Team 1: Maneuver Mobile

Project Proposal and Feasibility Study

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ENGR 339 Senior Design Project

Calvin College

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Executive Summary

The Calvin College engineering department proposed a project idea of taking the electric car mounted on the west wall of the engineering building, created by We Get Around in 2003, and restoring the car to a working condition. The engineering department will use this car to provide transportation for their faculty and staff while showcasing the senior design class for prospective students. Our team has taken the proposed project and will not only restore the car but will improve on the current design to make the car more maneuverable.

The team consists of Tyler DeVries, Doug Faber, and Wesley Richards. Each of the members is a mechanical engineer. All three have an interest in cars and chose the project for its potential in applying mechanical system knowledge to a design that will be unique from current car designs. The deliverable for this team by the end of the second semester will be an electric car that is able to maneuver in tight places.

Phil Jasperse removed the car from the wall in order for the team to determine the requirements to return the car to working order. With the car on the ground an assessment of the major electrical and mechanical system of the car showed what systems need to be changed/improved. Along with the physical analysis, a theoretical model was developed to help assist in the determination of what is needed for the improvements. This report contains the results of each system assessment and the recommendation for what needs to be changed.

To address the maneuverability problem of the vehicle the team will design a unique steering system. This system will allow for the driver to turn both the front and rear wheels together if the current steering system fails to provide enough mobility for any attempted driving maneuver. This report discusses the feasibility of the designs considered and the final proposed design.
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1. Project Overview

1.1 Problem Definition

The east wall of the Vermeer Project Center in the Engineering Building at Calvin College is currently home to what was once a functioning, joy-stick controlled electric vehicle designed and built by a Calvin College senior design team. In the last decade the vehicle has been stripped of its batteries and motor, leaving the frame, suspension, wheels, and dated control units on the wall. When the vehicle did function, it performed satisfactorily, outside of a debilitating turning radius.

Maneuver Mobile’s project focuses on the reconstruction and major improvement of Calvin’s wall-dwelling electric vehicle. The group’s primary design goal will be the addition of a unique steering system, allowing maneuvering capability well beyond that of a standard, four-wheeled vehicle. The vehicle will be outfitted with batteries and motor(s), to compliment the steering system, along with any necessary updates to the chassis, suspension, and braking systems.

The possession of an electric vehicle would be greatly beneficial to the Calvin College Engineering Department. The appeal and availability of electric vehicles have grown significantly in recent years, and a well-performing vehicle would provide the department with greater appeal to prospective students and professors, not to mention a fun way to get around campus.

1.2 Design Norms

The team has considered and will continue to consider stewardship, trust, and caring as design norms in the design and construction of the vehicle. The team’s investigation of electric motor implementation shows stewardship of God’s creation in the use of power devices that can readily use energy from renewable resources. Electric vehicles make it easier for the transportation industry to utilize sustainable energy, and the investigation of electric vehicle capabilities will increase the prevalence of these vehicles in the industry.

Trust is important to the team as the vehicle must be designed to perform safely and reliably at speeds up to 25 mph. Although this vehicle’s theoretical top speed is relatively low, injury can still occur as a result of substandard design or fabrication work.

Caring is shown through the construction of a vehicle that can be easily operated and maneuvered by any driver. We would also like to show caring through our intent to design a vehicle that is actually utilized by the engineering department and/or engineering students. The team’s goal is not to build a vehicle that will be put back up on the engineering building wall right away.
2. Project Management

2.1 Team Members

Tyler DeVries

Figure 1

Tyler is a senior mechanical engineering student at Calvin College. Tyler is from London, Ontario and, although he is undecided on what kind of engineering work he would like to do, he plans to return home to start a career in the mechanical engineering field.

Doug Faber

Figure 2
Doug is a senior mechanical engineering student at Calvin College. Doug hopes to work in the manufacturing or automotive components industry in either West Michigan or in the Chicago area.

Wesley Richards

![Wesley Richards](image)

**Figure 3**

Wesley is a senior mechanical engineering student at Calvin College. Wesley is currently working as a manufacturing and process engineering intern for Lacks Enterprises in Grand Rapids. Wesley wants to continue working in the automotive industry in either manufacturing or design in the Grand Rapids area after school.
2.2 Advisor

The team’s advisor is Ned Nielsen. Professor Nielsen graduated in 1967 with his M.S. in Mechanical Engineering from the University of Michigan. Professor Nielsen worked in the aerospace industry, and the laser construction tools industry. Professor Nielsen holds fourteen U.S. Patents for his inventions.

2.3 Budget

Wesley Richards will be in charge of updating and monitoring the team’s budget throughout this project. The budget will be developed in excel. It will ensure that the most important design modifications and additions will have the appropriate funds to accomplish the goals of the project. Smaller changes, such as aesthetics, will have a lower priority budget wise. When budget issues arise a team meeting will be scheduled to discuss ways to re-allocate money or to re-prioritize what aspects need more funds.
3. Schedule

3.1 Planning

The project consists of two phases, the first being a planning stage. The team developed the project schedule in Microsoft Project. The goal during the fall semester was to complete the system assessments, component research, and develop models for the new steering system. These goals, along with deliverables for class, were set as milestones with specific dates for completion. Table 1 shows these milestones and their desired due dates.

<table>
<thead>
<tr>
<th>Task</th>
<th>Due Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project Brief</td>
<td>10/15/14</td>
</tr>
<tr>
<td>Get Car Down</td>
<td>10/17/14</td>
</tr>
<tr>
<td>Finish “Make it Move Requirements”</td>
<td>10/22/14</td>
</tr>
<tr>
<td>Decided on Major Design Change</td>
<td>10/27/14</td>
</tr>
<tr>
<td>Poster</td>
<td>10/31/14</td>
</tr>
<tr>
<td>Design Modification Proposal</td>
<td>11/6/14</td>
</tr>
<tr>
<td>Finished Current Car Evaluation</td>
<td>11/7/14</td>
</tr>
<tr>
<td>Draft PPFS</td>
<td>11/10/14</td>
</tr>
<tr>
<td>Final PPFS</td>
<td>12/8/14</td>
</tr>
</tbody>
</table>

The majority of the semester consisted of researching the different options available to achieve the goals outlined for the project. This research included talking with suppliers about their products, as well as reading through documentation for different components. A large amount of time was also devoted to creating theoretical models. These models helped the team to quickly assess the feasibility of design options.

3.2 Execution

The execution of the plan developed during the fall semester will take place during interim and the spring semester. The execution of the plan includes: purchasing and installing components, building and installing the new steering system, and testing the vehicle. Table 2 shows the major tasks that will need completing. Due dates will be determined at a later date.
Table 2 Spring Milestones

<table>
<thead>
<tr>
<th>Task</th>
<th>Due Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Component Purchasing</td>
<td>TBD</td>
</tr>
<tr>
<td>Design Modification construction</td>
<td>TBD</td>
</tr>
<tr>
<td>Steering System Construction</td>
<td>TBD</td>
</tr>
<tr>
<td>System Testing</td>
<td>TBD</td>
</tr>
<tr>
<td>Final Report</td>
<td>TBD</td>
</tr>
</tbody>
</table>

The execution phase will end with a fully constructed and tested final design. The team will present the finished vehicle at the senior design night for the engineering department. The goal is to have all of the construction completed by this event.
4. Requirements

4.1 Power
The vehicle will be powered by one or more electric motors connected to a series of 12 volt batteries. The motor must be capable of reaching a maximum speed of 20-25 mph with four passengers weighing 190lb (average weight of American male). The vehicle must also be capable of accelerating to that top speed in a reasonable amount of time (6 seconds or fewer). Figure 5 shows the continuous motor power (hp) required to maintain various top speeds. Figure 6 shows the peak motor power (hp) required to reach the nominal top speed (25 mph) in different time intervals. Detailed power calculations can be found in Appendix B.

![Graph: Cruising Power Required to Reach Various Top Speeds](image)

**Figure 5: Cruising Power Required to Reach Various Top Speeds**
The batteries must provide the vehicle with an operating time of at least 30 minutes under standard driving conditions on a single charge. The motors must be mounted in such a way that they can provide power to wheels capable of 180 degree steering.

4.2 Interface

The joy-stick controls used in the previous design will be preserved and modified in the new design. Front wheel steering will be controlled with a standard steering wheel. The rack and pinion for the front wheels must be geared in such a way that a driver of standard strength must be capable of comfortably steering the front wheels. Acceleration and rear wheel steering must be controllable using the joy-stick model currently installed on the vehicle. Braking will tentatively be controlled with the lever design of the previous model, although the drum brakes will likely be swapped in favor of disc brakes.

4.3 Safety

The chassis and suspension must perform satisfactorily at the vehicle’s maximum speed of 25 mph. The braking system will be capable of stopping the vehicle in a reasonable distance from its maximum speed.
4.4 Capacity

The vehicle will comfortably seat four passengers and meet the previously set power requirements at an average passenger weight of 190lb.

4.5 Vehicle Body (if time)

If extra time is available to the team, a roof and windshield will be added to the chassis. The roof must be able to withstand a minor load (50 lb), and protect the passengers from direct rain/snowfall. The windshield must withstand a minor impact and protect passengers from direct rain/snowfall.
5. Research
The research section will provide details on all research performed on prospective purchased parts and utilized materials. The research in this section will be used to make informed decisions on which parts and materials will best serve the design of the vehicle.

5.1 Power Components

5.1.1 Motor
The main considerations in motor research were power capability and the ability to provide power to driving wheels with 180 degree steering capability. The ideal power source meeting these criteria is a wheel hub motor. A table of such motors and their specifications from various suppliers, along with different style motors as a contingency, was generated and used to decide which model would fit the vehicles needs best.

5.1.1.1 Hub Motor
Hub motors incorporate all of the electronics to control the rotation of the motor into one package. The Maneuver Mobile is currently set up to run with a central brushless electric motor. A continuously variable transmission (C.V.T.) along with a rear differential transfers the power from the motor to both rear wheels. Using a hub motor will eliminate the need for the C.V.T., the rear differential, and the live axle between the rear wheels.

The primary use of hub motors is for motorized bicycles. These wheels range from continuous power outputs of 100W to 1000W. So far there are two solutions with an output large enough to satisfy power the power requirements to get the car moving. These options and the relevant specifications are shown in Table C1.

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Model</th>
<th>Input Voltage</th>
<th>Output Power (max)</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Golden Motor</td>
<td>PW16D</td>
<td>24/36/40 V</td>
<td>2.6 hp</td>
<td>$250.00</td>
</tr>
<tr>
<td>Heinzmann</td>
<td>PRA-230</td>
<td>48V</td>
<td>2.4 hp</td>
<td>Not Available</td>
</tr>
</tbody>
</table>

5.1.1.2 Standard Motor
The other motor option will be a single, central motor power the vehicle. This is the type of motor the vehicle is currently setup to use. Using this type of motor requires the transmission and differential currently installed on the car. The use of the differential splits the power output of the motor between the rear wheels. The transmission allows for a continuous adjustment of gear ratios to maintain the torque required to keep
the vehicle rolling. If rear steering is not achievable the car will need to utilize the standard motor instead of a hub motor. Table C2 shows the options and relevant specifications for each motor.

Table C2. Standard Motor Options

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Model</th>
<th>Input Voltage</th>
<th>Output Power (max)</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Briggs &amp; Stratton</td>
<td>Etek (Brushless)</td>
<td>48 V</td>
<td>15 hp</td>
<td>$500</td>
</tr>
<tr>
<td>Mars</td>
<td>PMAC (Brushless)</td>
<td>48 V</td>
<td>15 hp</td>
<td>$500</td>
</tr>
<tr>
<td>Golden Motor</td>
<td>BLDC10kW</td>
<td>48 V</td>
<td>13.4 hp</td>
<td>$765</td>
</tr>
<tr>
<td>Montenergy</td>
<td>ME0909PMDC</td>
<td>40 V</td>
<td>12.5 hp</td>
<td>$385</td>
</tr>
</tbody>
</table>

5.1.2 Batteries

Battery research and selection was based mainly on motor specifications. A table of prospective battery types was generated and used to match whatever motor was selected for the vehicle. The team will attempt to find a battery that offers a good balance between energy capacity, power capacity, and price. Power capacity will be especially important as the team will attempt to power two separate motors at a continuous rate of about 2.6hp using a single bank of batteries, and lithium ion batteries are typically weak in discharge rate capacity. The batteries will also need to maintain a consistent discharge capacity through the majority of a charge cycle. Figure 7 shows typical discharge rates through a single charge in a lithium ion battery.

Figure 7. Typical Discharge Curve for LiFePO4 Batteries
(http://blog.mr2ev.com/wp-content/uploads/2013/05/lithiumcurves.gif)
Several types of battery were considered when choosing one for the car. The 3 main types that were researched were Lithium Ion, Lithium Iron Phosphate, and Lithium Polymer batteries. All of these types of batteries use lithium but there are some very big differences between them. Table C3 shows specifications for specific examples of the battery types discussed below.

5.1.2.1 Lithium Polymer (LiPo)
This battery is similar to the lithium-ion technology that it is based from but the big difference is that it is packaged inside a pouch. This means that the battery is not constrained to a rigid shape. There are advantages and disadvantages to this, the main disadvantage being that the battery lacks durability and rigidness, but this allows the battery to be manufactured into any desired shape. Some other characteristics of this battery type are they are safer than the traditional lithium-ion batteries but they lack in cycle life and energy density when compared to both lithium ion and lithium iron phosphate batteries.

5.1.2.2 Lithium Cobalt Oxide (LiCoO$_2$)
This battery type causes the most concern from an environment and safety perspective. These batteries use LiCoO$_2$ as the positive electrode, which is not as thermally stable as other battery cathodes. If this battery is overcharged or overheated from abuse the battery could explode or cause something near it to catch fire. Out of the 3 battery types listed above, LIB’s offer the highest energy density but comparative low power density. These batteries are also the cheapest to manufacture and take up less space. A very big disadvantage to LIB’s is that they only have a useable life of 2-3 years after manufacturing due to decrease in charge retention over time.

5.1.2.3 Lithium Iron Phosphate (LiFePO$_4$)
This type of lithium battery has many advantages in performance and safety when compared to the other types but it is more expensive to produce. Because the battery uses iron and phosphate it is has higher thermal stability than the previous LiCoO$_2$. The phosphate can handle much higher temperatures than cobalt oxide which reduces the chances of the battery reacting negatively when it is overheated or overcharged. The energy density of this battery is not as high as LiCoO$_2$ batteries, which means that in order to achieve an equivalent battery, the LiFePO$_4$ battery has to take up more volume. The big advantage with iron phosphate is the power density that it offers which is approximately 6 times that of a LiCOO$_2$ battery. Iron Phosphate batteries are not damaged when they are completely discharged and they take less time to charge compared to the other lithium-ion batteries.
5.2 Steering Components
The current vehicle design uses a rack and pinion steering system. The vehicle also utilizes the Ackermann steering principle. The current design is not set up to use a rear steering system. The team will develop several models utilizing original rear steering concepts as production cars do not utilize rear steering capabilities of more than a few degrees.

5.2.1 Rack and Pinion Steering
According to the paper Modeling of a Rack and Pinion Steering Linkage Using Multi-Body Dynamics “…The rack and pinion steering linkage is the most popular…and widely used in passenger cars” (Hanzaki, 1). Mechanically, the rack and pinion steering system (R.P.S.S.) is the simplest to implement. This system is utilized in passenger vehicles as well as other types of vehicles including: Riding lawn mowers, boats, golf carts, etc. The R.P.S.S can use a manual input or, more recently, a wireless system. The maneuver mobile uses the mechanical version of the R.P.S.S.
There are two primary components of the R.P.S.S. The first component is the actual rack. Figure 8 shows the current rack for the car. This connects to each of the tie bars for the wheels. When the rack travels left or right it translates a linear motion into a rotational motion. This is thanks to the bearings located at each of the wheels.

![Figure 8. Rack and Pinion Steering System](image)

The pinion is the component that makes the rack move. The pinion on our vehicle is a sprocket that is actuated by a servo motor. Figure 9 shows our vehicle’s pinion component. Since a gear relationship exists between the two components, ideally no rubbing should exist when moving. Figure 9 shows how the two components fit together.
5.2.2 Ackerman steering

When a car is turning it looks like the wheels are moving in parallel. However, to achieve proper turning the wheels should not move in parallel. The inside wheel, with respect to the turning direction, should be offset by a small angle. This relationship is known as Ackermann steering. The basic principle is that “…to achieve true rolling for a four wheeled vehicle moving on a curved path. The lines drawn perpendicular to the four wheels must be concurrent” (Dhuri, 70). Figure 10 comes from Dhuri’s paper explaining how Ackermann steering works and the basic equations needed to get the right relationship. Figure 10 shows the visual concept of the steering principle.

\[ \cot(\psi) - \cot(\theta) = \frac{c}{b} \]  

Figure 10. Ackermann Steering Model (Dhuri, 70)

The equation used for this model is the following:
$\Psi$ is the angle from the rear wheel axis to the outside wheel. $\theta$ is the angle from the rear wheels to the inside wheel. $c$ and $b$ are the distances between the two front pins and the distance between the center points of the front and rear wheels respectively.

### 5.2.3 Rear Wheel Steering

There are no real models to determine how to achieve front and rear steering. The Ackermann model as well as other mathematical relationships will help determine the correct rear steering development. The US patent US4953650A shows the design of a control system to be able to control both front and rear wheels (Ohmura). If this patent is feasible it may be possible to incorporate this design into the new system.

### 5.3 Material Studies

The material properties of the chassis and suspension components were briefly evaluated to outline performance capabilities. These properties come from the final report of the team *We Get Around*. The primary material used for construction of the car is Aluminum 6061 according to Appendix A of their report. Material properties for Aluminum 6061 were found and can be seen in **Table D1** (ASM). This material provided *We Get Around* the strength needed to support the loads seen on the car. Based on their analysis the material used is strong enough to support the design changes proposed in this report. Based on their report the seats and the frame can support four individuals weighing up to 250lbs. **Figures D1-D3** show the shear force and bending moment diagrams for the loading of the car. Based on the values computed in these figures the theoretical deflection calculate by *We Get Around* was 1.083 in. Their FEA analysis showed that using Aluminum 6061 would generate a maximum deflection of less than one inch. This reinforces our conclusion that the material on the car was the correct choice.

### 5.4 Previous Design

The documentation for the original design of the vehicle in 2003 by “We Get Around” was utilized extensively to gain familiarity with the current design. The controller specifications and circuit diagrams for the motor, batteries, and drive/steering controls were particularly helpful in evaluating and understanding the current vehicle setup.

### 5.5 Similar Product Survey

Active rear wheel steering has been implemented in several production vehicles in recent decades by manufacturers such as Nissan Motor Company, Mazda Motor Corporation, and Porsche AG. These designs have typically included rear wheels making slight (1-2°) adjustments to decrease turn radius. Due to the
complexity, cost, and relatively minor benefits, rear wheel steering systems have never been popular. There are currently no production vehicles with manual rear wheel steering capabilities.
6. Systems

The systems section will outline the components chosen for each system based on the research above.

6.1 Power

6.1.1 Motor

The maneuver mobile will utilize two PW16D hub motors from Golden motors, as discussed in section 5. The motors will be set up to run on a 48V system. These wheels have a peak power output of 2.68hp. This means the car will need to utilize two of them to achieve the power requirements discussed in Section 4. These motors will provide the most flexibility when designing the rear steering system since we will not need an axle, differential, or transmission. Figure 11 shows the CAD model provided by Golden Motor.

![Figure 11. PW16D Hub Motor (Golden Motor)](image)

6.1.2 Battery

After researching several different types of lithium-ion batteries the decision was made to use Lithium Iron Phosphate batteries (LiFePO4), or iron phosphate for short, to supply the required 48 V to the vehicle. The biggest reason for choosing this type of lithium-ion battery was because iron phosphate batteries have the highest power density, which is a requirement when considering powering an electric vehicle with batteries. There were several other advantages for choosing this battery type. First they have a wider operating temperature range because of the comparatively increased chemical stability of phosphate at high temperatures. The cathode of a LiFePO4 is made of iron phosphate which is safe for the environment. This means that when the time comes, disposal of this battery is much easier and safer. Iron phosphate batteries
have very good cycle life and they do not lose ability to hold charge as quickly as other batteries. Iron phosphate batteries are also not damaged when they are completely drained like other batteries could be and they have a comparatively fast charge time. Specifically 4 12V LiFePO₄ batteries were chosen as the power source for the vehicle. The specifications for these batteries can be viewed in Table C3 found in the research section.

6.2 Steering

6.2.1 Front Wheel Steering
The rack and pinion front wheel steering utilized in the current vehicle design will be kept intact for the Maneuver Mobile design. The front wheels are each connected to the steering rack with tie rods and currently controlled via joystick connected to a servo motor. It was decided that the front steering would be changed over to one that uses a steering wheel and not the joystick for control. The servo motor would be removed, as it is no longer required, but it could be used for the rear wheel steering.

6.2.2 Rear Wheel Steering
The final steering system for the rear wheels has yet to be decided. Please see section 7.2 for the steering system design options.

6.3 Control System
The current design’s joy-stick module will tentatively be used to control all power and the rear steering systems on the vehicle. The front-back motion will control forward and reverse acceleration. The left/right motion will steer the rear wheels. The joy-stick module will connect to the motor power controller as well as the control units for the rear wheel steering. Figure 12 shows the circuit diagram for the control system currently governing motor power and front wheel steering.

![Figure 12](image_url)
The steering control system currently connected to the front wheels will be connected with its servo motor to the rear wheels. The motor controller will be supplied with the team’s chosen motor(s). The steering controller will control servo motor attached to the rear steering system.

### 6.4 Braking
The braking system that will be used on the vehicle are disc brakes because the offer better braking performance than drum brakes, as discussed in brake research section. Because the rear wheels will actually contain the motors to drive the vehicle brakes will only be fitted to the front wheels.

### 6.5 Chassis
The current chassis will remain the same. This will provide the foundation for all of the systems we are adding/modifying. Any chassis modifications will be solely additions.

### 6.6 Suspension
The front suspension will remain the same as shown in Figure 13.

![Figure 13: Front Suspension](image)

The rear suspension currently uses a leaf spring system. Since the car will utilize rear steering the leaf spring design will change. Instead of leaf spring the suspension will be similar to the model shown in Figure 14.
Figure 14. Rear Suspension
7. Design

The design section will highlight the major system designs as well as the testing procedure for each of those designs.

7.1 Power System Integration

This section will detail the methods by which the power components (motors and batteries) will be installed, connected, and integrated with the other systems on the vehicle.

7.1.1 Motors

The Golden Motors wheel hub motors will come pre-mounted on wheel rims with tires. The wheel bearings will be mounted on short shafts with the vehicle supported directly above each wheel (see Figure 12 for clarification). This mounting system will allow the wheels to rotate 90° in either direction.

7.1.2 Power Supply

The power cells will be mounted in the center console of the vehicle, between the front and rear passenger seats. This will allow the batteries to be easily connected to the motor and steering controllers.

7.1.3 Brakes

The regenerative braking capabilities of the wheel hub motors will provide some braking force, and this force will be evaluated upon installation to determine whether additional braking power will be needed to effectively slow and/or stop the vehicle. Disc brakes will be mounted on the front wheels for maximum braking efficiency in the case that additional braking power is needed. The brakes will be controlled via a lever connected to the driver seat. A cable routed over a system of static pulleys will connect the lever to the disc brakes.

7.2 Steering System Design

One of the major goals of the project is to implement 90° steering capability. The sections below highlight the various design options the team will consider to meet this goal. Although wheel hub motors have been selected for the nominal power system, design options for several motor types will be outlined in this section.
7.2.1 Motor Style

7.2.1.1 Standard Central Motor
This style design will be treated as a contingency in the case that wheel hub motors cannot be obtained and/or installed on the vehicle. The rear wheels will be powered with a direct-drive electric motor. The motor would require special shaft and gear connections to provide power to wheels while allowing for a 90° turning angle. The shaft from the motor would most likely connected to a vertical shaft via bevel gear, allowing this (vertical) shaft to turn with the wheel.

7.2.1.2 Wheel Hub Motor
The use of individual wheel hub motors on 1, 2, or 4 wheels would eliminate the need to transfer power to the wheels via shaft. The only necessary connection to the wheel hub motors would be power cabling from the motor controller(s).

7.2.2 Steering Style
7.2.2.1 Front Wheels: Rack and Pinion
The wheel positions will be controlled with rack and pinion drives connected to the wheels via tie rods.

7.2.2.2 Rear Wheels: Belt/Chain
The live axle between the rear wheels on the current vehicle will be removed to introduce 90° steering capability. The wheels will be dismounted from the leaf springs and mounted on individual axles. The wheel positions will be controlled via a belt or chain placed pulleys fixed above each wheel and driven with a central pulley powered by a servo motor connected to the joy stick system. Figure 15 shows the current model with live axle and leaf springs (top) while Figure 16 shows a model of the proposed steering style (bottom).

![Figure 15. Current Rear Wheel Model](image-url)
7.2.2.3 Rear Wheels: Rack and Pinion
If the team deems it necessary to use the Ackermann model for the rear wheels as well, the chain in the above section will be replaced with a rack and pinion system connected to the rear wheels with tie rods. The tie rods will be connected in such a way that the pulleys above each wheel shown in Figure 16 will still be allowed to rotate in a 180 degree range.

7.3 Testing Procedure and Parameters
7.3.1 Electrical and Control Systems Response
Before connection with drive and steering motors, all connections between batteries and control systems will be tested using a digital multimeter (DMM). All connections and contacts will be tested for proper voltage/current/resistance.

7.3.2 Steering System
The front and rear wheels will be elevated to test steering response to steering control input.

7.3.3 Motor Response
The rear (drive) wheels will be elevated and their motors run at low power to ensure proper motor response.

7.3.4 Road Test
The vehicle will be driven on the main roads on the Calvin College campus to determine speed, braking, maneuvering capability, and drive time/distance capability.
8. Conclusion

8.1 Project Status
The Maneuver Mobile team sees a challenging, yet overall feasible project ahead of them. With the majority of the components selected and rough design plan, the team is ready to order equipment and begin construction (with continued design work) at the beginning of the spring semester. The team is confident that it will be able to meet its initial goals of 1) bringing the vehicle back to “running” status, and 2) introducing a 90° steering capability to the rear wheels through the use of wheel hub motors.

8.2 Design Concerns

8.2.1 Motor Power
The current design utilized a pair of 1.3hp (2.6hp max) motors, for a total rating of 2.6hp (5.2hp max). The curb weight of the vehicle is 460lb, with another 760lb of passenger weight (4 passengers). This is not enough to achieve the optimal top speed of 25mph, but enough to reach 20 mph. The peak power rating of the two motors (5.2hp) would be enough to reach that speed in under 6 seconds. This time is acceptable, but hopefully reduced through weight reduction measures. The team will continue looking for motor solutions while attempting to reduce the vehicle weight to improve this number.

8.2.2 Battery Current Capability
DC batteries generally have a current capacity of 40A. At 5.2hp (4kW) total motor power and 48V, the motors would draw 83A from these batteries. Vehicles have been designed in the past with similar battery and motor specifications, but the team will pay special attention to current capabilities and investigate the matter further.

8.2.3 Steering Differential Action
When powering more than one wheel of a vehicle, it is typically necessary to mechanically or electrically differentiate the speeds to account for the different paths taken by wheels depending on steering angle. The team will either attempt to differentiate power supplied to each motor if they are located on opposite sides of the vehicle, or place motors on the front and rear wheels of one side of the vehicle, significantly reducing the speed differential between the driven wheels.
8.3 Logistical Concerns

The purchased components necessary for this project will be expensive. The total cost is estimated at $2073.99 to make all of the changes needed to complete the proposed design. Calvin College will supply up to $500 as well as raw materials and tools for the project. The team will seek component (not cash) donations from manufacturers to take some of the strain off of the team budget. The team is also in conversation with Lacks Enterprises about the potential for them to purchase the $1574.99 needed for the parts not covered by the Calvin College contribution. If budgetary needs cannot be met under this budget the team will draft a secondary proposal using one central motor and lead acid batteries instead of utilizing the two hub motors with LiFePO4 batteries since these are the largest cost drivers for the team. Reference Appendix D for the detailed budget.
9. Acknowledgements

The team would like to thank the following for their advice, support, and encouragement through this point in the project:

**Calvin College Engineering Department**
The department provided the project space, building materials, and tools needed to be able to work on the project.

**Ned Nielsen – Faculty Advisor**
Professor Nielsen provided valuable feedback on reports and ideas. We are also grateful for his suggestion of the “car on the wall” rebuild at the beginning of the fall semester.

**Mark Michmerhuizen – Calvin College electrical engineering professor**
Professor Michmerhuizen provided helpful advice regarding electrical systems. His experience as an electrical engineering for Johnson Controls was extremely useful to the team.

**Phil Jasperse – Shop Supervisor**
Phil took upon himself the arduous task of removing the rolling chassis from its home on the west wall of the engineering building. Phil also provided the team with shop training, material suggestions, and tool suggestions.

**Ren Tubergen – Industrial Consultant**
Professor Tubergen provided input on control systems, steering systems, and power/torque calculations. His experience in the metal industry as well as with past vehicle projects was extremely useful to the team.

The Maneuver Mobile team would also like to thank the friends and families of the team members for their support, prayers, and interest.
Appendix A: Bibliography


Appendix B: Calculations

Motor Power Requirements
Motor requirements were calculated separately for cruising speed and acceleration. The required cruising power is a function of the friction and air resistance forces seen by the vehicle at the nominal top speed of 25 mph. Equations B1 and B2 calculate these friction and air forces, respectively.

\[ F_{\text{friction}} = W_{\text{vehicle}} \cdot r_{\text{rolling}} \]  \[ \text{B1} \]

Where \( W_{\text{vehicle}} \) represents the curb weight of the vehicle with 4 average weight passengers and \( r_{\text{rolling}} \) represents the rolling friction coefficient based on the Engineering Toolbox coefficient for rubber tires on pavement.

\[ F_{\text{air}} = 0.5 \cdot C_D \cdot \rho_{\text{air}} \cdot X_{\text{vehicle}} \cdot v_{\text{max}}^2 \cdot \text{lbf} \]  \[ \text{B2} \]

Where \( C_D \) represents the drag coefficient based on the Engineering Toolbox drag coefficient for a motorcycle and rider, \( \rho_{\text{air}} \) represents the density of air, \( X_{\text{vehicle}} \) represents the cross-sectional area of the vehicle (the area encountering air resistance), \( v_{\text{max}} \) represents the maximum vehicle velocity, and \( \text{lbf} \) represents a conversion factor from lb-mass*ft/s² to lb-force.

The total force seen by the vehicle at cruising speed is the sum of these two forces.

\[ F_{\text{constant}} = F_{\text{friction}} + F_{\text{air}} \]  \[ \text{B3} \]

This force is multiplied by the maximum speed of the vehicle to calculate the power required to travel at the maximum speed of 25 mph as shown in Equation B4.

\[ P_{\text{constant}} = F_{\text{constant}} \cdot v_{\text{max}} \cdot 0.001818182 \cdot \frac{\text{hp}}{\text{lbf} \cdot \text{ft/s}} \]  \[ \text{B4} \]

The acceleration power requirement was calculated as a function of the mass of the vehicle and the desired acceleration time from 0 to the maximum speed of 25 mph (Equation B5).

\[ P_{\text{accel}} = 0.5 \cdot m_{\text{vehicle}} \cdot lbf \cdot v_{\text{max}}^2 \cdot \frac{1}{t_{\text{accel}}} \cdot 0.001818182 \cdot \frac{\text{hp}}{\text{lbf} \cdot \text{ft/s}} \]  \[ \text{B5} \]

Where \( m_{\text{vehicle}} \) is the mass of the vehicle (lb-mass) and \( t_{\text{accel}} \) is the desired 0-25mph acceleration time.
## Appendix C: Part Lists

### Table C1. Motor Options

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Model</th>
<th>Input Voltage</th>
<th>Output Power (max)</th>
<th>Price</th>
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<tbody>
<tr>
<td>Golden Motor</td>
<td>PW16D</td>
<td>24/36/48 V</td>
<td>2.6 hp</td>
<td>$250.00</td>
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<tr>
<td>Heinzmann</td>
<td>PRA-230</td>
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### Table C2. Standard Motor Options

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Model</th>
<th>Input Voltage</th>
<th>Output Power (max)</th>
<th>Price</th>
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<tbody>
<tr>
<td>Briggs &amp; Stratton</td>
<td>Etek (Brushless)</td>
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<td>15 hp</td>
<td>$500</td>
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<tr>
<td>Mars</td>
<td>PMAC (Brushless)</td>
<td>48 V</td>
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<td>BLDC10kW</td>
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<td>Montenergy</td>
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### Table C3. Battery Options

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<td>Type</td>
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<tr>
<td>Voltage</td>
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<td>Voltage</td>
<td>12 V</td>
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<tr>
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<tr>
<td>Max Charge Current</td>
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<tr>
<td>Charge Time (@ 4 A current)</td>
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<table>
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<td>-</td>
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<tr>
<td>Max Charge Current</td>
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<td>Max Charge Current</td>
<td>20 A</td>
</tr>
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<td>Charge Time (@ 3 A current)</td>
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Appendix D: Material Study

Table D1. Aluminum 2021 (0 Temper) Material Properties

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<td>Brinell Hardness</td>
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<tr>
<td>Ultimate Tensile Strength</td>
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<tr>
<td>Yield Strength</td>
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<tr>
<td>Modulus of Elasticity</td>
<td>10000 ksi</td>
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(ASM)

Figure D1. Beam Diagram
Figure D2. Shear Force Diagram

Figure D3. Bending Moment Diagram
### Appendix E: Budget

<table>
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<tr>
<th>Date</th>
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Name of student submitting THIS budget and request for reimbursement: Wesley Richards

e-mail address: cwr3@studentcalvin.edu  
Student ID No. 1625422

Team Name: Maneuver Mobile

Team #: 1

Senior Design Advisor: Prof. Nielsen
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If a team reaches a negative balance situation then the Sr. Design Faculty member will need to sign below and communicate with the Department Chair the need for additional funds.

I understand that this team is overbudget and recommend funds to cover this shortage be drawn from ______________________________________

____________________________________________________________

Signature _________________________________________________