An Exploration of Electric Vehicles

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Spring 2022

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A Senior Project submitted to
The Division of Science, Mathematics, and Computing
of
Bard College

by
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Annandale-on-Hudson, New York
May, 2022

Abstract

The SPROJ will be an investigation into what it takes to build an electric vehicle, from design to engineering to the manufacturing. In the past couple years especially, companies have developed their own electric vehicles in search of an environmentally friendly and energy efficient way of using our Earth's resources. This project aims to produce a greater understanding of what this development entails. The main ideas were to develop a design that would be the blueprint for the vehicle, look into the physical properties of the materials and create an efficient power conversion from motor to wheels. The process and organization of this project clarifies how the development of electric vehicles today needs the collaboration of companies, utilizing their research and aspirations to achieve optimal output of power and energy efficiency using current technologies.

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Dedication

I would like to dedicate this project to my family for their continued support in my endeavors.

Acknowledgments

I would like to acknowledge the support of the Physics Faculty and students. Especially Professor Paul Cadden-Zimansky for his advice throughout my senior year.

1
Conception

Building a custom vehicles has been a part of manufacturing since the first motor vehicles were produced. Motorists of all backgrounds have taken up their tools and modified/built vehicles of their own design and desire. Following the current trend of electric vehicle (EV) manufacturing by established and entrepreneurial motor companies, motorists have taken up this challenge and begun building their own. To many this may seem like the first attempt at EV manufacturing, however the history of EV's actually dates back to the 19th century. Through the development of electromagnetic theory, starting with Barlow's Wheel in 1822 which was the first rotating device driven by electromagnetism, to the construction of the first electromagnet. During the mid 19th century many inventors and scientists contributed in developing our current understanding of electromagnetism, and due to this progress the first electric motor was created. Moritz Jacobi created a rotating electric motor in 1834 which was notable due to its production of mechanical power. These initial steps in researching electromagnetism led to the development of the first electric vehicles. Through developments in electric motors and electricity storage technology, we are currently able to produce efficient and powerful EV's. With the importance of environmentally friendly vehicles necessary now more than ever. We are grateful to our developed knowledge of electromagnetism. But to further expand the horizons of electric vehicles, experimentation done by current engineers is an essential aspect of progressing the availability and reliability of these vehicles.

1.1 Why Electric

The alternate fuel of the future for all road/off-road vehicles, at this point not set in stone yet a likely candidate is electricity. This is mostly due to an increasing necessity for more environmentally friendly vehicles. There is another type of engine which can also be considered as a zero emission engine, and that is hydrogen. A few vehicle manufactures over the past couple decades have tried their hand at producing a hydrogen engine vehicle, however they were unable to make an impression in the market, a major issue is due to the cost of hydrogen gas. But although these hydrogen engines are zero emissions, the process by which hydrogen gas is synthesized requires high energy inputs for only a small amount of usable hydrogen gas and therein resides the main problem, how to synthesize hydrogen while considering energy and cost efficiency. When initially considering the type of engine/motor to use, I only briefly looked into hydrogen as I had already decided that an electric motor would be the most cost efficient of zero emissions power source. Of course if we consider how our power supply is produced, in the case of electricity, then it must be said that there are multiple ways that electricity is created. Fossil fuels are often used to generate electricity through a power plant which have higher efficiencies then internal combustion engines, 45 percent and 33 percent. Considering even by using fossil fuels to create electricity there is an energy efficiency advantage over vehicles using combustion engines, EV's are albeit a small step towards cleaner travel. There exist other processes for electricity production that produce zero emissions, ways such as solar, wind, hydro-power. These processes have individual drawbacks and needs but for this project merely looking into ways of electricity production was of importance, in taking a glimpse at a larger framing of EV's. It is necessary to consider the process of energy creation as more EV's are introduced into the automotive market, and as we seek to reduce our carbon footprint. However current manufactured EV's are well above an affordable price for many. Therefore why not build our own? Where we can control what we want from a vehicle, and keep to our budget and custom fit to particular needs. How difficult can it be? Through the following chapters I will explain the process I went through in realizing this project.

2
The Vehicle

This chapter will delve into each aspect of the vehicle, from its design and components, to the physics that helps in understanding the technology and calculating the external forces of the environment and overcoming those forces.

2.1 Design

The design for the vehicle focused on the following aspects: small footprint, lightweight, minimal, and independent suspension. Independent suspension allows for a more versatile vehicle able to deal with varying terrains. The basic frame design is a narrow front with a wider rear, the narrow front allows for less wind resistance at the point of most resistance and the wider rear is necessary to accommodate enough space for the motor, driveshaft and driver. An important first step in vehicle manufacturing is the design or schematic for the building process to follow. The use of computer modeling programs are ever more important in the designing process; able to map any design by starting with simple 2D sketches, that can be turned into 3-Dimensional model of a vehicle. The modeling program used for this project is Autodesk's Fusion360, which has a relatively easy to learn interface and many online resources. I was able to get an understanding of Fusion through Autodesk's online lectures and tutorials, for more specific information about vehicle design. YouTube provided a vast collection of knowledge from other motorists that had create their own designs. Now with a basic understanding of the tools and process, it was possible to use my general ideas for shape and space to make a sketch of the frame. The vehicle would be constructed using metal tubing, two symmetric upper and lower portions separated by about 6" which would be held by 8 vertical tubes. First the floor section was created then mirrored 6 inches above to form the upper section, these were then connected using vertical lines.

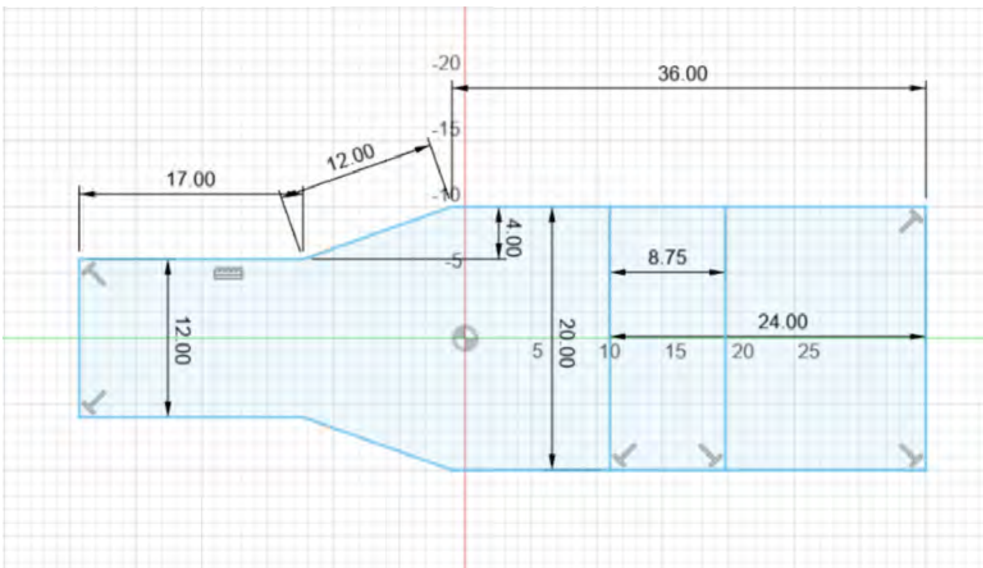

Figure 2.1.1: Lower frame section sketch with dimensions

Taking the sketch and using the tool "pipe" which allows the user to select the each line in the sketch and impose a 3-dimensional tube onto it, is the next step in realizing the design. This "pipe" tool allows for specification of the outer diameter(OD) and thickness of the tubing. How these dimensions were decided on are discussed in section 2.4. I now have a usable model for the frame which provides the dimensions to be followed for the build, however designs for the suspension arms and brackets are still needed. Due to a lack on understanding on how joints are formed in Fusion, I found it more useful to create separate design files for the suspension arms and brackets. These designs would be used mainly to define the cuts and bends needed rather than having a visualization of the final product.

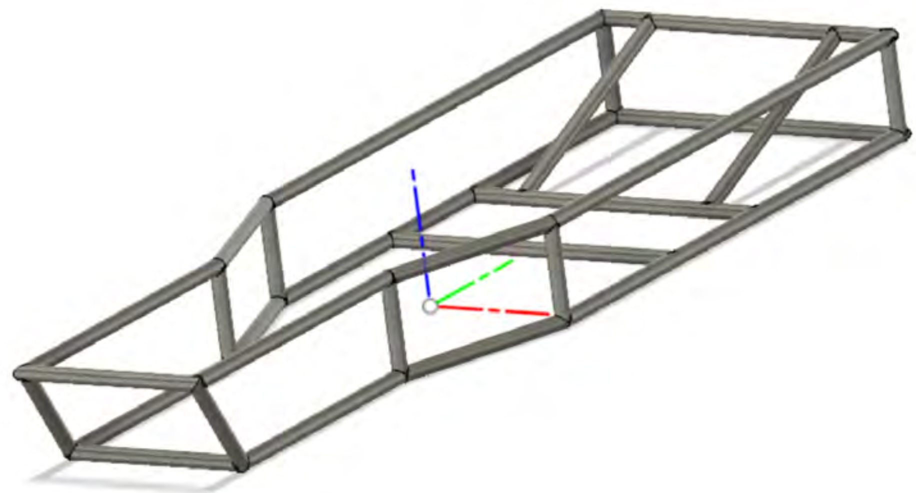

Figure 2.1.2: Frame structural design from Fusion 360

2.2 Power-train

The power train is the combination of components that drive the vehicle; the motor, battery, sprockets, chain, driveshaft, and axle shafts. The battery provides energy in form of voltage and current to the motor which creates mechanical energy in the form of rotation. A sprocket, which can be thought of as a gear, is one of a set of toothed wheels that alter the relationship of speed of the driving mechanism to the speed of the driven mechanism. A sprocket is a subset of gears that are used with a chain which acts as the connection from driver to driven sprocket. This vehicle power-train makes use of a chain to connect the electric motors sprocket to the sprocket mounted on the driveshaft. The driveshaft is a horizontally mounted rod that is fixed to the frame using mounted bearings, these allow the drive shaft to rotate about its principal axis, the sprocket which is fixed to the shaft is then driven by the chain.

As stated above in the design, the goal is to create independent suspension, this means that all wheels must be able to move up and down independently of each other, in order to achieve this for the rear driven wheels, axle shafts are used. Axle shafts make use of two Universal joints that allow for linear movement while undergoing rotation. At one end they are connected to

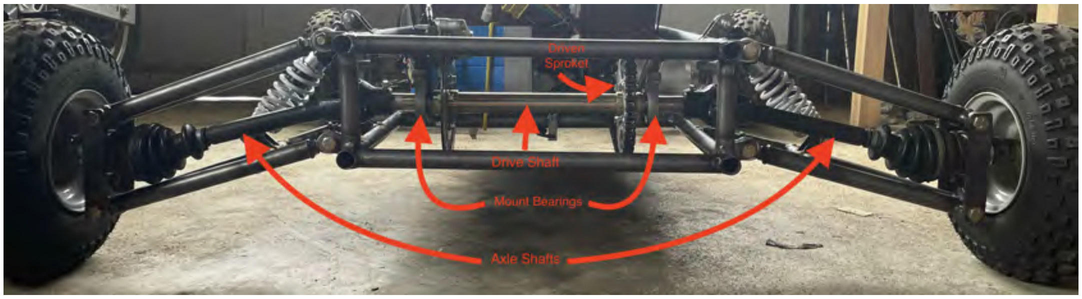

Figure 2.2.1: Completed power train of the vehicle

the ends of drive shaft, to drive them, at their other end they are connected to the wheel which they then drive.

2.2.1 Electric Motor

There are two broad categories of electric motors; they are AC (alternating current) or DC (Direct Current). Researching a better subset of motors for electric vehicles, it was found that the best options would be either a 3-Phase AC or a brushless DC motor (abbreviated as BLDC). Looking into the two, 3-Phase AC motors typically have higher efficiency and power ratings while operating at higher voltages than DC motors. To control the speed of these motors; an AC motor receives a sinusoidal wave current which generates smooth accelerations and transfer of power, a 3-Phase motor receives 3 sinusoidal waves at a specified offset so that the magnetic field of one stator, a stator is the stationary component of the electromagnetic circuit which generates magnetic fields around the rotor and induce rotation, is peaked and then dissipates while the next magnetic field generates increasingly stronger fields. A similar principle is used for driving the BLDC motors using a controller which takes the direct current (DC) from the battery and converts it into a trapezoidal waveform that delivers the current to the appropriate stator in the same way as the AC. The trapezoidal nature of the current waves causes slower acceleration and lower efficiency.

However, to get the power required given an estimated weight and desired maximum velocity for the project, AC motors are expensive and, due to limited budget, out of reach. Another consideration is that DC motors and, more specifically, brushless DC motors, have advantages

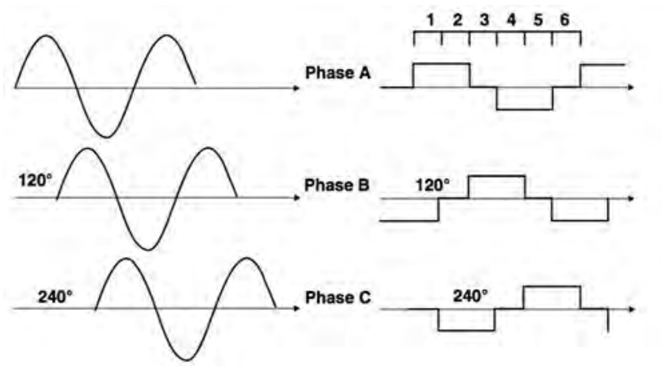

Figure 2.2.2: The phase wave pattern: the left of an AC current, the right a DC current transformed into a trapezoidal current

with both size and weight. Why specify brushless? There is no physical contact of materials within the motor, meaning that the energy usually lost to heat generated by friction in brushed DC motors does not occur. This translates to a more energy available to drive the rotor. For these reasons, choosing a BLDC for this project is the best option given power per cost and availability of kits that include current and variable speed controllers. Searching for a relatively inexpensive motor, with a power rating and suitable load capacity of 200kg, a 3000W 72V BLDC motor was chosen. This motor works as follows; the center rotor is a permanent magnet having north and south poles, the outer part, known as stators, is wound with wiring which, when a current is applied, creates a magnetic field. There are multiple stators surrounding the rotor which is the permanent magnet. To spin the rotor, a current is applied to one pair of stators which generates a magnetic field and pulls the rotor in that direction. The BLDC has a phase degree of 120°, which which controls the 3 pairs of stators. The controller converts the direct current into a trapezoidal wave current; at a wave's peak the stator has the maximum pull on the rotor, which is almost before they are matching each other. The current wave then takes decreasing steps, dropping the magnetic field and thus the pull from this stator. The next wave form is ramping up at the next stator, pulling the rotor to its next position, and so forth. To know when the current waves are needed, Hall sensors measure the magnetic fields on the stators, they determine when the current is ramping up or down. Basically, speeding up means the current waveforms are occurring at faster rates, and smaller gaps of time switching magnetic fields from one stator to the next, this rate of switching means increasing rotations for the rotor, typically measured in revolutions per minute(rpm). Taking a look at the physical properties of the motor is important in determining our expected velocity and confirming that the mounting bracket will hold the motor fixed. Let's first look into the torque produced, because we will need more background before calculating expected velocity. Using torque formula:

$$P = \tau\omega$$

$$\omega = 2\pi n_{rps} = \pi n_{rpm}/30$$

$$\tau = 30P/\pi n_{rpm}$$

Where P is the motors rated power in Watts, τ is the torque in Newton meters, and ω is the rotating frequency which is converted into units of rpm. The max torque that the motor will produce due to rotation was then calculated using the motors specifications for power and maximum rpm,

$$\tau = 5.85Nm$$

2.2.2 Gearing

There are two sprockets one connected directly to the motor's rotor, the second is mounted on the driveshaft, they are called the driver and driven sprockets respectively. The driver and driven sprockets are connected by chain to each other this is how the motors rotation is used to drive the vehicles rear wheels.

A mechanical efficiency between two gears, or sprockets in this case, is given by the ratio:

$$GearRatio = T_{driven}/T_{driver}$$

Where T is the number of teeth, grooves, on the sprocket. This project used sprockets, of size $T_{driver} = 10$ and $T_{driven} = 41$. Giving the ratio:

$$GearRatio = 41/10 = 4.1$$

The ratio can be used to find the rpm of the driven sprocket given the known rpm of the driver.

Figure 2.2.3: The chain drive setup of the vehicle, displaying the sprocket size between driver and driven

2.3 Expected Forces

The vehicle experiences a number of forces during operation. These forces combined are the total force the vehicle's motor must match to achieve constant velocity and exceed in order to accelerate.

2.3.1 Normal

The normal force is a fairly common force discussed in physics, it is calculated for a vehicle on a flat surface meaning the normal was simply the force due to gravity, g, and the vehicles mass, m. If only considering the vehicle's weight and its components then this would be the vehicle's resting weight, however the drivers mass is needed to calculate the vehicles normal force when in use. In order to calculate the initial expected weight(normal force) of the vehicle before any assembly, a sum of the mass of each part ordered was done, the result was $m_{initial} = 75kg$. Using this estimate of weight I was then able to calculate the normal force. Where $g = -9.81m/s^2$,

$$F_{Normal} = mg$$

$$F_{Normal} = (75kg) * (-9.81m/s^2) = 735.75N$$

This calculation however only takes into account the weight of the vehicle and does not include the driver, the drivers weight $m_{driver} = 77kg$ this makes a new normal force of:

$$F_{Normal} = (75kg + 77kg) * (-9.81m/s^2) = 1491.12N$$

Using this value, I then went onto calculating the Rolling resistance force.

2.3.2 Rolling Resistance

The rolling Resistance force can be thought of as the frictional force between the vehicles wheels and the surface, this is the force that the vehicle must overcome to move. This force is mostly dependent on the weight or normal force and a coefficient which represents the frictional resistance of the two materials in contact. For this vehicle the intended surface meant to be driven on is asphalt, so I need the coefficient of friction for a rubber tire on asphalt. Many sources exist for tire on asphalt friction coefficients, resorting to one which gives values for multiple tire types and estimating it to $c_{friction} = 0.75$

$$F_{Resistance} = F_{Normal} c_{friction}$$

$$F_{Resistance} = (1491.12N)(0.75) = 1118.34N$$

This is the initial force the wheels must overcome to move the vehicle. Then when the vehicle is moving this resistance force changes to what is called rolling resistance force, this is a greatly reduced force as the vehicle only needs a fractional amount more force to keep the vehicle moving, the rolling resistance coefficient is $c_{RollResistance} = 0.02$. To find the expected velocity, calculate the force of rolling resistance as it the active for felt while driving, the Resistance force previously calculated is necessary in considering the initial force output of the vehicle.

$$F_{Resistance} = F_{Normal} c_{rollresistance}$$

$$F_{Resistance} = (1491.12N)(0.02) = 29.82N$$

2.3.3 Aerodynamic Drag

Aerodynamic drag is a force due to the flow of wind in opposition to the vehicles movement. A simplification for this calculation without extensive experimental analysis is necessary for this project, as experimental analysis would require a wind tunnel. This simplification will be that the aerodynamic drag of the vehicle is dependent solely on the frontal shape, the shape in direct opposition to the flow of air, which will expedience the most wind resistance. In the case of this vehicle the majority of the aerodynamic drag would come from the drivers seated position, which I estimated to be a rectangle, with height from the lowest portion of the frame to the top of the drivers head.

$$F_{AerodynamicDrag} = 1/2 A\rho v^2 c_{Drag}$$

Similarly to the frictional force, aerodynamic drag is dependent on a coefficient, known as the drag coefficient, c_{Drag}, the shape of the object in direct resistance to air flow is the main component in the determining the drag coefficient of a vehicle. For the simplification of the vehicle and drivers shape as a rectangle the drag coefficient is, $c_{Drag} = 0.8$. The frontal area is another factor for calculating the drag force, using the idea of estimating the drivers upper body as a rectangle, I measured an area from the bottom of the vehicles seat to the top of the drivers helmet and the width of the most exposed potion of the body to wind resistance, $A_{FrontalArea} = 0.28m^2$. The fluid density in which the vehicle travels is an factor, $\rho = 1.225kg/m^3$, the density of air.

2.3.4 Total Resistant Force

The total force acting against the vehicles motion can be written as,

$$F_{Total} = F_{Aero} + F_{Resist.}$$

$$F_{Total} = 1/2 c_{Drag} * v^2 A\rho + Mgc_{friction}$$

From this the fact that the force is dependent on the aerodynamic drag force, with constant rolling resistance, which is dependent on the rate of travel makes discerning the expected velocity of the vehicle difficult.

Given a specified total force calculating the velocity of the vehicle would be done using,

$$P = F_{Total} v/\eta$$

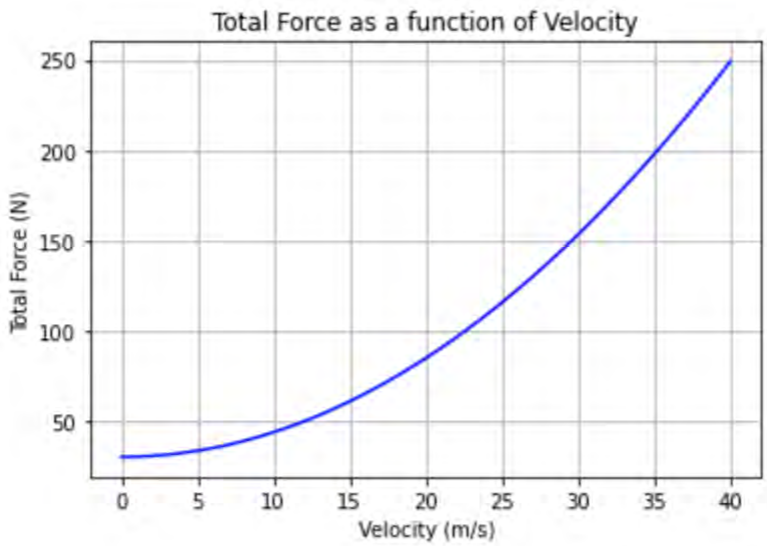

Figure 2.3.1: Showing the effect of velocity on the total force opposing the vehicles forward motion.

Where η is the transmission efficiency or translation of power from motor to the wheels, and P is the power rating of the motor, P = 3000W.

2.4 Material

The material used for the vehicle's construction is steel. The form and dimensions of the steel need to be determined, start point for determining the proper form to use. By researching the construction of automotive frames, I found that round tubing and square tubing were the most frequently used. The advantage however goes to round tubing due to the distribution of strength and 20 percent lighter than square tubing of the same strength. By using round tubing for the project it made it possible for the frames design to be as minimal as possible while maintaining its rigidity. Using the lightest material possible would also allow for a higher power output considering the weight capacity of the motor. Since form was decided upon the grade of steel was the next consideration, this project used McMaster-Carr for sourcing the material which offers a range of steel grades. McMaster also provides descriptions for each steel grades uses, given its strength and carbon composition. This narrowed the selection down to two steel grades, then considering price per foot of each material the selection was reduced to one. 4130 alloy steel was used for this project, due to its malleability and strength. The composition of this steel grade makes it a good material to weld with. A high elongation percentage for metal means the steel can be bent and shaped without inhibiting the integrity of the metals strength. Tubes with an outer diameter of 1" and 0.049" thickness were chosen. The total amount of

Mechanical Properties	Metric	English
Modulus of Elasticity	205 GPa	29700 ksi
Ultimate Tensile Strength	670 MPa	97200 psi
Tensile Yield Strength	435 MPa	63100 psi
Rockwell B Hardness	92	92
Elongation at Break	25.5%	25.5%

Figure 2.4.1: Mechanical Properties of 4130 Steel

tubing required for the project was calculated from the designs for the frame and swing arms created in Fusion 360. Along with the steel tube, the project would need sheet metal as well. Sheet metal would be used for suspension brackets, motor mount, rear wheel hubs, and other mounting brackets. The sheet metal needed thick enough to support the vehicles weight without deforming and allow for strong weld connection to the tubing. By using the same grade 4130 steel, the welds between sheet and tube would make strong bonding. A 12" x 24" sheet of 0.125" thick steel was purchased, this would provide more than enough material to construct all the known brackets and mounts.

3 Building

The building of the vehicle was split into preparation and assembly. Preparation included collecting all the materials and tools needed for the project, then moved into the cutting, bending and mapping of the vehicles sections. The assembly consisted mostly of welding sections together and then properly mounting components that were purchased.

3.1 Preparation

Using the design from Fusion 360 as a template, it was possible to begin the actual construction of the vehicle. The designs provided the specific measurements for cut lengths and bend angles, which were done before any welding took place. Preparing all pieces in advance allowed for an efficient work flow and a rough mapping of all components to ensure that the designs were properly followed. The designs created were a simple frame layout including the swing arms. This meant that for pieces such as the motor and steering rack, it was important to first see how the frame would be physically manifested. Then carefully consider where these pieces would mounted, how to optimize the seating position and placement of controls for operation.

3.1.1 Bending

Bending was done using a hydraulic press, to bend the tube it was first packed with sand in order to keep a pressure within the tube acting to resist the metal from folding in on itself. Once the tubes were packed the ends were sealed with duck tape, then placed in the press. Then the press was pumped forcing the pipe to bend at the centered point, Figure 3.1.1. As there were no degree indications for how much the tube was being bent, it was necessary to check the bend angle by using a template. By using the designs measurements I translated these onto cardboard, then made cutouts and used them to verify bend angle for each tube section. The count of pumps it took to achieve the necessary angle was recorded for the part, this was then repeated for all sections with the same bend angle. Checking against the template to ensure consistency for each section.

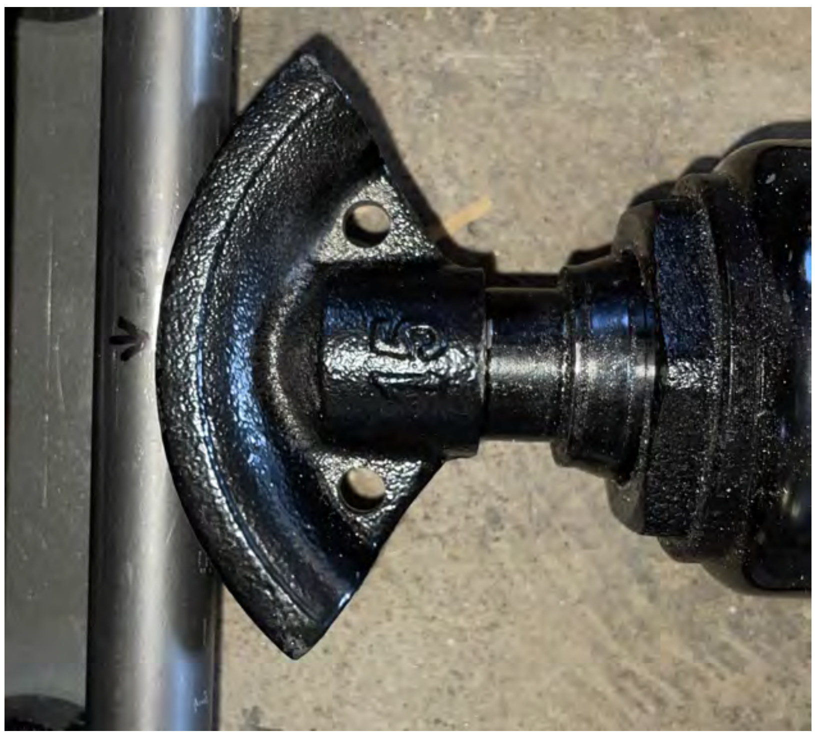

Figure 3.1.1: Tube section mounted in Hydraulic press, marking indicates the bend point.

3.1.2 Cutting

Cutting was needed for both the tubes and sheet metal. Cutting the sheet metal was done on a band-saw which allowed for straight well defined cuts. The tubes were cut depending on placement. If their ends were being welded to other tube sections, cuts were done using a tube notcher. To create solid welds between the pieces of the frame, a 1” tube notcher was used to cut a perfect match to the adjoining tube. For pieces that needed specific angles cut, such as

Figure 3.1.2: Fit of a notched tube to adjoining section

the swing arm sections and a few frame cross sections, the tube mount on the notcher can be rotated to form different angles, Fig. 3.1.3. For the rest of the tube sections that only required straight cuts then an angle grinder with a cutting wheel was used. Once cutting is completed an important step before welding could be done is cleaning the section ends that were going to welded. To form strong welds the metal must be clean of debris. An uncleaned welding surface causes the molten metal to splatter, which is hazardous, and also results in fast oxidization (rust) within the weld. Cleaning the surfaces was done using a wire brush attachment for the angle grinder.

3.1.3 Welding

Welding is a process using heat to fuse materials together, for this project it will be used to bind metal sections together. There are different welding processes, however this project was

Figure 3.1.3: Tube piece set into notcher, display shows the ability to change the cut angle.

done using only one such process, known as Metal Inert Gas welding or MIG for short. This project will be constructed using a mild steel, which determines the type of gas and wire being used for the MIG welding process. The gas is a 75/25 Argon/CO2 mixture and wire is 0.035" diameter wire. As mentioned other types exist, however MIG welding is most easily learned and requires less technique then other processes to form strong welds. The specific type of welder used for this project was, MIG200GDSV. Based on the metal thickness the welder must be set to a specific voltage and feed speed, this was determined using the chart given on the welder, then adjusted with a few trials to find an optimal voltage and feed rate of: 16.2V, 128 in/min. Welding sections together was done in steps, as it was first necessary to make sure the physical realization matched the design. The first step was to tack weld each section into place: small dot welds are used for preliminary placement of component segments forming a weak bond but allowing for the work piece to be moved without disrupting the alignment of segments. If placement needed adjustment the tack was ground off and section adjusted. Once placement of each section matched the design's measurement a bead weld was done around the tubes circumference. Bead welding is done with constant flow of welding wire in small circular movements while moving around the section that is being welded. Slow and smooth movements achieve strong bonds between sections.

Figure 3.2.1: Lower and upper frame tubes after bending, laid out to match up bends

3.2 Assembly

Once all tube lengths were cut and necessary bending was done, it was time to start the assembly. The first step in the process was welding all frame sections together, then forming and welding the suspension arm. Once this was complete, the suspension brackets were welded to the frame. Mounting the drive shaft was the next step

3.2.1 Frame

Starting with the lower frame section, all cut pieces were placed in their set location based on the Fusion design.

Welding magnets were used to hold the pieces in place, then tack welds 3.1.3 were done at each connection to ensure the tubing were held in place. Once each piece of of the frame was tack welded in place, I was then able to complete the welds of each tube connection. The tack welds were needed as welding the circumferences of the tubes required lifting and orienting the frame. Once the lower section was complete, I then moved on to the upper section which was done using the same steps as the lower. The vertical tubes were then held in place on the lower section using welding magnets and tacked in place, the upper frame section was subsequently placed onto these vertical pieces, and tacked. The tubes were then fully welded which required the frame to be oriented in three ways to fully weld the vertical tubes to the upper and lower frame sections. This completed the basic frame that was ready for mounting of the swing arms and suspension brackets.

3.2.2 Suspension and Steering

This section describes the setup of the vehicles independent suspension, as well the steering rack mounting. Starting with the swing arms themselves which make up this independent suspension, two designs were used, one for the front and one for the rear. Four identical swing arms were fabricated for the front suspension and four for the rear. Figure 3.2.2 shows the two designs used. As seen in the figure, the designs are just the metal tubing, however, how they attach to the frame is not included. At the bottom ends flange nuts were welded and rod ends were screwed into them. The rod ends act at the connection point between the swing arms and frame. Suspension brackets added where the rod ends attach to the frame to act as the rigid connection to the frame. A rectangular 2"x1" piece of metal was cut from the sheet metal, a .5" hole was then drilled which would then be bolted to swing arm rod ends. The rod ends allow for rotation about their mounting point which corresponds to the movement the swing arms will undergo when passing over uneven surfaces.

To attach the swing arms to the frame, the brackets were bolted to the swing arm ends. Starting with the lower swing arms the frame was set on a level surface and the swing arms were placed and laid flat, then the brackets were tack welded into place and the motion of swing arm was tested. At the other end of the swing arm is where the wheels will be placed, for the front wheels a connection that allows the wheels to turn about the vehicle's vertical axis is necessary to steer, while the rear connection needs to house a bearing which allows the axle shafts to be

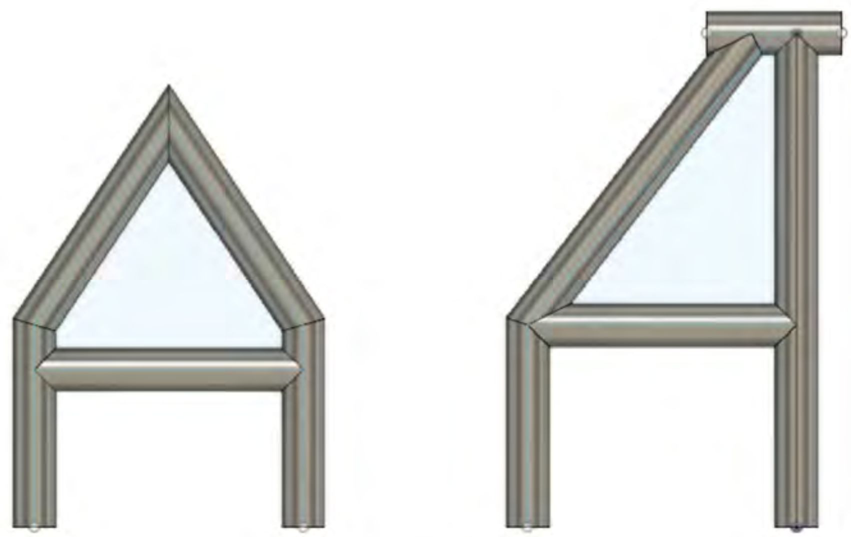

Figure 3.2.2: Top view of designs for swing arms. Left: front, Right: rear

held while under rotation. The connection pieces, which I will refer to as wheel hubs, function to keep the upper and lower swing arms vertical movement parallel.

Once the wheel hubs, shown in Figure 3.2.2 were made, they were mounted to the lower swing arms. The frame with lower swing arms attached was flipped, with the upper portion of the frame laid flat on the ground. The upper swing arms were connected to the wheel hubs, and then laid flat on the ground with brackets touching the frames upper section. Using a right angle the swing arms were adjusted so the wheel hubs were perpendicular to the working surface. Tack welds loosely secured the swing arms in place and the motion of the swing arms was tested. To adjust this motion the rod ends were unscrewed to give more length if necessary. Once the vertical motion of the swing arms satisfied the travel length of the shock absorbers, the brackets were completely welded to the frame.

The vehicle's and driver's weight is elevated from the wheel's motion by the suspension, which is a combination of a shock absorber and a spring coil. A shock abosorber takes the compression/rebound of the spring coil and dampens the force, creating a smooth transition over rough terrain. They also act to keep the vehicle elevated at a certain height above the

Figure 3.2.3: A completed front swing arm; the rod ends at the bottom are those previously described, at the other end a tie rod end is welded. Tie rod ends allow for rotation and sweep an angle that will allow the swing arms to move vertically while keeping the wheel parallel to the surface of travel.

ground. Viewing Figure3.2.4 you can see that the mounting brackets for the shock absorbers use the same basic design as the swing arm brackets, however with smaller diameter mounting holes. Welding the shock brackets to the frame was done by elevating the frame 3" above the ground with lower swing arms attached. This height determined the resting height of the vehicle. The shocks, with brackets attached, were then placed with one end on the upper frame section and the other end to the cross piece of the swing arms. The brackets were then tack welded, the shock absorbers removed, then fully welded. This was done for all four lower suspension arms. This completed the independent suspension system of the vehicle, the next step was mounting the rack and pinon.

The steering system, is a simple rack-and-pinon step-up that was purchased. To mount the rack-and-pinon, two pieces of flat stock with half circles the diameter of the rack were placed perpendicularly between two cross sections at the front of the vehicle, equidistant from the center

Figure 1: The rear wheel hub holds a bearing for the axle shaft to be connected to wheel. Two bolts are used to fix the top and bottom to the ends of the rear swing arms

Figure 2: Front Wheel mount: at either end of the tube a bolt was welded flush. This is where the tie rod ends screw into place. A 5/8” bolt was welded through the center; the wheels will be mounted on these and held by a lock nut.

of the vehicle, to hold the steering point of the rack at the center of the vehicle. These pieces were then welded into place using U-Bolts to hold the steering rack down. Their own plates were welded to hold the rack fixed to the vehicle. It was then needed to connect the steering rack to the front wheel hubs to control their direction.

3.2.5

3.2.3 Drive-Train

This section describes how the power-train, (Section 2.2), was fabricated. A rigid drive shaft kit was purchased including sprocket, disc brake and mount bearings. However, as one goal was to create independent suspension, each rear wheel was driven using an axle shaft, meaning the length of the drive shaft had to be adjusted. First the drive shaft was cut on the other end using a cutting attachment on the lathe and a hole was drilled through each end. This hole was used as the connection point to the axle shafts. Second the splines on the axle shafts needed to be removed to have a flush connection to the drive shaft. Pins of diameter equal to the holes on both drive and axle shafts secured the shafts together, see Figure 3.2.4 The mounting points for the drive shaft bearings were drilled out then the tube sections were placed on the frame and welded into place. Once welded, the drive shaft was mounted and axles attached. The axle

Figure 3.2.4: Swing arms connection to frame; bolted to suspension brackets using rod end to allow arms to rotate about fixed point.

bearings were placed in the rear wheel hubs and its mounting ring welded to the hub. The axles could then be held in the wheel hubs and suspension. The vehicle at this point has drive train complete, however connecting the axles to the wheels and mounting the motor are still left.

The axle shafts were bought from a manufactured vehicle, this made it possible to purchase the hub splines to fit the axles. The splines then need to be mounted and secured through the wheel's rotating axis, for the axle shafts to drive the wheel. Figure 3.2.7 displays the hub splines after using lathe to reduce their diameter to fit into the wheel. The hubs were then welded into

Figure 3.2.5: Steering system mounted on vehicle, showing connecting brackets for wheel hubs and rod ties.

Figure 3.2.6: Removing splines for connection to Drive Shaft

the wheels, the axle shafts were now able to drive the wheels, at the other end a washer welded into the wheel and the axle shaft nut held the wheel on.

The motor was the final part of the power train mounted. Flat stock welded to a 8.75" notched tube acted as the mounting plate. Holes were drilled into the mounting plate to fit the motors, then the holes extended allowing the motor to slide backwards, increasing the distance between driver and driven sprockets. This would make it possible for the chain's tension to be increased after being attached. The notched tube was placed between the two rear cross sections of the frame, the driver and driven sprockets were aligned, then the tube was welded into place. Once this was complete the motor could be mounted and the chain connected. The motor was forced back to add tension to the chain and secured in place.

Figure 3.2.7: Hub splines after reducing diameter; fitment to axle end

Figure 3.2.8: Final assembly of axle shaft held by wheel hub and bearing. The connection to wheel using splines from original vehicle

3.2.4 Battery, Controller, and Controls

In order to mount the battery and controller a wood piece was used to act as the mounting plate for the battery and controller. Two right angle brackets were welded to the frame on either side of the wooden piece, the piece was then secured with screws through the brackets and wood. The controller was then fixed with screws and the battery fixed with a strap, allowing it to be removed for easy access. The controls needed are the brake, accelerator pedal, and a small panel which houses the ignition switch and reverse switch. The brake caliper and master cylinder came as part of the drive shaft kit. This system is known as a hydraulic brake which requires a brake line, that has been pressurized. In the original design a brake pedal would have been used, however, the hydraulic line that was provided was to short to allow for this. To avoid buying a new line a hand brake was fabricated and mounted on the left side of the vehicle. See Figure 3.2.9 The accelerator pedal was mounted at the front right side of the vehicle. The accelerator

Figure 3.2.9: Hand brake, displaying master cylinder

pedal was elevated by a plastic bracket, which was then bolted to a square piece of sheet metal. This square bracket was then welded to the frame at the position that best suited the driver. The pedal was then secured to the plate and the wiring was ran to the controller.

4
Experimentation

This section was meant to display the achieved velocity and acceleration of vehicle, and test the limits and range of the battery. However due to time constraints only a very small set of data was taken.

4.1 Velocity and Acceleration

Before any actual data was collected, I was able to take a few test drives soon after completion. During the runs I used a speedometer app to get a rough estimate of the vehicles top speed, v = 13.41 m/s, was achieved. For the official data collection a couple timed runs were done to find the top speed and acceleration of the vehicle. To find the top speed of the vehicle a 50m section of road was marked out, an assistant stood by to take times at the vehicle passed through the allotted distance. The vehicle started before the marked section with enough distance to reach maximum velocity, once the vehicle crossed the first marker the timer was started and stopped at the vehicle passed the second marker. Using $v = d/t$ to calculate the velocity of travel within the measured distance, Figure 4.1.1 displays the data collected. The second trial was a single run over 90m, for each interval the velocity was calculated.

$$v_f = v_i + at$$

$$a = (v_f - v_f)/t$$

Distance (m)	Time (s)	Velocity (m/s)
50	3.760	13.298
50	3.910	12.788
50	4.190	11.933
50	4.000	12.500
50	4.100	12.195
	Avg. Velocity:	**12.543**

Figure 4.1.1: Timed runs at maximum velocity over 50m section

Using these the acceleration between each interval was calculated then averaged. This being done for a single run makes the data questionable as a larger data set would be more useful to get a better estimate of the vehicles acceleration.

Split Distance (m)	Split Time (s)	Velocity (m/s)	Acceleration (m/s^2)
30	2.39	12.552	1.317
30	3.19	9.404	1.656
30	7.28	4.121	0.566

Figure 4.1.2: One run over 90m starting from v = 0m/s. For each 30m interval a split time was taken.

5
Summary

The project set out to design, build, and test an electric vehicle. The vehicle build was completed with the features set for the goal of the project. However, the majority of time went into completing the vehicle build and due to time constraints testing the vehicle to the fullest was not achieved. Through the research for this project, the history of electric vehicles and the physics behind them was seen to be a cohesive path of manifesting and experimenting with electromagnetic theory.

Appendix A
Parts and Cost

Parts	Source	Specifications	Cost ($)	Quantity
Drive Shaft	Amazon	Length: 32", OD: 1"	197.69	1
Suspension	Amazon	Length: 9.25", Travel Length: 1.97", Max. Load: 181.44kg	79.78	4
Steering	Amazon	Length between Steering Brackets: 36.4"	85.99	1
Motor & Controller	Amazon	Motor: 72V, 3000W Control: 50A, 120 Phase Degree	300	1
Batteries	Amazon	36V, 20Ah Li-ion	450	2
Axle Shafts	Ebay	Front Axle Shafts from 2000 Polaris Sportsman 500	107.95	2
Hub Splines	Ebay	Front Wheel Hub Clutch from 2000 Polaris Sportsman 500	128.04	2
Metal Tubing	McMaster-Carr	Grade 4130 Steel: Length: 6', OD: 1", Thickness: 0.049"	379.18	10
Sheet metal	McMaster-Carr	Grade 4130 Steel: 12"x24"x1/8"	51.56	1
Hex Bolts	McMaster-Carr	Grade 8 Steel: Length: 1.5", Thread: 1/2"-20	17.96	20
Ball Joint Rod End	McMaster-Carr	Thread: 1/2"-20	150.88	16
Tie Rod End	McMaster-Carr	Thread: 1/2"-20	58.92	4
Hex Nut	McMaster-Carr	Grade 8 Steel: Thread: 1/2" - 20	13.75	50
Flange Nut	McMaster-Carr	Thread: 1/2" - 20, Flange OD: 1.03125"	27.62	20
Bearings	McMaster-Carr	ID: 1.0625", OD: 2.5625"	101.64	2
Wheel Bolts/Nuts	Ace Hardware	Length: 8" OD: 5/8"	11.36	2
Wheels	SPROJ 2021	Radius: 7.25", Bearing: ID: 5/8"	0	4
		Total Cost ($):	2162.32	

Figure A.0.1:

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