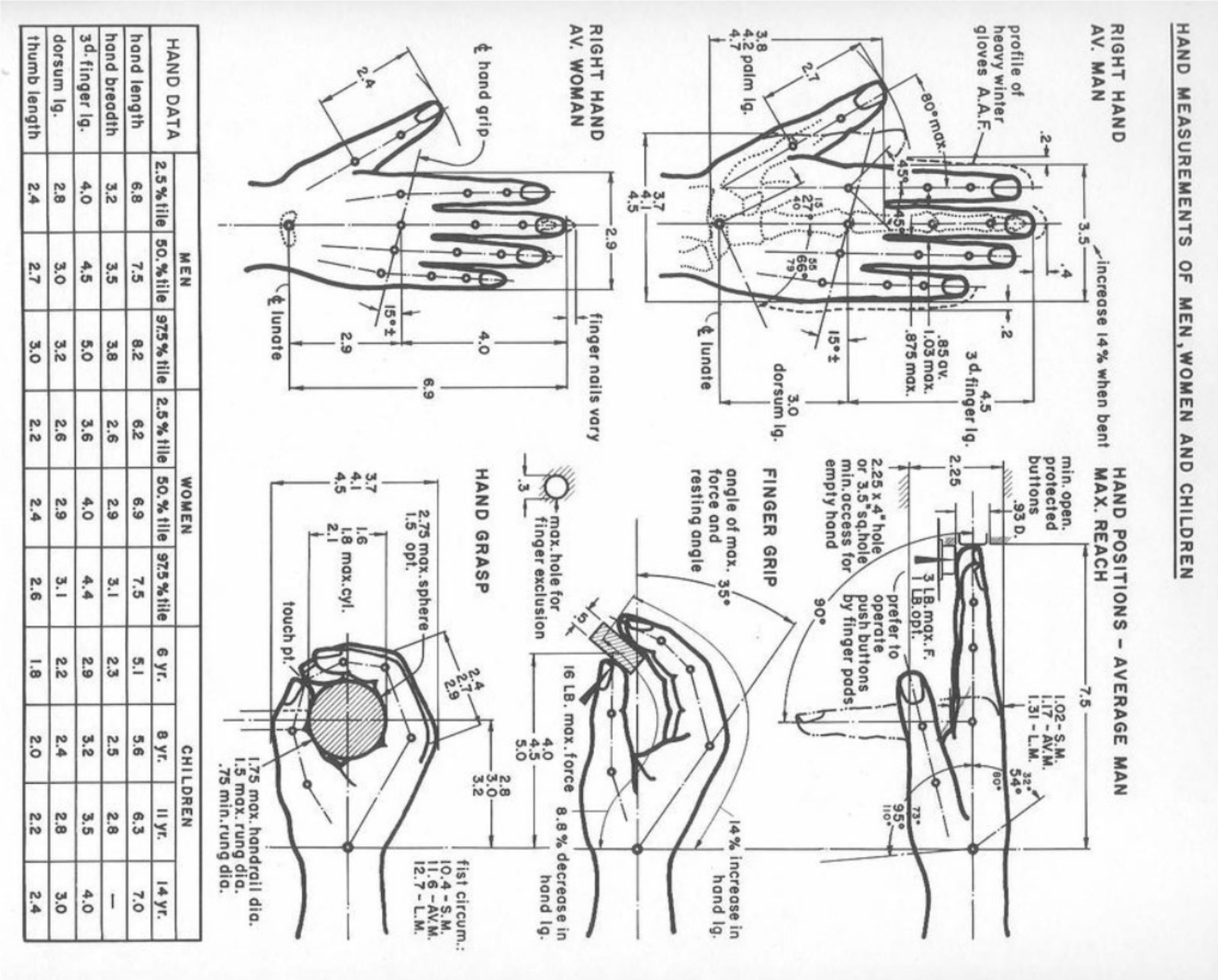
Off the trails the forest floor looks mostly like this. Littered with mostly leaves, acorn shells, branches and twigs. In the summer it is also dusty, and when it's wet it's not much different as the water filters through to the ground underneath. The tires usually flick up small bits of debris, but nothing too damaging as they are all quite small and light. Sometimes the debris gets stuck in the wheel. If I use a friction drive this would be an issue as it might interfere with the contact between the motor and the wheel.

Finally, there is mud. In Epping Forest the mud is a thick and viscous clay mixture when it rains. This type sticks to everything and is quite difficult to remove. This is the most difficult terrain to protect the kit against. It means it must be easily cleanable, waterproof, grit and dirt proof, and would entirely prevent a friction drive from working.

So, in conclusion I must make sure that the components near the wheels and on the frame (as shown by the photo) must be waterproofed and resistant to grit and debris. It should also be easily cleanable, and if possible, I should avoid a friction drive method to get maximum power output.

ANTHROPOMETRICS AND ERGONOMICS

As part of making my design easy and safe to use I need to research the measurements of human hands and leg width when sitting on a bike. The hand dimensions will aid me to design a throttle system which is intuitive and easy to reach, and easy to let go of.



HAND DATA	MEN 2.5%tile	MEN 50%tile	MEN 97.5%tile	WOMEN 2.5%tile	WOMEN 50%tile	WOMEN 97.5%tile	CHILDREN 6 yr.	CHILDREN 8 yr.	CHILDREN 11 yr.	CHILDREN 14 yr.
hand length	6.8	7.5	8.2	6.2	6.9	7.5	5.1	5.6	6.3	7.0
hand breadth	3.2	3.5	3.8	2.6	2.9	3.1	2.3	2.5	2.8	—
3d. finger lg.	4.0	4.5	5.0	3.6	4.0	4.4	2.9	3.2	3.5	4.0
dorsum lg.	2.8	3.0	3.2	2.6	2.9	3.1	2.2	2.4	2.8	3.0
thumb length	2.4	2.7	3.0	2.2	2.4	2.6	1.8	2.0	2.2	2.4

The thumb length is what is relevant to a thumb throttle, which I have in mind. This information tells me that the end of the switch should be no more than 2.7inches (about 7.5cm) from the end of the handlebar grip. This will ensure that the throttle is always readily available but is also out of the way when not in use.

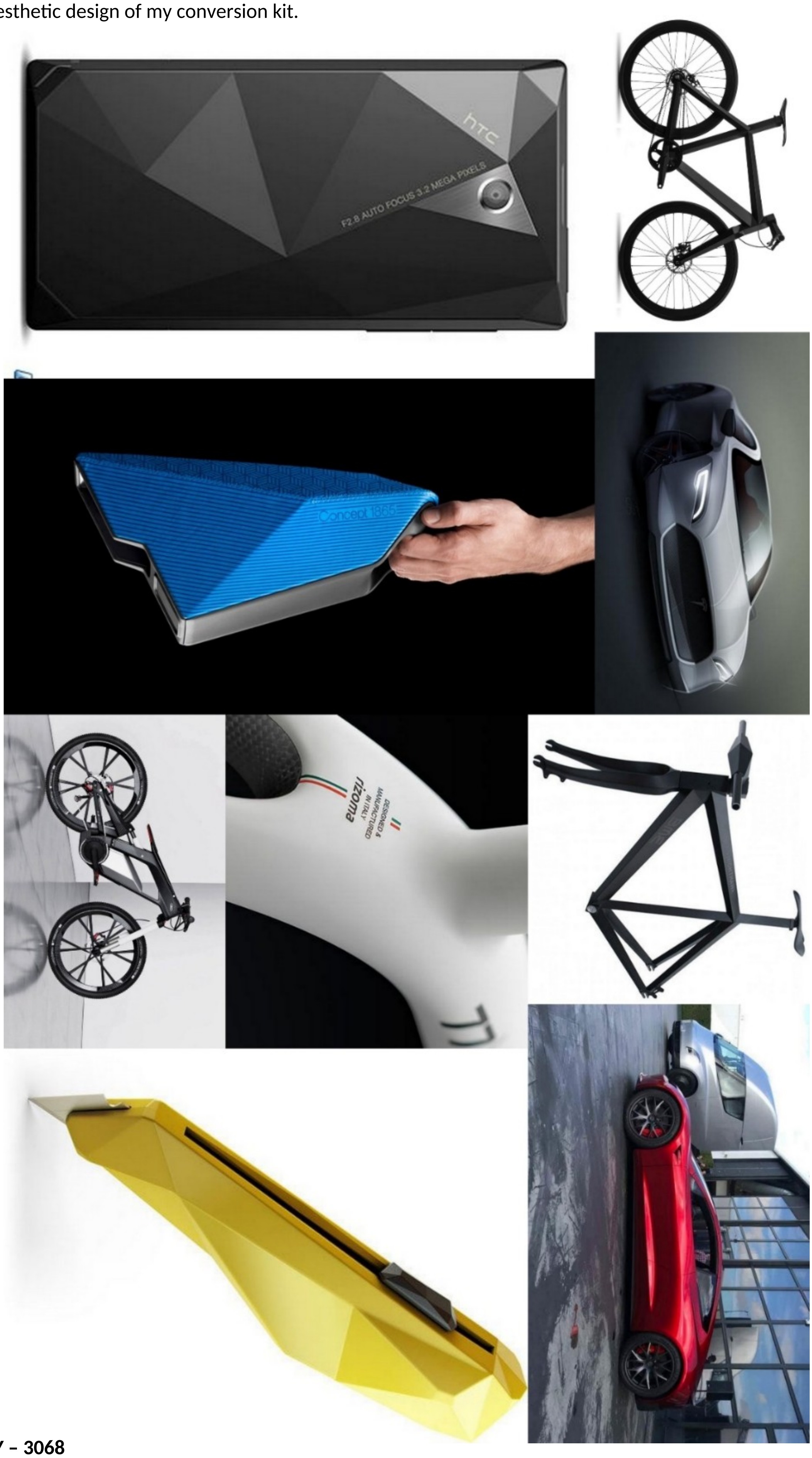
As for the measurements of the user on the bike, they will be similar for every user as the pedals define the distance between your legs. I found that this is about 260mm between the pedals, and subtract a bit for width of shins – 70mm on average on each side. Therefore, nothing should stick out from the inside of the frame more than 120mm in total to avoid clashing with the user when pedalling.

To make the throttle comfortable to use for long rides, it should be ergonomically designed to mimic the negative shape of a thumb. There should be no sharp corners and should be comfortable during testing. It should also be designed so that the throttle goes from 0 – 100 % in a short range that is easy to operate with your thumb.

DESIGN CONSIDERATIONS

MOOD BOARD AND STYLE RESEARCH

My client is the Tesla Motor Company. To reflect their style of products my design should be sleek to fit with their existing products. In addition, I chose these images to form a mood board of products and styles I found aesthetically pleasing to help inspire the aesthetic design of my conversion kit.



IDENTIFYING USER NEEDS

SURVEY RESULTS

To get a better idea of how I should design my kit I asked 11 people which features they would look for when buying an electric bike.

CRITERIA	NOT IMPORTANT	SOMEWHAT IMPORTANT	SIGNIGICANTLY IMPORTANT	ESSENTIAL
MUST HAVE A LONG RANGE (BATTERY LIFE)	0	1	6	4
MUST BE POWERFUL (HIGH ASSIST LEVEL)	0	5	6	0
HIGH TOP SPEED	6	2	2	1
MUST BE EASY AND INTUITIVE TO USE	0	0	2	9
SHOULD HAVE SWAPPABLE BATTERIES	2	4	3	2
MUST BE QUICK TO REMOVE	5	4	2	0
MUST WORK WITH MAJOROTY OF BIKES	0	0	5	6

Q: How far do you ride when you go cycling and why?

> **A:** I ride about 5 miles on my commute to work.
>
> **A:** I don't ride that often, but I usually go about 4 kilometres for exercise.
>
> **A:** I ride every weekend for fun and I go about 9 miles.

Q: What sort of terrain do you ride on?

> **A:** Road and pavement mostly.
>
> **A:** Gravel, pavement, mud, leaves – general off-road conditions.
>
> **A:** In a forest, so mainly mud rocky trails.

Q: Do you ever ride when it's wet or raining?

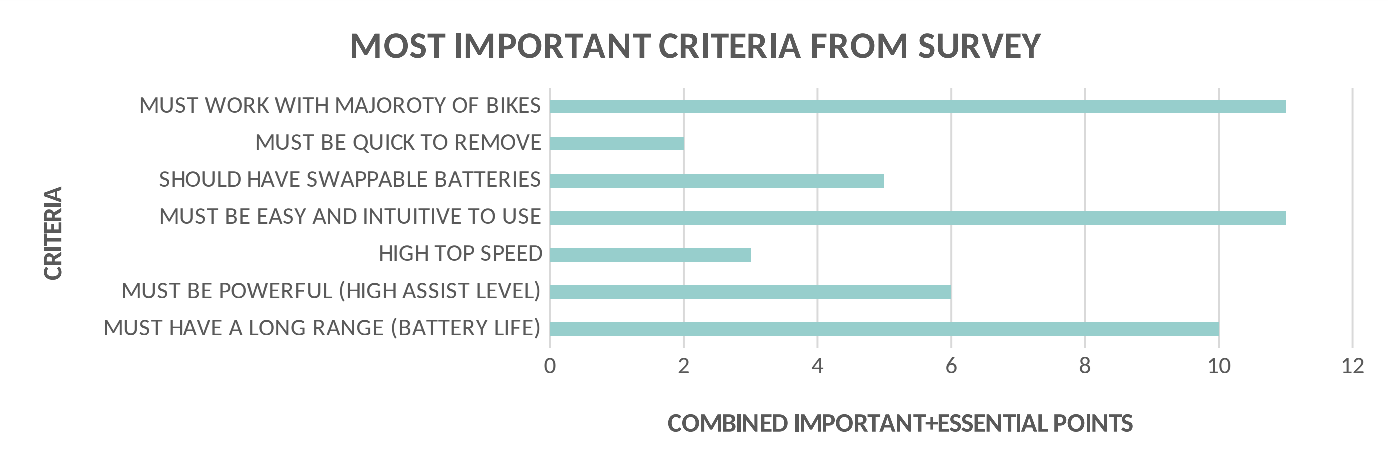
> **A:** Yes, depending on how rainy. If it's too wet I take the car.
>
> **A:** No.
>
> **A:** Sometimes, as it makes it more fun.

Q: Do you get tired on your ride going up hills or other difficult terrain?

> **A:** Yes, sometimes, especially when the weather is warm or very cold.
>
> **A:** Yes, because I don't exercise often.
>
> **A:** Yes.

Q: If you wanted to get an electric bike would you buy a specially built bike or a conversion kit to use your existing bike?

> **A:** I would buy a conversion kit to save money, as my bike is already quite expensive.
>
> **A:** I don't know I'd have to look
>
> **A:** I would spend the money on a new bike as I think it would work better than a conversion.



From this graph and the questions I asked I know what the most important things that I identified in my product analysis. This will help me focus on the most important aspects of the design so I can make the product as attractive to users as possible, instead of focusing on things that do not matter.

I found that the range should be a minimum of 10 miles, it should be waterproof, it should work on all terrain, that it should provide adequate assistance to the rider and most importantly that users want or would prefer a conversion kit over a new bike.

SUMMARY OF RESEARCH

From my product analysis, inspirational visit, mood board and questionnaire I put together this table outlining what I found from all my research, based on my research plan.

AREA FROM TASK ANALYSIS	WHAT DID WANT TO FIND OUT?	WHAT DID I FIND?
Product analysis – e bikes and safety products.	How do other electric bikes work? What is a typical range? How fast do they go? How useful are different safety products.	There are several drive methods (see above) using pedal assist. The range is about 60 miles average, although I would think this optimistic. Limited by law to 15MPH. The bike lights I found had very bright LEDs and differing patterns of flashing.
User needs – What does the user need/want?	How the user will use the bike, where, in what weather, and what features they would like to see in the bike, what users do not like about electric bikes.	From my sample the kit should be able to withstand off road conditions and a daily commute. It should be waterproof and be substantially powerful and have a range of at least 10 miles.
Ergonomics and Anthropometrics	Dimensions of hands on handlebars, how the body moves while on the bike, shape of hands,	I found the maximum size of the components I can fix to the bike where they might impact normal riding (120mm), and the measurements of hands in order to design an ergonomic throttle.
Location Visit	How my product should look and how it should perform, in which conditions	My visit to the bike shop showed me how the technology could be integrated into bikes and my inspirational visit to the forest showed that my kit has to hold up to a variety of conditions.
Aesthetics/Styles	My client's design style (Tesla), other bike styles and designs. What would fit well with existing bikes?	My bike shop visit also helped me find out how it should look, and my mood board aided my ideas on how to make the kit sleeker.
Materials	Which materials are strong enough to withstand the forces on the bike, which are durable to withstand crashes, and which are cost effective?	Through testing prototypes and ideas, I found that steel or aluminium would work well thanks to its high strength to weight ratio. 3D printed parts are suitable for smaller parts that have less load.
Safety	What voltages do electric bikes run at? Do they have safety features? What dangers are present?	I found most bikes run at between 48 – 60 volts DC. This isn't enough to injure the user, although the high capacity battery is dangerous if handled incorrectly. There is a motor cut off when you pull the brake but apart from that the motor could start accidently. If implemented correctly the dangers should be no different from a normal bike.
Sustainability	What is the lifetime of the parts/ product? What is the shortest lifespan	The battery is the most perishable component on the bike, as their performance degrade over time. If the rest of the components are

	component and will it render the bike useless, meaning it has to be thrown away? How can I extend its lifetime?	made correctly they should not need replacing. Electric scooter conversions are also common and people say that the most common part to fail is the speed controller.
Environment	Where will the bike be used? Which conditions will it be subject to?	(See Inspirational visit)
Manufacture	How can I attach the product to the bike without changing or modifying the bike?	From looking at bike lights clamps around circular tubes like the seat tube seem to be a good idea. Using bolts already on the bike is less preferred as these might not be the same on all bikes.
Function	What features do other electric bikes have? How do they work, what kind of electric bike are they?	(See e-bike comparison table) They have pedal assist and sometimes a range/speed meter.

From my research I can develop a specification which incorporates the areas which I found to be important, which will help me design my kit so that it performs well and appeals to a wider audience

DESIGN SPECIFICATION

Based on my research, this will tell me what I must include when designing the kit.

RANK	SPECIFICATION	TESTING METHOD	QUANTITATIVE/QUALITATIVE	EVIDENCE FROM RESEARCH
1	**FUNCTION –** My kit should be easily fitted and taken off and be able to hold up to rough off-road conditions. This will make it worth buying.	It should be given to users to assess the ease of application, and should propel the bike	Qualitative – does the user think it has met the specification? Does it take under 10 minutes to attach and use? Is it resistant to dirt and mud – yes/no.	The bikes I saw were well build, rugged and performed well (on paper). They integrated seamlessly with the bike which mine cannot do, so it must be removable.
2	**UNIQUE SELLING POINT** – The kit should appeal to off-road enthusiasts more than road users to fill a market gap and sell more units.	Compare the specifications and functions against existing conversion kits.	Qualitative – how does the bike appeal compared to a purpose built off road bike from an enthusiast's perspective?	There were far more road-oriented bikes at the shop and only two designed for off road use.
3	**PERFORMANCE –** my conversion kit should perform as well as or better than existing electric bikes to make it appealing to users who want an electric bike.	Use the product – test performance up hills, speed tests on flat ground and a variety of rough terrain to prove that it can handle its intended environment.	Quantitative – does the power output reach 400 watts? Does it reach at least 20mph? Does it still work after riding through the intended conditions?	The bikes I saw were powerful and had a long range, but were limited by the law (vehicle tax).
4	**SAFETY -** The batteries that I may use can be dangerous if handled incorrectly, and if the user falls off the conversion should not injure them. It should be designed to reflect this.	Make sure the components meet any safety standards like BSI. When the bike is crashed the motor should shut off, and the housing should be used in-situ to determine its suitability to house electronics.	Quantitative – test the kit against the standards – it will either pass or fail.	The bikes had sprung throttle levers or only applied power when you pedalled. In this way there is no way the bike could operate without the user wanting it to. The batteries also had charging and overcharging protection to protect the battery.

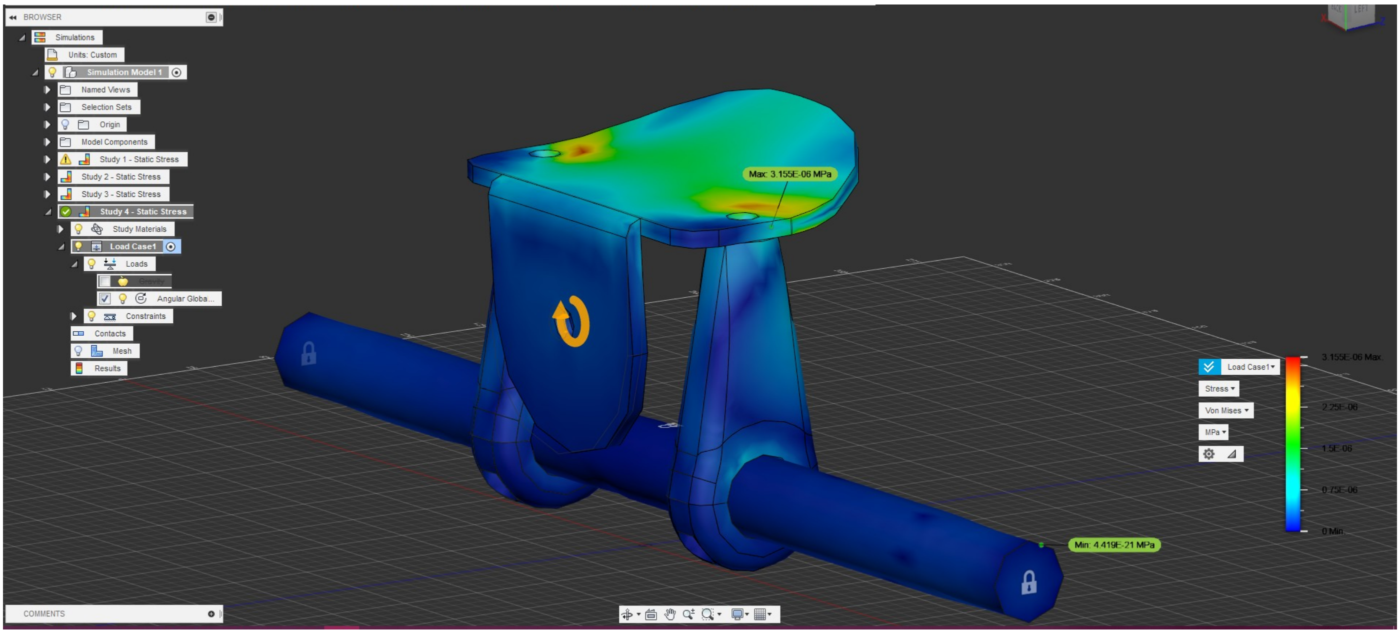
5	**ERGONOMICS –** However I implement the solution it should be comfortable and should not hinder the rider in any way, and any pieces that come in contact with the rider should be designed to fit the user.	A group of users should find it easy and comfortable to use the controls, if not then it has not been ergonomically designed.	Qualitative – it is comfortable? Different users may have different opinions.	The controls were all in reach of the user's hand when on the handlebars. There were no parts on the main triangle of the frame that stuck out much further than the frame to stay out of the way.
6	**MATERIALS –** The conditions that my kit will be used in can be challenging and rough. The kit should be made of a material which allows it to be durable and aesthetically pleasing.	Use the product (or functional prototype) in the intended environment and check for any damage which could affect the performance.	Quantitative – is it suitable for environment? Does it withstand the stress of the motor – does it bend or flex under 3 kilos? Have the materials corroded or has the dirt interfered with the motor?	The bikes I saw were all made from tough injection moulded ABS or aluminium, which are tough and durable.
7	**WEIGHT –** It should be as light as possible to avoid having to carry more than is necessary of its own weight.	Weigh the all the components together and check that it is not too heavy. Test on the bike – does it unbalance the bike or make it feel clunky?	Quantitative – the kit should weigh no more than 2 kilos.	The bikes had a minimal structure around the components and the user should still be able to use the bike normally.
8	**AESTHETICS –** It should be aesthetically pleasing to fit with the existing style of the bike and to appeal to the user.	In a focus group of target users the design should be popular and should be similar to the design styles in my mood board.	Qualitative – is it aesthetically pleasing? Different people may think differently.	The bikes all had sleek designs to make the electric components look as inconspicuous as possible.
9	**COST –** To make electric bikes more accessible to users they need to be less expensive.	Compare to other kits on the market and see whether it is competitively priced.	Quantitative – should not cost more than £300, preferably as low as possible.	E-Bikes are all quite expensive as shown by the research, so it should b competitive with those.
10	**FINISH –** The finish should be durable to hold up to adverse conditions and should fit with most existing bikes.	The finish should match products of the same nature and also the bikes it should be fitted to.	Qualitative – is it what would be expected from the price? Does it hold up to the intended conditions yes/no	The off road bikes I saw were all finished in tough wearing finishes to hide wear and tear and contribute to aesthetics.
11	**TARGET MARKET -** My target market is off-road cyclists so should appeal to what the target market needs and wants.	Show the product to the target market and collect their thoughts, what they like and which features are good/bad.	Qualitative – does the target market like it? Different opinions on features etc.	The majority of people I talked rode off-road.
12	**SUSTAINABILITY –** The product should be durable to last as long as possible, but when the product does come to the end of its life cycle it should be recyclable and not cause any harm to the environment.	Research the recyclability of all the materials and components that I could use and pick the most sustainable options	Quantitative – are the materials recyclable, disassembly needed, environmental impacts of material.	The bikes in the shop were all sturdy and well build and I would expect them to last for the high price.

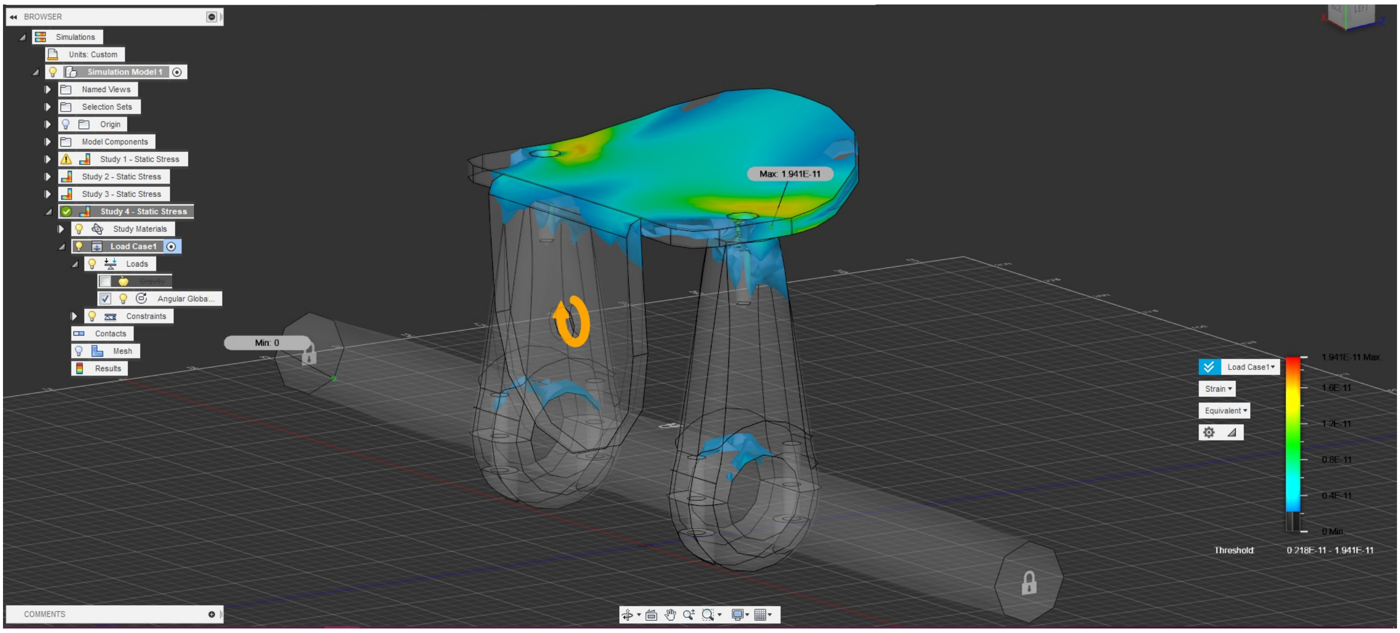
13	**MANUFACTURE –** It should be able to mass or batch produced.	Research methods of production and check that parts can be made using the techniques.	Quantitative –are there alternative methods that can apply to mass production? If not it cannot be used.	Sales of E-Bikes are rising so to meet the demand it should be mass produced.
14	**SOCIAL, MORAL, SPIRITUAL -** My product should not offend of conflict with any group or religion.	Check my product against beliefs etc.	Quantitative – does it conflict with anyone or any culture?	This is an important issue and should be designed as such to reach a larger audience.

PROTOTYPING AND MATERIAL TEST RESULTS

FUSION 360 STRESS TESTING MATERIALS

From my initial tests and prototypes I knew that I would have to use either aluminium or steel, as the wooden and 3D printed parts I made were too flexible or not strong enough to withstand the forces involved. I decided to make my first design in CAD using 5mm thick aluminium. I could then virtually stress test it so that I knew it was strong enough under the forces that the motor would apply. Under the normal forces the tests showed no movement and very little stress. I then performed the test again with much higher forces to see how it would react. Here are the results with abnormal forces.

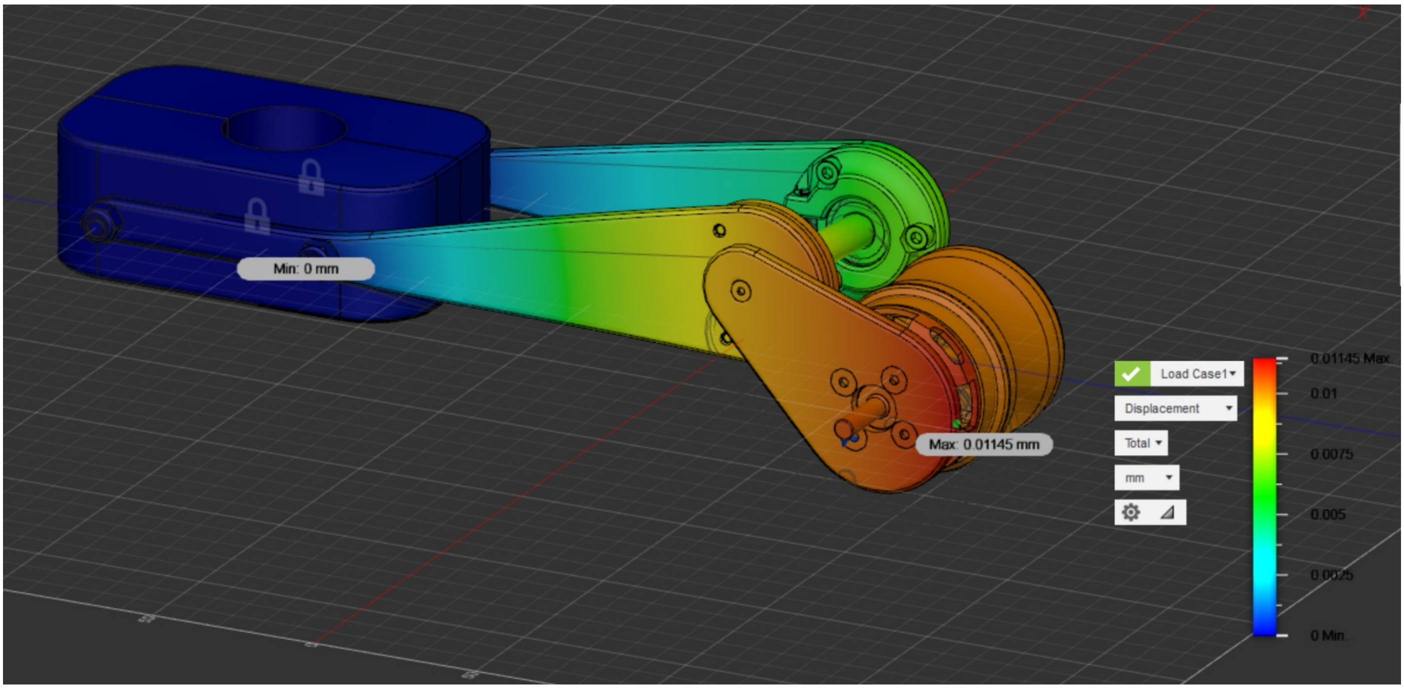




This shows where the force hotspots are and how the material will bend under stress. Since this is under abnormal load I know that 5mm aluminium sheet is strong enough to use for the sheet sections of my design, and anything thicker will hold up just as well. It also shows me if the parts were to fail, where and how badly. I can use this data to create a stronger and more durable design.

Therefore, I decided to design the most structural parts of my kit from aluminium which I know will hold up under the stress. The less crucial parts I can 3D print. Aluminium does not corrode like steel does and if protected properly will not corrode at all. It's durable enough for a prototype and for the final product.

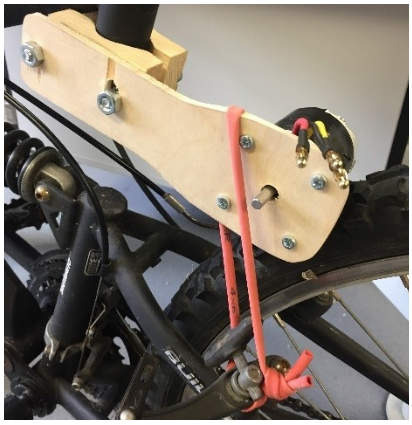
Although The design held up to stresses, I was forced to take another approach to powering the bike. Instead of using a belt drive directly to the back wheel I decided to use a friction drive system. This is simpler, however less powerful. I redesigned my idea in Fusion and also stress tested it to make sure it would not break. I made the made components from aluminium, and some bearing carriers from 3D printed ABS these will be strong enough for the test / prototype but should aluminium or pressed into the other parts for the real product. Once again, the model held fine under normal stress, so I increased the force until I found the structure became distorted. This is well out of the reach of any force that could be put on the components but shows that it is strong enough. Below is simulation under a normal operating load.



This shows the new design with a force of 20N acting parallel with the motor arm and shows displacement. The maximum displacement is 0.01mm, which is negligible. Interestingly one side flexes more than the other. Still, this shows aluminium is suitable for the prototype and so will be my main material of choice.

DRIVE METHOD TESTING

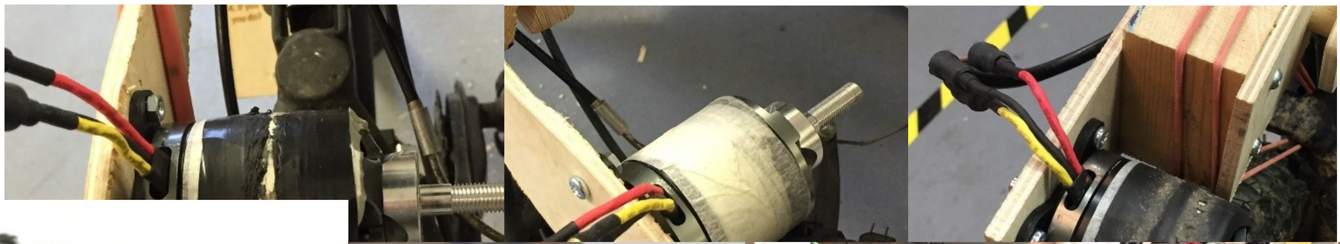
After testing driving the back wheel through the chain and trying to fabricate a toothed belt pulley, I was forced to change my design as I could not get it to work properly. I decided on a friction drive because it was simple and would work. It is not the ideal design but to make a functional product I will have to take this approach. I found that for a chain drive the chain was not long enough to stretch to the cog and got in the way of the rider. Additionally, the pedals span when the motor was activated and did not stop immediately when the throttle was released. This would lead to the pedals getting caught up in your feet and would not be ideal. However, this might work with a small motor and a pedal assist system, which only powers up when you pedal. I think this would be most effective as it also uses the built-in bike gears, but this is also the most complicated. I tried for many weeks to get a belt drive directly to the back wheel to work but could not design the cogs correctly. If I could have gotten this to work it would be the second best after the chain drive. However, after doing the calculations I found for the diameters of the cogs, the motor would not have enough torque and would be too highly geared. This is when I decided to switch to the friction drive, which at full speed would give a theoretical maximum speed of 30mph. A lower ratio would be even more ideal, but this would do for the prototype.

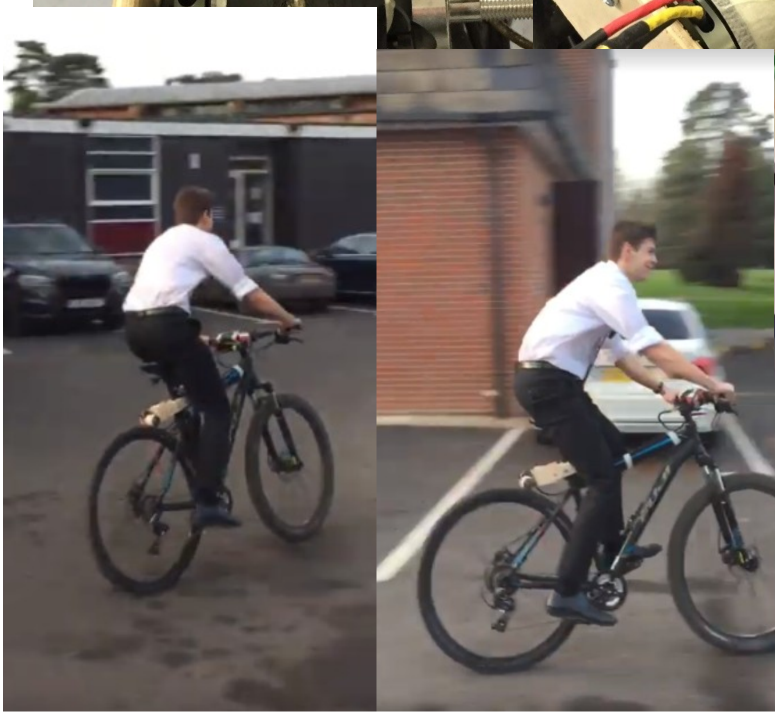


After building some prototypes, I found that the two factors which play a huge part on how much power is transferred to the wheel from the motor were contact pressure and surface material. I used rubber tubing to apply different tensions on the motor, with a higher tension resulting in more grip. However, the motor was still spinning against the wheel, as the tape I originally wrapped round the motor to keep it protected was quickly worn away. I tried different tapes, an inner tube and tried knurling some aluminium and trying them out. I found the knurled aluminium had the best grip, but due to the size of the motor I could not design a sleeve to go around the motor without casing a special diameter of tubing to machine. I finally tried sandpaper which worked the best on grip, but also wore away quickly.

Therefore, I decided to 3D print a sleeve to protect the motor and then cover it in sandpaper to get the best grip. The sandpaper would wear away, but it shows the principle for the prototype.

For the tension on the motor I decided to use springs for their durability over rubber, the large selection that is available. Air struts could also be a possible way of keeping pressure on the wheel, but I did not test this.





You can also see by these photos that the contact pattern is only in one place. If I could increase that contact area there will be more friction and less chance that the motor will slip. I decided a concave profile to match the tyre would work well. The information from these prototypes will allow me to design a final product which will overcome the problems I have come across so far.

Testing the prototype

These initial tests after each change to the design helped me identify what worked and what needed improving. I then made chages depending on the results and kept improving the design.

The results were promising so I decided to use this layout and design for my final prototype.

TESTING AND EVALUATION

IN-USE PRODUCT TESTING

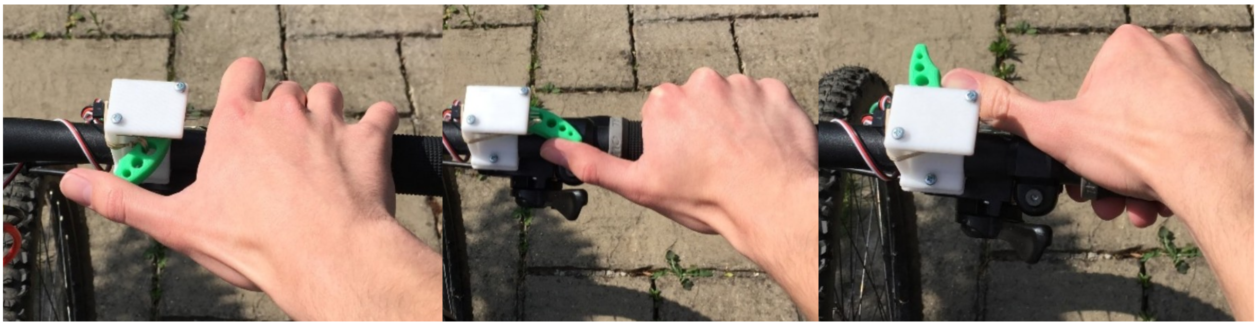
To test the durablility and suitability of the e-bike I will use the bike as I would normally and record what, if any, problems I encounter.

Over about a 2 week period I used my bike as much as possible – going to shops up the highstreet, leisure rides and a few outings specifically to test range and speed.

I used it with the motor in contact with the wheel all the time, even when I rode without the battery attatched.

INITIAL IMPRESSIONS AND TESTING

- **CONTROLS AND MONITORING**
  I designed the thumb throttle to be easy to reach and comfortable to use. This is the case when the throttle is in the mid position, but due to the wide range of the potentiometer the lever turns out of the area that your thumb can comfortably reach while gripping the handlebars. To initially start the bike you have to take your hand off the grip to bring it to the midway position to use it comfortably. However, this is also the case when you need throttle past the midway position. The lever swings all the way around, so you must take your hand off the handlebars and use the back of your thumb to push it all the way. It is functional but not suitable for consumer use. Furthermore, I used a rubber band in place of a small spring, which I was unable to locate while building the bike. Functional for the prototype, but not suitable for consumer use. I found the positioning and shape comfortable while in the midway position. The aesthetics are not suitable for production, and the circuit board is open to the elements. For a consumer product this would definiately have to be altered. The display which shows you power and battery voltage is also a feature of the prototype design, but is well positioned in the middle of the handlebars and is easy to glance at while riding. For the consumer verison this would be a simple LED bar graph or display which shows battery remaining and power output. All the components are connected using removable connections, which makes the bike modular. This was particulally useful during prototyping when I had to keep removing and installing the components.



- **MOTOR MOUNT, CLAMP AND BATTERY MOUNT**
  The motor mount is sturdy and functional, although I noticed several negitive points about it. Putting it on is difficult and finiky as you have to adjust both bolts on the clamp to make sure that the two bearing arms are paralell, and also at the right height to make good contact with the wheel. If it is too far up the tyre can sometimes be compressed by the force of the spring, and the motor arm can flip round to be on the other side of the tyre. This happens violently, and if someones fingers were in between the two plates they could be injured. A backstop would prevent this. The spring also has to be streched over the clips after instilation which is fairly difficult, and potentially dangerous. The bearings also

have to be lined up with reasonable accuracy, and therefore I designed some excess room to position the arms. This is useful, but also difficult and not particlully functional. The motor arm scrapes on the bering arm when it swings, although this could be fixed with a washer. The wire for the motor is also left free, with the excess wrapped around the frame. This is not ideal, and is not aestheically pleasing either. I would have to impliment a better connection for the product. I also found that while trying to adjust the clamp on the seat tube it scratched off the paint. This would not be acceptable for the finished product. There are also no safety features which stop items or fingers getting caught in the mechanism or in between the tyre and motor, which must be implimented on the final product. The battery mount is functional, with a satistying click when putting the battery in. It is very easy to install and remove but secure when in use. The mount is not of a production quality, but works well for the prototype.

- **TEST RIDE**

  After installing the battery, the motor beeps 3 times and is then ready for operation. The throttle control is finiky and only works when used in a specific way. For the motor to start initially you have to be moving very slowly. If too fast or stationary, the motor starts juddering and does not start spinning. In this case you have to wait for the motor to stop and try again. Once started however, the throttle works well and is responsive. As long as you don't stop moving, the throttle will start from 0 as would be expected, but if you come to a standstill you have to go through the process described. This is quite inconveneint and not what would be expected from a production bike. Interestingly, this seems less prominent when the battery is fully charged. This is probably due to the voltage being slightly higher, and therefore the motor having more torque at low speeds. This is somewhat expected as the motor is running at or below its minimum rated voltage. With a higher voltage battery this would likely not be a problem.

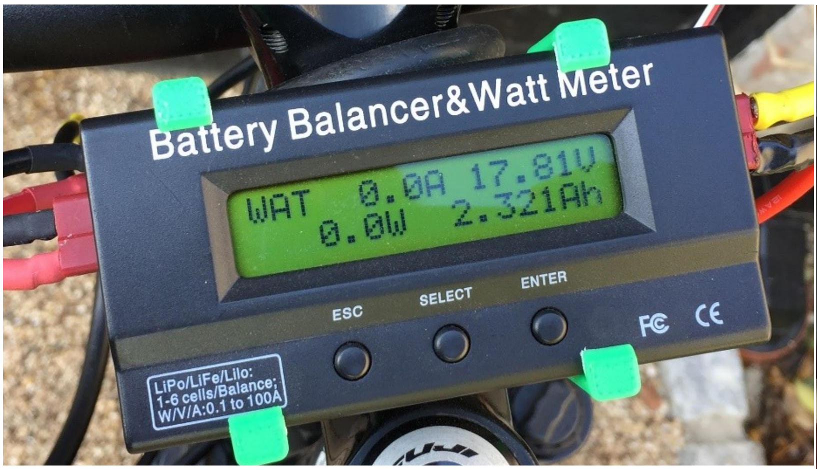
  The noise of the motor contacting on the back wheel is substantial, and definitely draws attention – not desirable for this product. The electronic hum that is common with these motors is not very noticable in comparison.

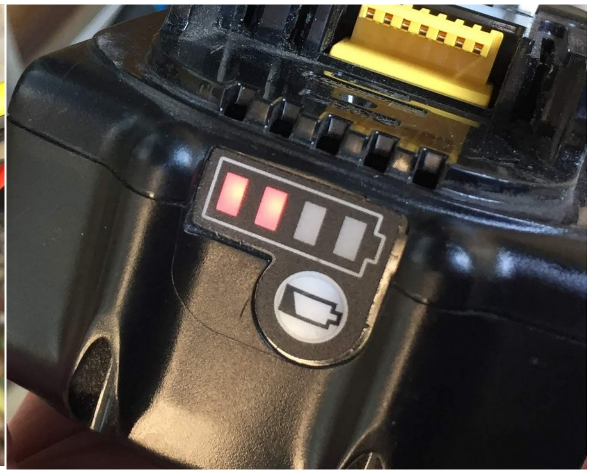
  The motor has exvessive torque once it gets running, so you must also match the throttle to the back wheel by lisitening to the noise from the motor contacting the wheel. If you apply too much throttle for the speed, the motor starts spinning independantly of the back wheel and destroys whatever protection or coating is around the motor body, as well as burning rubber from the tyre. Below shows what happens when the motor spins.


- • **RANGE AND PERFORMANCE**

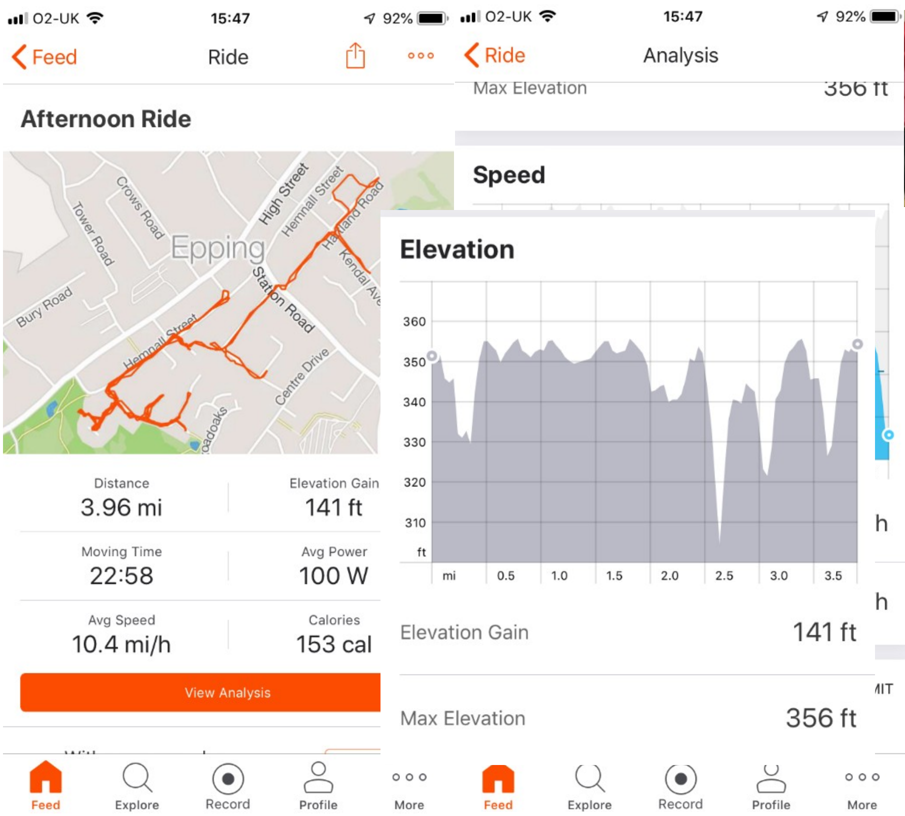
  I tested top speed and range on the bike. Speed was easy to test on a long empty road, however range was difficult to test to it's extent. As the ESC is not designed to work with the Makita battery, there might be a kind of limiter or over-discharge circuit that I am unaware of in Makita products. With the intetent of not damaging the battery I did not want to discharge it fully. I rode for about 4 miles, with about 2.4 Ah used as reported by the watt meter. The battery idicator on the battery showed half – about what I would expect. This means in theory the bike will go a total of 6 miles before the battery is exhaused. This could be extended using a larger makita battery, which are sold. The one I used for the test was a 4.0 Ah 20v battery. When full charged the battery was at about 20 volts, and after a long ride dropped to as low as 16 volts. Under loading the voltage also drops to about 2 volts below whatever it is at the time. It is noticably more powerful when the battery is fully charged at 20V, and after my range test of 3 miles, the power was significatny reduced. I relied on the motor heavily while riding around, usually crusing at an indicated 350-400 watts on the battery meter. I saw it go as high as 450 watts in some cases. Although this was about the maximum. I used the Strava app on my phone to measure speed and distance. The maximum speed I reached was about 25 MPH, with an average speed of

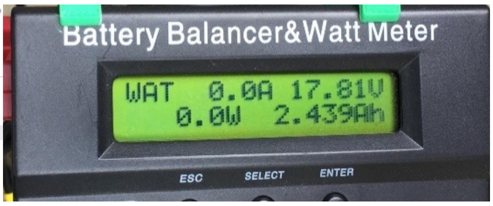
10 MPH on most of the rides. This is fast enough for the consumer product. The motor makes starting off from a standstill much easier and going up steep hills a breeze. I found that it will only work in dry condions, as in the wet the back motor just spins. Overall the performance is acceptable.





A 3 mile bike ride, battery usage.





The longer 4 mile ride statistics, with a second highest speed of 24.2MPH.

USER FEEDBACK

For my user feedback I got my various people to ride the bike and share their thoughts on it. I had 3 different people try it, with varying levels of input from myself. They are all competent on bikes, although I told them to go slowly and cautiously, given the quirks of the bike and the absence of helmets. They all ride bikes on a regular basis to the shops and in the forest, so are idea target users for the e-bike.

The first subject had seen me ride the bike previously so was easily able to easily install the battery. The controls were intuitive enough for him to ride off with little guidance, apart from the specific starting procedure stated above. The battery was fully charged so it was straightforward and started immediately. He controlled the throttle as I found it works best intuitively without needing to be told, and was able to stop easily. The only comment was that the throttle was difficult to operate.

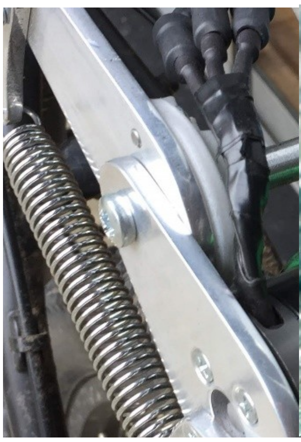

The second person to try my bike had also seen me use the bike before, so also easily installed the battery. Given the success of the first test, I gave little to no instruction for the first time to see how he would react. He got on the bike and before I could say anything, put the throttle to 100%. This casued the motor to spin on the back wheel, with the smell of buringing rubber and the sound cracking of 3D prints as he rode off down the street. Putting the throttle to full straight away would not usually be a problem on an electric vehicle – but in this case where the motor can spin it is not good. This resulted in the 3D printed sleeve that I printed for the motor breaking. This concluded test number two. He comented that it was no different from a normal bike but the throttle was awkward.



Test 3 was unconclusive, as the seat was too high for the user, and given the dificulty in adjusting the seat with the motor attatched it was agreed that she would just manage with the seat how it was. Only a shot test ride, but she had difficutly using the throtle and keeping the bike balenced going at a slow speed, keeping in mind that you must semi-remove your hand from the handlebar to reach the throttle. The battery was installed easily however.

PROBLEMS DURING TESTING

When I first rode the bike, I found that the small M3 screw which takes the force of the motor and spring and attaches the motor plate to the spindle, bent and stretched under the forces. As this was the first test I did, I had to modify the bike to continue testing. To solve the issue I drilled and tapped a larger thread to accommodate a larger bolt. This worked well and fixed the issue. I after the second test the motor sleeve also split. To get traction on the back wheel after removing it and to protect the motor I bought some grip tape designed for steps. I wrapped this around the motor, which worked well, but didn't have as much contact area as the concave motor sleeve.



SPECIFICATION CHECK

To see if I fulfilled the task I set for myself in designing an e-bike, here I check the finished product against the specification I wrote earlier. This will help me more accurately pinpoint the good and bad areas of my design.

RANK	SPECIFICATION	LEVEL OF SUCESS? DETAILS	QUANTITATIVE/QUALITATIVE CRITERIA	QUANTITATIVE/QUALITATIVE EVIDENCE? FAIL/SUCCESS?
1	**FUNCTION –** My kit should be easily fitted and taken off and be able to hold up to rough off-road conditions. This will make it worth buying.	The kit it not easy to remove or put on and is difficult and time consuming to adjust. As there was no rain, I was only able to test it no dry dirt tracks, but this seemed no problem for the kit, and all the components stayed secure while riding and going over bumps etc.	Qualitative – does the user think it has met the specification? Does it take under 10 minutes to attach and use? Is it resistant to dirt and mud –yes/no.	Kit took about 30 minutes to install all parts and adjust, testing in between to make sure everything works. Therefore, I have not met the specification in this aspect.
2	**UNIQUE SELLING POINT –** The kit should appeal to off-road enthusiasts more than road users to fill a market gap and sell more units.	The kit is not very well suited for off-road use, wet conditions cause it to become unusable, and there are other friction drive products which do the same job.	Qualitative – how does the bike appeal compared to a purpose-built off-road bike from an enthusiast's perspective?	This is also a failed specification point. In comparison to the bikes at Halfords, this under performs in all aspects apart from speed. Not what would be needed for an off-road enthusiast.
3	**PERFORMANCE –** my conversion kit should perform as well as or better than existing electric bikes to make it appealing to users who want an electric bike.	The bike is reasonably powerful and goes quite fast, although underperforms on range and suitability for it's intended use.	Quantitative – does the power output reach 400 watts? Does it reach at least 20mph? Does it still work after riding through the intended conditions?	I have achieved this specification point – the bike reaches upwards of 450 watts and goes 25MPH. I was unable to test in harsh conditions, but the product holds up under general day to day use.
4	**SAFETY -** The batteries that I may use can be dangerous if handled incorrectly, and if the user falls off the conversion should not injure them. It should be designed to reflect this.	The throttle resets to 0 when released and there are no exposed electrical connections. However, there are no measures to prevent clothing or fingers getting trapped in the back mechanism.	Quantitative – test the kit against the standards – it will either pass or fail.	Kit would not be suitable for consumer use as it not optimised for safety.
5	**ERGONOMICS –** However I implement the solution it should be comfortable and should not hinder the rider in any way, and any pieces that come in contact with the rider should be designed to fit the user.	None of the components interfered with the rider while in use, and the throttle was comfortable, although not easy to operate.	Qualitative – it is comfortable? Different users may have different opinions.	The users who tested my bike all said that the throttle was difficult to operate, but in a good position. The other parts of the bike were not an issue, so I have mostly achieved this specification point.

6	**MATERIALS –** The conditions that my kit will be used in can be challenging and rough. The kit should be made of a material which allows it to be durable and aesthetically pleasing.	I had no issues with the aluminium body of the product, but I found that the 3D printed parts broke easily, and an undersized screw also bent.	Quantitative – is it suitable for environment? Does it withstand the stress of the motor – does it bend or flex under 2 kilos? Have the materials corroded or has the dirt interfered with the motor?	I had no problems with the majority of the materials, and the aluminium was definitely suitable for the product. There was no flex, and the grit and rubber which accumulated did no affect the performance. Having being left outside under cover, none of the materials showed any signs or corrosion or stress.
7	**WEIGHT –** It should be as light as possible to avoid having to carry more than is necessary of its own weight.	The kit is overall quite light, but some weight could be saved.	Quantitative – the kit should weigh no more than 2 kilos.	Without a battery the kit weighed 1.5 kilos, with the battery 2.1 kilos. This was semi-successful.
8	**AESTHETICS –** It should be aesthetically pleasing to fit with the existing style of the bike and to appeal to the user.	As my product turned out to be a prototype, the aesthetics are not what would be expected from the production product.	Qualitative – is it aesthetically pleasing? Different people may think differently.	Everyone who saw the product remarked that it looks good, and was very unassuming, despite it being a prototype. Technically this is a fail as it did not blend with the rest of the bike well.
9	**COST –** To make electric bikes more accessible to users they need to be less expensive.	The manufacture cost includes stock material and components, but not a battery.	Quantitative – should not cost more than £300, preferably as low as possible.	Kit cost about £130 to make, not including a battery, which costs around £40. Therefore this was a success.
10	**FINISH –** The finish should be durable to hold up to adverse conditions and should fit with most existing bikes.	The finish is good, but not what was set out in the specification.	Qualitative – is it what would be expected from the price? Does it hold up to the intended conditions yes/no	Although the finish was clean and professional looking, it did not blend with the bikes aesthetic. However, for a low price I think it is acceptable. This was semi-successful.
11	**TARGET MARKET -** My target market is off-road cyclists so should appeal to what the target market needs and wants.	Prototype shows working principle, but not finished form which would make it suitable for target market.	Qualitative – does the target market like it? Different opinions on features etc.	I was not successful, as the bike cannot function well off-road.
12	**SUSTAINABILITY –** The product should be durable to last as long as possible, but when the product does come to the end of its life cycle it should be recyclable and not cause any harm to the environment.	The materials I chose to make the prototype from are all recyclable	Quantitative – are the materials recyclable, disassembly needed, environmental impacts of material.	Success – it is all recyclable and is well build to last for many years.
13	**MANUFACTURE –** It should be able to mass or batch produced.	Despite the prototype design, it could me commercially manufactured, as there are no processes which are un-replicatable by mass production.	Quantitative –are there alternative methods that can apply to mass production? If not it cannot be used.	Success – the design can be mass and batch produced, although this is the prototype which is not meant to be mass produced.

14	**SOCIAL, MORAL, SPIRITUAL -** My product should not offend of conflict with any group or religion.	Does not conflict with any religions etc.	Quantitative – does it conflict with anyone or any culture?	Success

SUMMARY OF SPECIFICATION CHECK

Overall, my bike works well, and I am pleased with the result. However, it only met 7 of the 14 specification points, specifically the most important ones which gave my product a specific place in the market. To be a commercial success my functional prototype would have to have many improvements in design, performance and aesthetics. By quantitative data I have not fully achieved my brief, although I have learnt what I should do if I were going to commercially produce the bike.

RISK ASSESSENT

Due to the nature of my product, being a prototype, there are several safety hazards which would be unacceptable for a consumer product, so must be observed when testing the bike.

RISK	HOW CAN IT BE MINIMIZED?
Clothes could be caught up in the motor and wheel.	Avoid wearing long clothes and tie back long hair, alternatively I can design a shroud to pro
Motor pivot could spring back and injure	Either a different mechanism which would eliminate the problem entirely or make a guard to prevent fingers getting caught in it. Keep fingers away when installed.
Bike goes 25MPH and a crash could cause serious injury	Wear a bike helmet and use caution when using the bike.
Spring can trap skin when it retracts	Use pliers when stretching the spring to hook it round the mount.

AREAS FOR IMPROVEMENT

- Throttle system – instead of a throttle an Arduino could be used to sense the speed of the wheel, when apply a slightly higher throttle automatically. This way the motor is always helping you, and you do not have to think about controlling it. If a manual throttle is still required then a simple twist grip could be used, which would have a much more usable range of movement than the thumb throttle.

- Aesthetics – although the parts are functional, the lack the finish and style that would be expected of a finished product. A proper housing and protection for each of the components would be needed.

- Range – the distance tested was 4 miles, although the power dropped towards the end of the test. A much larger battery in the order of 10Ah would be more suitable to make the range closer to 10 miles, preferably even more.

- Battery – apart from capacity, a higher voltage would be needed for this motor. As I have seen the performance is much better when the battery has a higher voltage.

- Drive method – although the friction drive works, it only works in dry conditions. The motor is also too powerful, so spins. I would have liked to implement my original plan of a direct belt or chain drive, which would have improved efficiency, noise and power. It would also work in more diverse conditions.

- Motor pivot – for this prototype the force of the spring was not suitable for the configuration of the frame. The spindle dug in to the plate, and the bearings were separate of each other which made them difficult to line up. I would have the bearings lined up in one single piece of aluminium to prevent this.

- Frame clamp – was heavy and not convenient to install. It also marked the seat tube. I would make it from a softer material and with a simple quick release, to eliminate the two bolts which were difficult to get lined up and adjust.

- Configuration – I would move the speed controller to be part of the motor assembly. This way only a battery cable has to be run, and the throttle. Fewer wires to deal with.

- Motor protection – this will stop debris and moisture from entering the motor and stop the user from getting things caught in the motor.

- Shape of motor arms – From the stress simulation I found that I can remove a lot of excess material from the arms and still retain its strength.

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