Conversion of a Prime Mover: One-third Scale Model-T from Gasoline to Electric Power

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Abstract

The ultimate objective of any academic program is for students to gain the ability to transfer classroom knowledge to real world practice. Students gain these skills and disciplinary habits of thought through the practice of *doing things* in a discipline. Challenges experienced through projects become some of the best learning moments. One such challenge was given to a group of students as a special project. The goal of this project was to convert a gasoline powered one-third scale Ford Model T vehicle to electric power without a reduction in its prime moving capabilities while retaining as much of its original controls as possible. Other requirements given by the vehicle client included vehicle safety, performance, and cost. The students who undertook this project were motivated by the technical challenge and environmental responsibility that accompanied such a project.

The conversion process was expected to be completed in one semester, but it ended up taking slightly more than three semesters. This paper provides insight in to the motivation of the students and faculty for undertaking such a problem, as well as complications incurred in both technical and logistical settings, and the resilience of all parties to ensure satisfactory completion of the project. Technical issues stemmed from sources such as vehicle age and the students' knowledge base. The logistical challenges also came from more than one source. Access to the workspace at certain times of the year was difficult. Acquiring the proper fabrication tools was a challenging and sometimes required designs changes to match the tooling available. In all, the project was a difficult, but rewarding experience for everyone involved.

Introduction

Experiential learning theory defines learning as "the process whereby knowledge is created through the transformation of experience. Knowledge is a result of a combination of grasping and transforming experience" [1]. Experience created by overcoming the challenge to perform an energy conversion of a prime mover is regarded as a convergence approach. The converging style dominates learning areas of abstract conceptualization and active experimentation. Individuals with such learning preferences work best with technical tasks and problem solving. This learning style is best suited for people who enjoy experiments, simulations, and practical applications [2]. The challenge presented here required such a learning style.

Motivation

A client communicated with the University of Georgia College of Engineering that he had an old Shriners' type vehicle that he was restoring and wondered whether its prime mover could be changed from gasoline to electric while maintaining its original driving qualities which included range, power, and speed. A dynamics instructor who is also the faculty advisor for the university's Society of Automotive Engineers (SAE) was approached to determine the feasibility of such an undertaking. The instructor welcomed the request as an opportunity to offer experiential learning to interested advanced students. With the College of Engineering's great support of the project, the instructor began searching for prospective students. It was envisioned that the project would offer a learning platform to students allowing them to generate novel methods of applying energy conversion, while providing a practical result to the client.

The laboratory background of this project was a 1/3 scale 1960's style Ford Model T built by McCullough Co, changed to Toro Co, then to Sharp Mini Cars. The charge given by the client was to convert the vehicle's prime mover from gasoline to electrical using the design criteria outlined below:

Hard Project Requirements

- Retain original controls for Front, Neutral, and Reverse [F-N-R] using a lever on the left-hand side [LH] and the throttle which was a lever on right side of the steering column.
- Achieve a top speed of 13 mph.
- All parts and components must fit within current envelope.
- Have the ability to run 3-5 mile run time if possible (at parade speeds).
- Use as many off the shelf components as possible for ease of maintenance and repair. Custom parts can be fabricated as needed.
- Use batteries as the power source and include a charging system.
- Budget: around $1000

Soft Project Requirements

- Bonus Points if you can add a better braking system (but still must be handle actuated).
- If possible, a decorative trunk should be fabricated to hide and protect the motor.
- Have fun with the project and get creative/think outside the box.

Course development

A special course was developed for this project. The scope of the course, as listed in the syllabus, was presented as energy conversion from gasoline to electric for a land vehicle. The broad objectives of the course were: (1) to enable the student to develop skills/understanding of topics on an individual or team basis; and (2) to enable the student to develop deeper understanding of a specific engineering topic related to the student's academic interest.

The 3-credit hour course description was as follows: "Land vehicles are powered using various energy sources such as fossil fuel base, and alternative sources. Increasingly, efforts are being made to develop less polluting land vehicles; hence studies on conversion from fossil fuel to use of alternative energy sources such as electrical, solar power, fuel cells, and even biomass are being explored. This course will offer the platform to convert a gasoline powered land vehicle to an electrically powered vehicle."

The specific course objectives were:
(1) Inform students about approach to client work.

(2) Stimulate students intellectually through problem-based learning by involvement in real life work.

(3) Stimulate creativity in problem solving.

(4) Promote team work and individual responsibilities.

These objectives were to be exceeded as the students completed the project.

Recruitment

Criteria for student recruitment were established to ensure that the project would be successfully completed. The criteria included the following: students need to be at a junior standing preferably in mechanical engineering. This criterion assured that a selected student had most of the engineering mechanics and electrical requirements completed. Knowledge from aforementioned courses is required to understand design, functions, and operations of a powertrain. The student was to be in good standing in classes. This criterion ensured that the student did not just complete the course work in the identified classes but, understood the concepts. The student would indicate interest in vehicle engineering and technology. This criterion was to ensure a sustained motivation throughout the project duration. Three students were deemed appropriate to tackle the problem. Recruitment of students was through word of mouth. Several students were contacted by the instructor and three enrolled.

Spring 2018: Rolling Out of the Project

Having the project scope and objectives determined, and the student recruitment completed, the next step was to arrange a meeting between the relevant parties. The meeting was attended by the client and the university team, composed of the students and instructor, as well as the school chair. During the meeting, the client gave the background of the problem and established a relationship with the university team. In addition, he provided details on what type of restoration was acceptable, the budget and answered the team's questions which included the vehicle delivery details. After the meeting, the university team began discussing a plan to tackle the problem. This discussion included the frequency of future team meetings, expectations, and timelines. It was agreed that biweekly meetings and reports were necessary to maintain steady progress.

During the first biweekly meeting, a project timeline was created and agreed upon between the students and faculty mentor. This schedule included such things as how much time to work on the project per week and the format of biweekly meetings and progress reports. At this meeting, it was agreed that all activities related to this project including design, fabrication, and cost documents will be recorded in design notebooks. Originally the project was planned to occur over one semester, however, it soon became apparent that more time would be needed because of the condition of the vehicle and the many unforeseen obstacles facing the team. A major portion of the spring 2018 semester was devoted to vehicle assembly, data gathering and new knowledge development.

Project Storage and Work Space

The immediate need, following the initial meeting, was to find a location to house the project. Since the vehicle was to be delivered mostly in pieces it was imperative to allocate a secure site for storage with low foot traffic (see figure 1 and figure 2). The college of engineering (CENGR) workshop manager offered a site to keep the vehicle. Once a storage site was allocated for the project, the vehicle was delivered by the client to the CENGR workshop. Then a tarp was purchased to cover it in order to reduce its attraction to curious workshop visitors.

Figure 1: Original Transmission

Figure 2: Vehicle Body

Vehicle Assembly

Because the vehicle was received mostly disassembled and had limited documentation, much of the first month was devoted to vehicle assembly. This activity took considerable time. Without the original engine, determining the proper operation and function of the linkages was difficult to determine. Another issue facing the team was worn or damaged parts on the vehicle. Multiple defective parts were found during assembly including worn bushings, damaged steering gears, out of round tires, sticking linkages, and even missing parts. The bolts that attached the wheels to the hubs were also previously overtightened causing them to fail during assembly. Toward the end of the project, during testing, the front bearings were also discovered to be damaged and were later replaced. The state of the vehicle was relatively poor and caused an unforeseen delay before design could begin.

Measurements and Data Gathering

While replacement parts were being designed and fabricated, or ordered, measurements of the vehicle were taken. This included physical constraints of the engine compartment. Considering the future dynamic calculations that would be needed, the vehicle was massed. A wheel was also removed from the vehicle and massed for the inertial load that it would impart during acceleration. This wheel was also drawn in Autodesk Inventor so that an accurate estimate of the moment of inertia could be calculated. The inertial load of the wheel and tire assembly is important because, while they will have no affect while driving at a constant velocity, they will affect the acceleration of the vehicle.

Once the vehicle was sufficiently assembled, the team began collecting friction data. Friction in the tires, bearings and air drag are what will determine the top speed of the vehicle. Without these forces, the vehicle's speed would continually increase without limit if the prime mover supplied torque to the wheels. Therefore, these forces must be known to determine the acceleration and top speed of the vehicle. Knowing the end goal, to determining the force required to overcome the frictional forces at all speeds, the team was faced with a new issue. How can this be done? Many different approaches were considered including:

- Towing the vehicle behind a car with a force gauge.
- Rolling the vehicle downhill and recording the acceleration.
- Placing the vehicle on a dynamometer.

The above approaches were ruled out because of safety issues, low accuracy or cost. The team eventually proposed to place the vehicle on a treadmill with a force gauge attached to the front of the vehicle. This plan was a great balance of safety, cost and accuracy. While this method did not measure the air-drag associated with the actual operation of the vehicle, it was assumed negligible considering the relatively low operating speed of 13 mph. A search was conducted to try to find a treadmill large enough to fit the entire vehicle, but no such treadmill was available. An idea then surfaced to support half of the vehicle from overhead and multiply the results by two in order to get an accurate estimate of the frictional forces. Figure 3 shows the testing setup of the vehicle. A level was used to ensure the rigging was vertical, so it only held the weight of the car and did not take any force in the horizontal direction. The vehicle was then loaded with weights to account for the driver and prime mover. To collect accurate data, a laser tachometer recorded the wheel speed while a force gauge collected the frictional data. This method allowed for acceptable data collection at various speeds. Figure 4 shows the data collected from the friction testing and a linear approximation of the data was used for future calculations.

(a) Driver Side View (b) Passenger Side View (c) Support System

Figure 3: Friction Testing

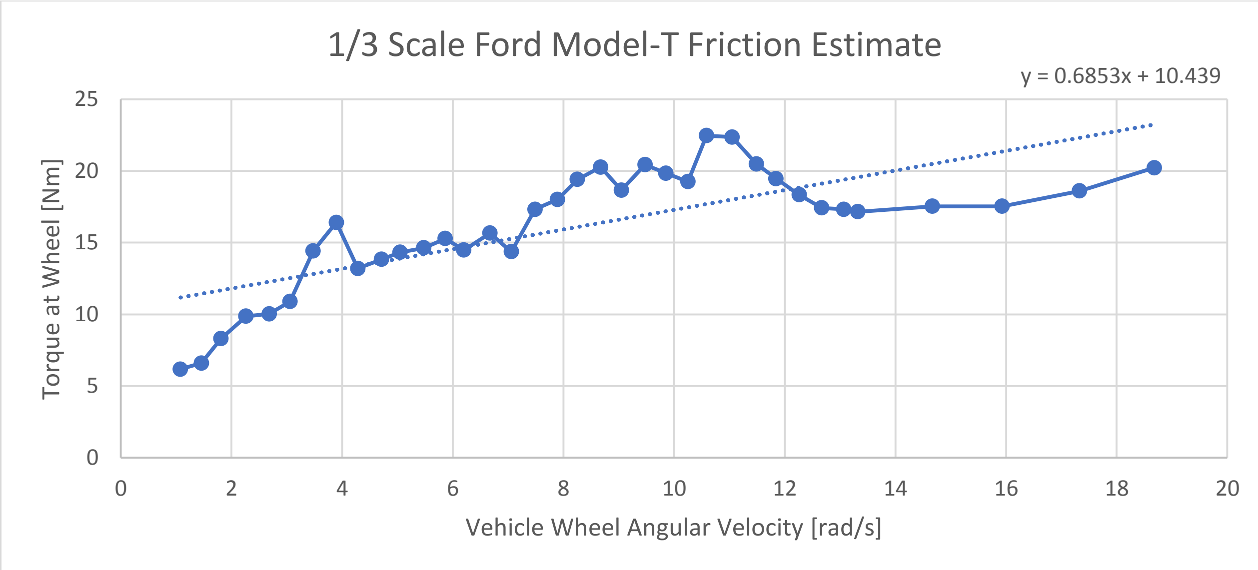

Figure 4: Friction Data from Testing

The force was measured using a digital force gauge and, in hindsight, was not the best choice due to the sampling rate of the device. Because the rear tires were out of round, a cyclical force was created by the car jumping up and down and the digital force gauge, which had a slow sampling rate, could not accurately capture the frictional forces of the car. To err on the side of caution, the gauge was observed multiple times at each increase of the treadmill speed and the highest value was taken.

Personnel Changes

During the 2018 spring semester, a team member withdrew from the class citing a course work overload. With a reduction in personnel and a heavy course load on the remaining students, the students approached the instructor and communicated the difficulties with the client. After some discussion, the decision was made to extend the project into the summer and fall semesters of 2018. The students were working at local internships over the summer and were able to meet and continue work on the vehicle’s design.

Summer 2018: Mathematical Modeling and Motor Selection

MATLAB Modeling

To size the motor required to accelerate the vehicle in a reasonable time frame and achieve the desired speed, a mathematical model of the vehicle was developed. Before delving into the model approach, some knowledge of how the motor operates is helpful. A standard DC motor torque curve behaves as follows. First, when the angular velocity of the motor is zero, the motor outputs its max torque, known as stall torque. When the angular velocity of the motor is at its max, free spin, the torque output is equal to zero. This means the vehicle would have its max torque at the start and would accelerate until the motor reached its max velocity.

Using a numerical methods approach, the vehicle's acceleration was found in the following manner. If the torque curve of the motor is known, as it would be provided with any quality motor, then using a chosen gear ratio, between the motor and axle, the torque at the wheel of the vehicle can be found. If for a very short period of time, say 0.001 seconds, and the acceleration of the vehicle is assumed linear, then the vehicle's new speed can be found. Relating this back to the motor angular velocity, a new value of torque can be found from the torque curve of the motor and the process repeats giving the acceleration of the vehicle at all points. Writing all the forces as a function of torque on the drive wheel of the vehicle, (1) was formed. By adding the drag estimate to the numerical method, a more accurate acceleration and the estimated top speed was found. The MATLAB code can be found in the appendix.

$$a_{car} = \frac{T_m * \frac{r_a}{r_m} - T_f}{I_m * \frac{r_a}{r_w * r_m} + \frac{I_a}{r_w} + \frac{I_w}{r_w} + M_{car} * r_w} \quad \ldots\ldots\ldots \ (1)$$

- a_{car} = Acceleration of the car [m/s^2]
- T_m = Torque of the motor [Nm]
- T_f = Frictional force converted to a torque on the rear wheel in [Nm]
- r_a = Radius of the axle drive gear [m]
- r_m = Radius of the motor pinion gear [m]
- r_w = Radius of the wheel [m]
- I_m = Moment of inertia of the motor pinion [kg*m^2]
- I_a = Moment of inertia of the axle gear [kg*m^2]
- I_w = Moment of inertia of the wheel [kg*m^2]
- M_{car} = Mass of the vehicle [kg]

Motor sizing

The mathematical model of the vehicle gave a starting point for the motor search to begin. Interpreting the MATLAB model revealed that a 2-kW motor with a DC torque curve would give the desired acceleration and top speed with the chosen gear ratio. After discussing many options with electrical engineering faculty and through the team's research, a motor operating on the brushless direct current (BLDC) principle was chosen. This type of motor does not require a power inverter since the power source is DC and this type of motor is the most common for small go carts and scooters. Moreover, since these motors require motor controllers, many of the client's requirements could be met through software changes in the controller. The BLDC motor's torque curve was approximated as that of a DC motor for modeling purposes.

The search for a motor was now the primary focus of the team. The biggest challenge turned out to be finding manufacturing data sheets to accompany the motor. Simply having the motor power leaves many questions about the performance. While the max power of the motor gives the top speed of the vehicle, how that speed is achieved while driving the vehicle is just as important as reaching that top speed. A primary example of this is turbocharged cars that have erratic acceleration curves because of the acceleration boost that only occurs within a specific engine speed range. To understand the acceleration path of the vehicle, a torque curve of the motor was needed. While many BLDC motors had performance data, most of the motors with data were outside of the budget. After much searching, a motor from a Chinese supplier was found that included its torque curve and was reasonably priced. The motor was a 2-kW BLDC motor manufactured by Kun ray (see figure 5). The torque curve and data sheets are shown in figures 6 and figure 7.

Figure 5: Kun ray Motor [3]

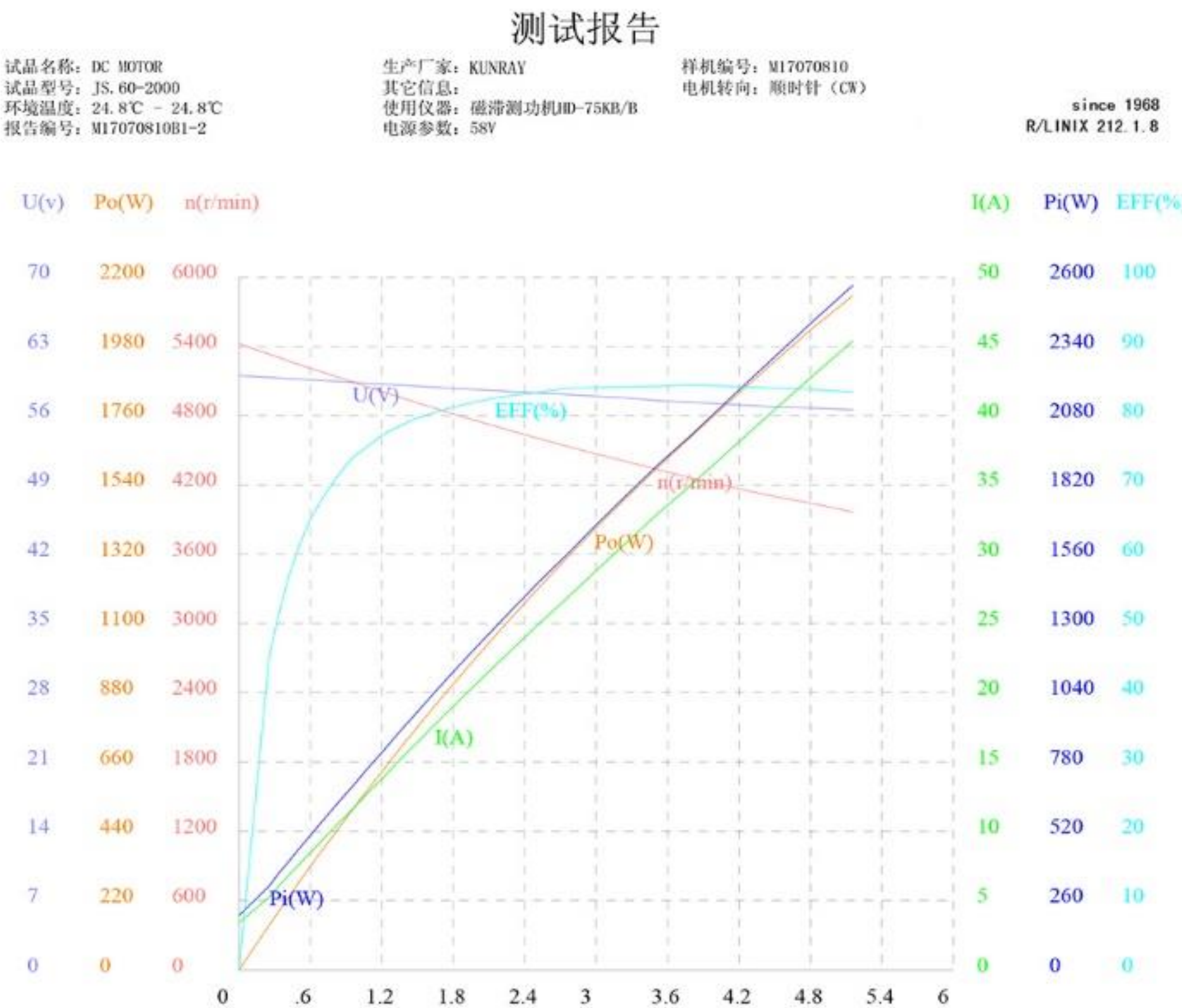

Figure 6: Kun ray 2 kW BLDC Motor Power and Torque Curve [3]

NO.	n(r/min)	T(N.m)	Po(W)	U(V)	I(A)	Pi(W)	EFF
1	5423.2	0.0000	0.0000	60.027	3.3998	204.08	0.00%
2	5332.7	0.2546	142.19	59.874	5.2527	314.50	45.21%
3	5305.1	0.3301	183.35	59.817	6.0172	359.93	50.94%
4	5273.4	0.4158	229.59	59.753	6.7860	405.49	56.62%
5	5240.9	0.5116	280.73	59.684	7.6576	457.04	61.43%
6	5206.0	0.6160	335.81	59.607	8.5894	511.98	65.59%
7	5169.4	0.7239	391.85	59.527	9.5848	570.55	68.68%
8	5132.1	0.8345	448.47	59.449	10.562	627.91	71.42%
9	5093.1	0.9534	508.45	59.365	11.588	687.95	73.91%
10	5050.5	1.0793	570.81	59.273	12.747	755.53	75.55%
11	5005.4	1.2137	636.15	59.181	13.901	822.69	77.33%
12	4959.9	1.3541	703.26	59.079	15.157	895.48	78.53%
13	4912.8	1.4942	768.66	58.979	16.370	965.48	79.62%
14	4864.8	1.6444	837.65	58.873	17.691	1041.5	80.43%
15	4813.2	1.8039	909.19	58.763	19.042	1119.0	81.25%
16	4762.4	1.9720	983.37	58.649	20.475	1200.8	81.89%
17	4709.7	2.1498	1060.2	58.530	21.943	1284.3	82.55%
18	4654.5	2.3331	1137.1	58.407	23.457	1370.0	83.00%
19	4598.2	2.5312	1218.7	58.273	25.085	1461.8	83.37%
20	4539.0	2.7441	1304.2	58.136	26.724	1553.6	83.95%
21	4473.4	2.9842	1397.9	57.969	28.693	1663.3	84.04%
22	4405.9	3.2383	1494.0	57.792	30.708	1774.7	84.18%
23	4333.5	3.5135	1594.3	57.521	32.898	1892.3	84.25%
24	4254.4	3.8199	1701.7	57.325	35.166	2015.9	84.42%
25	4179.5	4.1416	1812.6	57.121	37.673	2151.9	84.23%
26	4104.9	4.4795	1925.4	56.910	40.281	2292.4	83.99%
27	4038.8	4.8223	2039.4	56.759	42.895	2434.6	83.76%
28	3967.0	5.1545	2141.2	56.578	45.396	2568.4	83.37%

特征点	n(r/min)	T(N.m)	Po(W)	U(V)	I(A)	Pi(W)	EFF
空载点	5423.2	0.0000	0.0000	60.027	3.3998	204.08	0.00%
最大效率	4254.4	3.8199	1701.7	57.325	35.166	2015.9	84.42%
最大输出	3967.0	5.1545	2141.2	56.578	45.396	2568.4	83.37%
最大转矩	3967.0	5.1545	2141.2	56.578	45.396	2568.4	83.37%

Figure 7**:** Kun ray 2 kW BLDC Motor Power and Torque Data Sheet [3]

Controller

Once the motor was selected, the team needed a way to control the vehicle systems. The design requirements dictated that there had to be certain features built into the controller while having the ability to control a 2kW BLDC. These features included the ability to run in forward and reverse, a switch to cut the motor throttle while braking, and the option to set up a safety circuit that would not allow the car to operate without a driver. The controller that the team selected was able to meet all of these requirements and had several other features including regenerative braking capabilities, electric braking assist, cruise control and anti-theft.

Battery Power Determination

Once the motor size was determined and the controller selected, a battery had to be chosen to meet the motor's requirements that are shown in figure 7. The battery was sized primarily by the motor's required input voltage of 60VDC. The battery criteria were then selected as a nominal output of 60VDC and amperage output of 100A, in order to give a two times factor of safety slightly above 2 when considering the motor's peak draw. After these criteria were taken into consideration, the team proposed two different battery setups that could work. The first was a set of several lead-acid batteries, and the second was a single lithium-ion battery pack that came with a charger. Both selections were roughly 25-Ah. The two choices were given to the client with a list of pros and cons of each. The client chose the lithium-ion battery pack.

Delays in the Process

The main components were selected, and the purchase order request was sent to the client in the early part of summer 2018. However, the parts were not received until August. While the team was waiting on the parts arrival, they began initial design work on the motor mount and overall layout of the components in the vehicle.

During this time, initial sizing of the motor chain began. The selected motor came with a T8F chain sprocket however, the team was unsure is this chain would be sufficiently strong to carry the load. The necessary calculations to determine if the chain size T8F would be strong enough for the application were conducted. The results indicated that the T8F was acceptable, so the team selected an axel gear to meet the selected gear ratio. After this point, little progress was made until the parts were received.

Fall 2018: Design and Fabrication

Motor Mount Design and Fabrication

The motor mount design was one of the most challenging aspects of the project. There were many different concept designs and many of which were sound but, were too complicated to be fabricated with the equipment at the team's disposal.

Eventually, the team had an idea to overcome these obstacles. They decided to purchase an adjustable motor positioning base to hold the motor mount and then fabricate a motor mount with 16-gauge steel (see figure 8 and figure 9). The fabrication of this mount required the use of a roll bender however, the team did not have access to one. To overcome this issue, the team designed and built a roll bender as a project for another class. Then they purchased some mild steel and had the instrument fabrication shop at UGA cut out the blank with a water jet. The next step was to bend the steel. The roll bender the team made worked well enough to get most of the shape. The other were made with a sheet metal brake in the CENGR shop. Unfortunately, there were a few flaws in the design that were later found in testing.

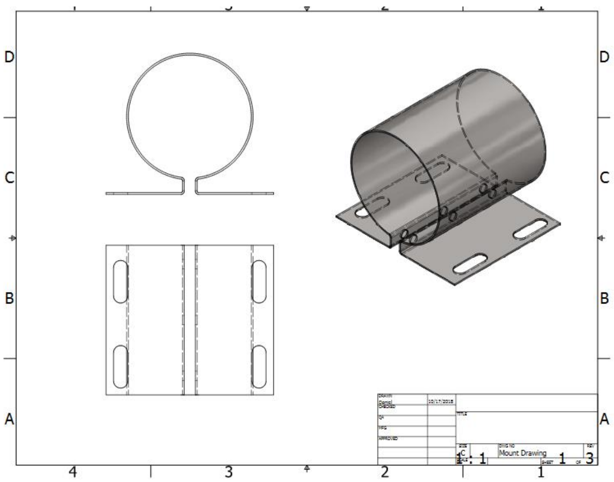

Figure 8: Concept Design of Motor Mount

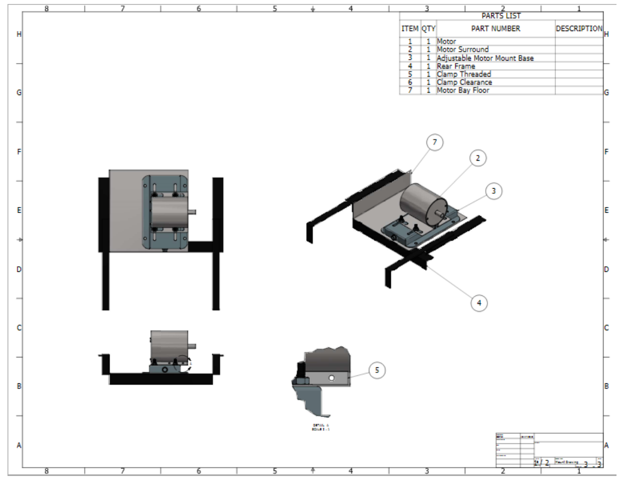

Figure 9: Concept Design of Mount Assembly

Electrical Design and Controller Setup

The wiring diagram for the controller was an important piece of information that the team was missing. It was not given on the website, where the controller was purchased, and this controller could not be found on any other site. Lacking this information, the team was unable to make certain design decisions until it arrived, causing delays. Once the controller, motor and battery arrived, the team plugged in the included USB drive that was supposed to contain the controller's software, however, there was no software present. This issue led the team to contact the supplier.

After the first contact with the supplier, the team was provided a wiring diagram and the software. However, the new software was corrupted. The supplier then took several weeks to get the team an uncorrupted version. Waiting for the software, the team was able to make decisions on the throttle sensor and control switches.

Once the supplier provided the corrected software and a throttle sensor was obtained, the team connected the motor and the necessary sensors to the controller to begin setting up the controller. After much trouble shooting and testing, the wiring was figured out (see figure 10).

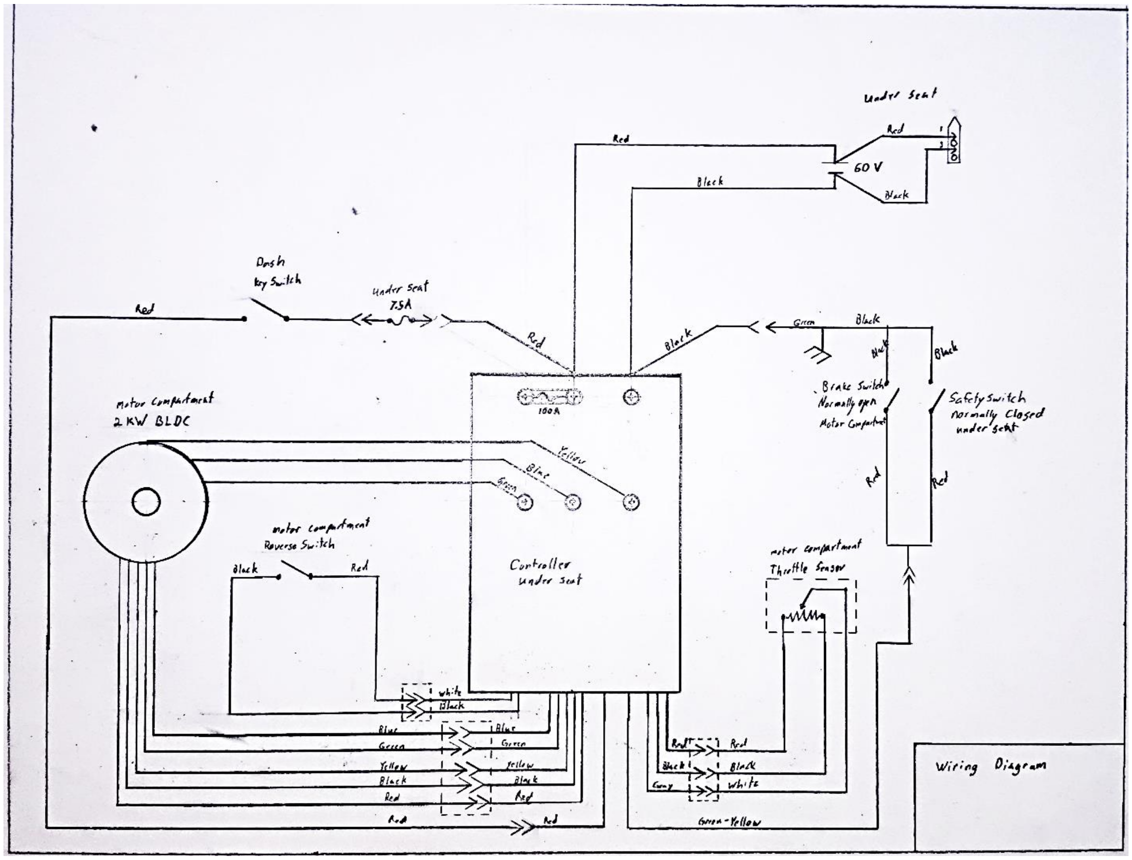

Figure 10: Model T Wire Diagram

Other Components

Knowing how to choose a normally open or normally closed switch for each application is one thing. Figuring out how to hold the switch in the right position is something else. The need to hold the switches gave rise to many other components that had to be designed and fabricated to be able to operate the vehicle. Several switch mounts had to be designed where the linkages from the original control rods could make mechanical contact with the switches. The switch mounts for reverse and brake are in the motor compartment and were designed to be simple to fabricate out of sheet metal and need little to no modification of the bodywork (see figure 11).

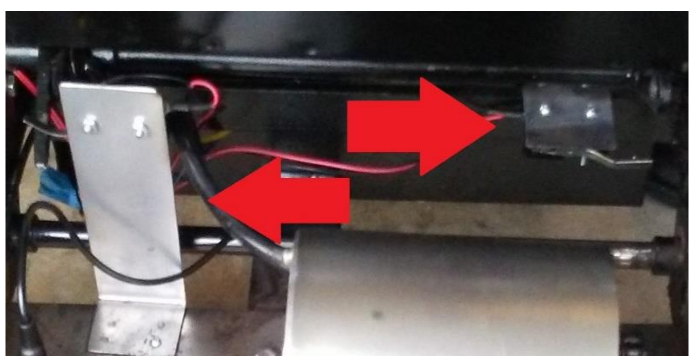

Figure 11: Switch Mounts

A lot of time was spent deciding how to set up the safety circuit; both the location in the vehicle and on what control circuit it should communicate with. Safety was a primary concern during the design of the vehicle. One such concern was what would happen if the operator stood up while driving the vehicle or what would happen if the operator was outside of it and turned it on. There was talk about using the safety switch to cut power but, because the team was planning to use the controller's motor braking system to help supplement the mechanical brake, this was decided against. After much consideration, it was decided to use a normally closed switch under the seat which would open if there was not enough weight in the seat and apply the electric brake.

Continuing with safety in mind, because part of the reason the client is having this conversion performed is for future grandchildren, who can access the vehicle is important. The decision to make the on-off switch a keyed switch was an easy choice and a switch mount was made to hold this switch near the steering column (see figure 12).

The vehicle, being a toy replica of a Model-T, did not use a throttle pedal like the real Model-T, instead it uses a lever on the right side of the steering column to control the throttle of the engine through a control cable. To keep the controls the same, a throttle sensor for an electric motor scooter was purchased and attached to the throttle cable. Using a copper pipe of the correct diameter, the throttle switch was mounted to the engine compartment where the cable could easily reach (see figure 13).

In order to mount the motor to the vehicle frame, a piece of 16-gauge mild steel was bent with a sheet metal brake to span motor bay (see figure 14). The motor bay floor gave ample room to mount sensors and switch mounts as well as the motor mount.

Figure 12: Key Switch Mount

Figure 13: Throttle Sensor Mount

The battery and motor controller were mounted underneath the seat (see figure 15). The battery shelf was made with one major bend down the front to increase the moment of inertia and reduce deflection caused by the weight of the battery. It also has several tabs bent up to stop the battery from sliding around. Underneath the battery is the motor controller.

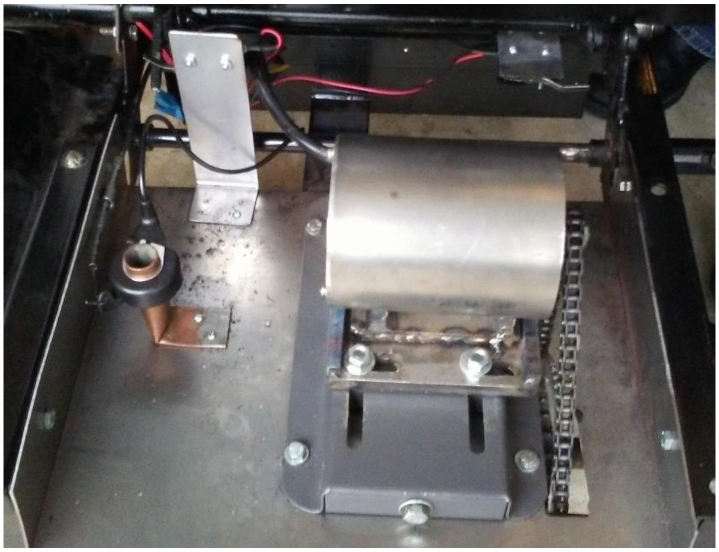

Figure 14: Motor Bay Floor with Components

Figure 15: Battery Shelf

Testing and Solving Issues

Now that all the parts were fabricated and assembled, testing could begin. At first, testing was conducted in the garage making sure all of the settings for the controller were in a range that was safe for operating the vehicle. The brake and reverse switches were checked for proper operation.

The first attempt at driving the vehicle showed a flaw in the design of the motor mount. The fabricated motor mount yielded after driving forward so a supporting bracket was designed and added which corrected the problem (see figure 14).

After fixing the motor mount, during the next test drive, a clicking sound was heard coming from the motor and the vehicle had a very slow, jerky take off, but, only when driving forward. When driving in reverse, the vehicle performed very well. The difference in quality of operation between forward and reverse had the team confused for some time. A camera was mounted to the frame to record the motor in operation. After testing with the camera and reviewing the video, the team began to understand the problem. The motor bay floor and rear axle were deflecting and creating significant slack in the chain which was more prominent in drive because of the different angles involved due to the motor placement. The sudden jerk of the chain was causing the motor controller to energize the incorrect coil in the BLDC motor. This led to a jerky motion and a clicking sound.

Now that the team had figured out the cause of the noise and jerking, they had to find a way to solve it. Attempting to reduce the deflection would require redesigning most of the rear of the vehicle. Instead, a spring-loaded tensioner was employed to take up the slack when the deflection occurs. After designing, fabricating, and installing the tensioner, the problem was corrected.

Finally, the vehicle was driving in forward and reverse properly. The team's focus shifted to improving the overall vehicle operation. The first improvement was to turn on the electronic braking in the controller. This new braking made a significant improvement in the vehicle's ability to slow down in conjunction with the mechanical brake. Next, while in reverse, the vehicle was limited to a fraction of the speed that it was allowed in forward. The regenerative braking was turned on as well to increase the range of the vehicle. And finally, the speed of the vehicle was limited to 13 mph as per request of the client.

Addressing Vehicle Mechanical Issues.

At almost every stage of the project, mechanical issues with the existing components were discovered. While the vehicle was being assembled, the steering kept skipping teeth (see figure 16), several tire inner-tubes would not hold air, the steering shaft could pull out of the column, the steering wheel could pull off from the steering shaft, the control rods were sticking together, and many other corrosion related issues. The steering bushing and innertubes were the only parts that were replaced early in the project. The rest of the issues were dealt with later.

Figure 16: Broken Steering Bushing

During testing, several more issues were discovered. The front bearings would lock up when driving forward, the rear axle bearings were worn through, and the steering knuckles were upside down and on the wrong sides. All these issues were dealt with at the time of discovery. The front bearings were upgraded from greased sleeves to ball bearings to further reduce the frictional forces. The steering knuckles were corrected fixing the vehicle's alignment.

Spring 2019: Finishing

Once the team was satisfied with the vehicle's performance, the last stretch of the project had come. The main difference between a completed project and a finished project is in the details. The vehicle was fully disassembled and meticulously inspected for cosmetic defects and mechanical issues. At this time the team repaired all the remaining mechanical issues. To securely attach the steering wheel to the shaft, the shaft was drilled and tapped allowing the wheel to be bolted on. The control rods were cleaned with a wire wheel and re-greased. All newly fabricated parts for the conversion were ground, primed, and painted. Wire loom was installed to protect the wiring. The wheel hubs were removed, cleaned, and all bolts were replaced to repair the damage from the previous overtightening. The tires were replaced, and all the body mount bolts were replaced for cosmetic purposes. The vehicle was re-assembled and aligned. Finally, documentation was gathered and written for the vehicle owner.

New Additions to the Vehicle

In the process of finishing the vehicle, several other parts were fabricated for cosmetic purposes. Real Model-T's had a trunk on the back so one was designed and made for the back of this vehicle (see figure 17). The trunks purpose is twofold, first, it is a cosmetic upgrade, second, it serves as an additional safety to protect hands from the chain and motor. The trunk also has a removable shelf in it to hold the charger, data cable, and a CD containing the software and documentation. The last component that was made is a cover for the underside of the seat. It covers the battery and motor controller and has the charging and data ports mounted to it.

Figure 17: A box built to cover the motor as mounted on the vehicle

Discussions and Conclusion

The ultimate goal of any university program is to provide the students with the skills necessary to accel in the work force. This project has exceeded this goal. Over the course of the project, the students were able to learn the design process and affectively apply their skills and abilities to solve the challenge at hand. Moreover, they were able to learn how to effectively communicate with their client and suppliers. The project was completed in 13 months and allowed the students to witness the many joys and challenges of the design process. The scope of the project was more than the conversion of the prime mover because it involved restoration of the vehicle. However, the university team worked tirelessly in spite of various setbacks they encountered. In the end, the vehicle capabilities were met or exceeded as shown below:

- 25+ mph … stronger motor for acceleration time… limited down to 13 mph for safety for children per client request.
- Braking slightly improved by using electric motor controller
- 15 – 20-mile range (estimated), tested over 12 miles

The university team and vehicle are shown in figure 18 and the project expenses are shown in figure 19.

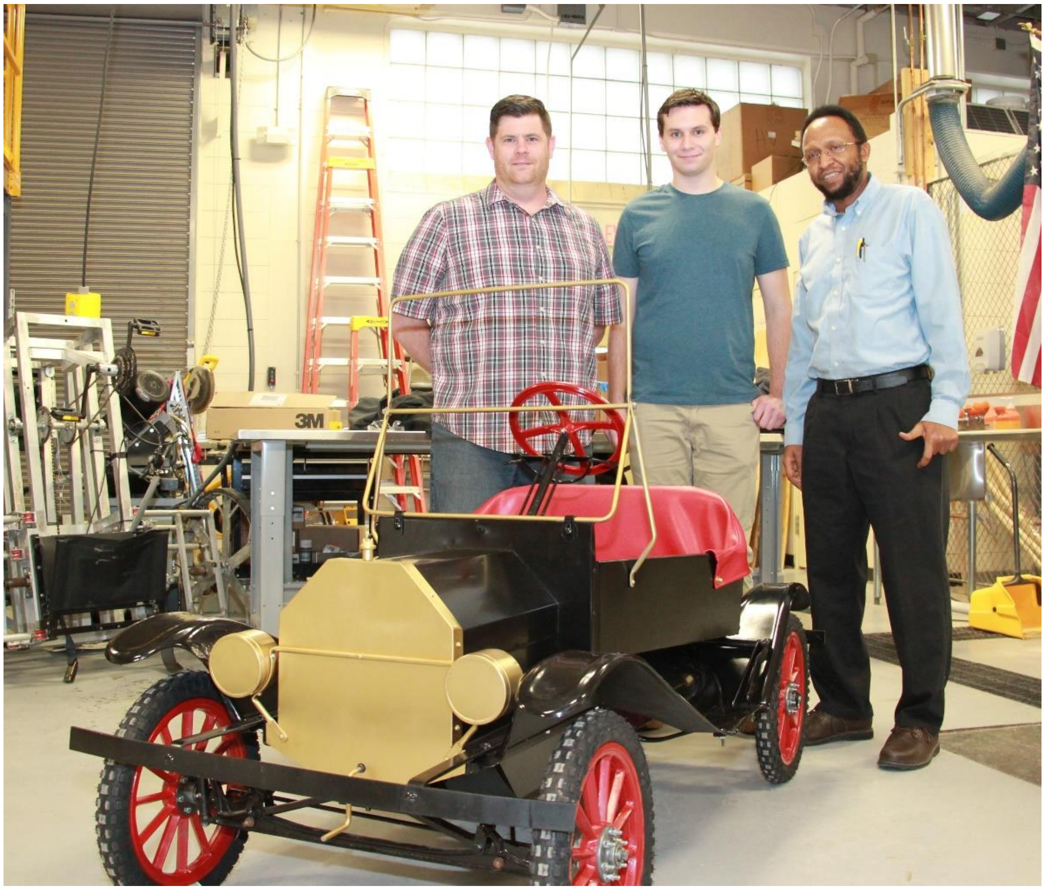

Figure 18: University Team and Completed Vehicle: Daniel Plant (left), Daniel Wallon (middle), Dr. John Mativo (right)

Conversion		Repairs		Cosmetic	
Part	**Price**	**Part**	**Price**	**Part**	**Price**
Wiring Connector	$8.99			Wood	$16.01
Panel Mount USB	$8.45	Rear Axle Bearings	$13.76	Wire Loom	$5.55
Tensioner	$8.03	Front Bearings	$36.45	Paint	$8.55
Wiring Connector	$9.99	Tires	$49.39	Paint	$4.96
Throttle Sensor	$12.95	Hardware	$27.22	Paint	$3.96
Sheet Metal	$20.32	Inner-Tubes	$12.87	Brush	$0.57
Hardware	$17.88			Wood and Hinge	$22.42
Switches	$32.08			Leather and Buckle	$11.18
Hardware	$1.38				
Chain and Sprocket	$35.84				
Motor Mount Base	$32.21				
Sheet Metal	$25.38				
Master Link	$3.95				
Cutting Disks	$20.76				
Force Gauge	$19.84				
Motor	$122.61				
Controller	$192.80				
Battery	$551.02				
Total	$1,124.48	**Total**	$139.69	**Total**	$73.20
Total for Prime Mover Conversion	**$1,124.48**	Total for Project Including Repairs and Cosmetics	**$1,337.37**		

Figure 19: Expenses on energy conversion and vehicle restoration

Student Reflections

Daniel Plant

The prime mover project is a good representation of the kind of projects that I enjoy. While this project was a class, it felt a lot more like a hobby toward the end. During this project we had the ability to take something from concept fully through the design process, fabrication, assembly, and testing. I feel that we learned a lot more about how things are made than we already knew, and we learned about the effects on the design process due to how things are made.

Daniel Wallon
Taking on the prime mover project allowed me to showcase my abilities as a future engineer. Moreover, the project allowed me to see the design process and learn about the joys and many difficulties that exist in the design world. However, projects such as these are not to be joined without much consideration. They require a lot of dedication and interest from the students, instructor and client. Moreover, strong wills are needed when the project seems impossible. Fortunately, the students, instructor and client had all these traits which made this a great experience and a successful project.

Instructor Reflection

Dr. John Mativo

One great satisfaction of problem solving is the learning of methods that offer a sound and systematic approach for finding solutions. The challenge of energy conversion, at this scale, from gasoline to electric was new to us and the outcome of this experiential learning had to meet the client needs/criteria.

The “team” dynamics were exceptional. The “team” here refers to the Client, Students, and the Instructor. The client provided clear outcomes he expected. As an engineer himself, he was aware of the possibilities and limitations of the process and this made communication with him effortless. He understood when we could not deliver in one semester as had originally been planned. He was supportive of the decision to purchase directly from overseas and followed up with the vendor when difficulties occurred.

Great students have good qualities. Initially three students signed up for the course and one dropped as mentioned earlier in the paper. The two students worked smart and tirelessly. The students and the instructor set a meeting schedule and kept at it throughout the project. In addition to having a working schedule, the students were not only top in their class but also had deep working knowledge of vehicles. This peculiar skill set, kept the students focused on the engineering design, testing of systems, building of parts, assembly of the vehicle and finally testing and optimizing the final product. My role in the process was mostly of a sounding board to them. The students were innovative in finding a working space and using relevant parts of this project to account for other class term projects. They were able to use other faculty as resources in this class and gained deeper understanding of specific systems they worked on at the given time.

The overall experience was good, demanding, required patience, and very rewarding. If a similar project is posed to me, I would certainly hope to have such a supportive and understanding client, and great students! The new knowledge on the conversion of a prime mover for a 1/3 Model T vehicle is now available and the team has made a contribution to the field.

Reference

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Appendix:

MATLAB Code:

```
clear
clc
%Inputs
    Motor_Max_Power = input('Please input the motor''s max power in Watts\n');
    Motor_Rated_Speed_RPM = input('Please input the motor''s rated speed in RPM\n');
    time_incrament = input('Please input the time incrament for preferred
accuracy\n');
    time = input('Please input the length of time for viewing\n');
    Gearing = input('Please input a gear ratio  axel gear / motor gear\n');

%Fixed Parameters
    I1=4*.117856; %tires moment of inertia kg m^2
    I2=.0104; %axle gear moment of inertia kg m^2
    I3=0; %motor gear moment of inertia kg m^2
    r1=.205;% Radius of tire
    m=215.49;% Mass of car 90.78kg, Mass of 200 lb person=90.71kg, Mass motor+batt
34kg

%Motor specs and friction

    %Equation for motor Torque curve
        Motor_Rated_Speed_rad_s = Motor_Rated_Speed_RPM*0.104719755;
        T_stall = 4*Motor_Max_Power/Motor_Rated_Speed_rad_s;
        Motor_Speed = 0:Motor_Rated_Speed_rad_s;
        Motor_Torque = T_stall-Motor_Speed*(T_stall/Motor_Rated_Speed_rad_s);
        figure(1)
            subplot(2,2,1)
                plot(Motor_Speed,Motor_Torque);
                title('Motor Torque vs Motor Speed ');
                xlabel('[rad/s]');
                ylabel('[N*m]');

    %Frictional torque and motor torque
        Wheel_speed = Motor_Speed/Gearing;
        Friction_Torque = 0.3427*Wheel_speed+5.2195;
        Friction_Motor = Friction_Torque/Gearing;
        subplot(2,2,2)
            plot(Motor_Speed,Motor_Torque)
            hold on
            plot(Motor_Speed,Friction_Motor)
            title('Torque vs Motor Speed'), xlabel('[rad/s]'), ylabel('[N*m]')
            legend('Motor Torque','Frictional Torque','Location','northeast')
            hold off

%Motor speed vs vehicle velocity
    %Selected gear ratio
        Velocity = Motor_Speed*r1/Gearing;
        subplot(2,2,3)
            plot(Velocity,Motor_Speed)
            title('Motor Speed vs Vehicle Velocity with Selected Gearing Ratio')
            xlabel('[m/s]'), ylabel('[rad/s]')

    %Multiple gear ratios
        Gears = 1:10;
        c1 = 1;
        figure(2)
            hold on
            while c1 <= length(Gears)
```

```
                vector = Gears(c1)*Velocity/r1;
                c1 = c1+1;
                plot(Velocity,vector)
            end
            title('Motor Speed vs Vehicle Velocity with Multiple Gear ratios')
            xlabel('[m/s]'), ylabel('[rad/s]')
            legend('1','2','3','4','5','6','7','8','9','10','Location','northwest')
            hold off

%Initial conditions and vector creation
    t = 0:time_incrament:time;
    v = zeros(length(t));
    a = zeros(length(t));
    w_motor = zeros(length(t));
    N = zeros(length(t));
    w_wheel = zeros(length(t));
    Tm = zeros(length(t));
    Denominator = (I1+I2)/r1 + I3*Gearing/r1+m*r1;

%Calculations
    c2 = 1;
    while c2 <= length(t)
        w_wheel(c2) = w_motor(c2)/Gearing;
        tf = 0.3427*w_wheel(c2)+5.2195; %torque of friction @ axel
        Tm(c2) = T_stall - w_motor(c2)*(T_stall/Motor_Rated_Speed_rad_s);   %torque
output of the motor
        a(c2) = (Tm(c2)*Gearing - tf) / Denominator;    %Acceleration of vehicle
        alpha3 = a(c2)/r1*Gearing;      %angular acceleration at motor
        w_motor(c2+1) = w_motor(c2) + alpha3 * time_incrament;  %Updating motor speed
        if c2 < length(t)
            v(c2+1) = v(c2)+a(c2) * time_incrament; %Updating Vehicle velocity
        end
        N(c2) = m*a(c2);    %Force at road
        c2 = c2+1;    %Updating the counter
    end

%Plotting
figure(3)
    subplot(2,2,1)
        plot(t,a)
        title('Acceleration vs Time');
        xlabel('[s]');
        ylabel('[m/s^2]');

    subplot(2,2,2)
        plot(t,v)
        title('Velocity vs. Time');
        xlabel('Time [s]');
        ylabel('Velocity [m/s]');

    subplot(2,2,3)
        plot(v,w_motor)
        title('Motor Speed vs. Velocity');
        xlabel('[m/s]');
        ylabel('[rad/s]');

    subplot(2,2,4)
        plot(v,N)
        title('Force at Road vs Velocity');
        xlabel('[m/s]');
        ylabel('[N]');
```