Shell Eco-marathon

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Team 14

Concept Generation and Selection

Document

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Contents

Introduction

Need Statement:

Due to the significant number of vehicles running on finite resources as a means of transportation, it has become necessary to research and develop means to stretch those finite resources further. The Shell Corporation has sponsored a competition to promote this research and development in the field of fuel efficiency. The scope of this project is to design, build, test, and present a vehicle that conforms to the set requirements and constraints to produce a vehicle that will produce extremely high fuel efficiency.

Goal:

The team's goal for this semester is to accurately and appropriately design an internal combustion engine powered vehicle for the Shell Eco-Marathon Competition that will have several subsystems working together to reach a fuel efficiency of at least 500 mpg. The team will be focusing on the powertrain, fuel, electrical, braking and the technical documentation for the competition. The team will work in conjunction with another team from Northern Arizona University that will be working on the remaining systems to complete the vehicle design.

Focus:

Our focus is on the design of the engine, drivetrain, fuel system, electrical system, and braking components.

Engine Choices

Overview

The engine selection for the Shell Eco-Marathon car is one of the most important aspects for the vehicle's success. Since the goal is to improve fuel efficiency, finding a motor that will be able to power the vehicle while using the least amount of power is important.

Since the engine will be cycled on and off during the competition, overall motor efficiency was deemed more important than total power output. Most current small engine choices suffer from the same design flaw: they are carbureted. Carburetors deliver fuel less efficiently than fuel injection, hurting fuel economy. Finding a motor that was fuel injected or that could be easily modified to become fuel injected is a priority.

Motor compression ratios are another way to improve engine efficiency. It is possible to improve engine compression by changing parts but using a motor that has a higher compression ratio to start with is a better option. As a small school, our budget is limited, so finding the best cost/performance ratio for the motor is important.

3 main engine options were considered: a Honda GY6-QMB 50cc, a Honda GX25 25cc, and a Honda GX35 35cc. Figure 1 shows the GY6-QMB, figure 2 shows the GX25, and figure 3 shows the GX35. The engines were compared in terms of their power output, compression ratio, aftermarket support, starter type, clutch type, initial fuel consumption, and cost. Table 1 shows the decision matrix used to compare the engines. Engines were scored with possible values of 1, 5, and 10 with 10 being the best possible score and 5 being the worst. The score is then weighted by the importance, giving the final total score.

Figure 1: Honda GY6-QMB

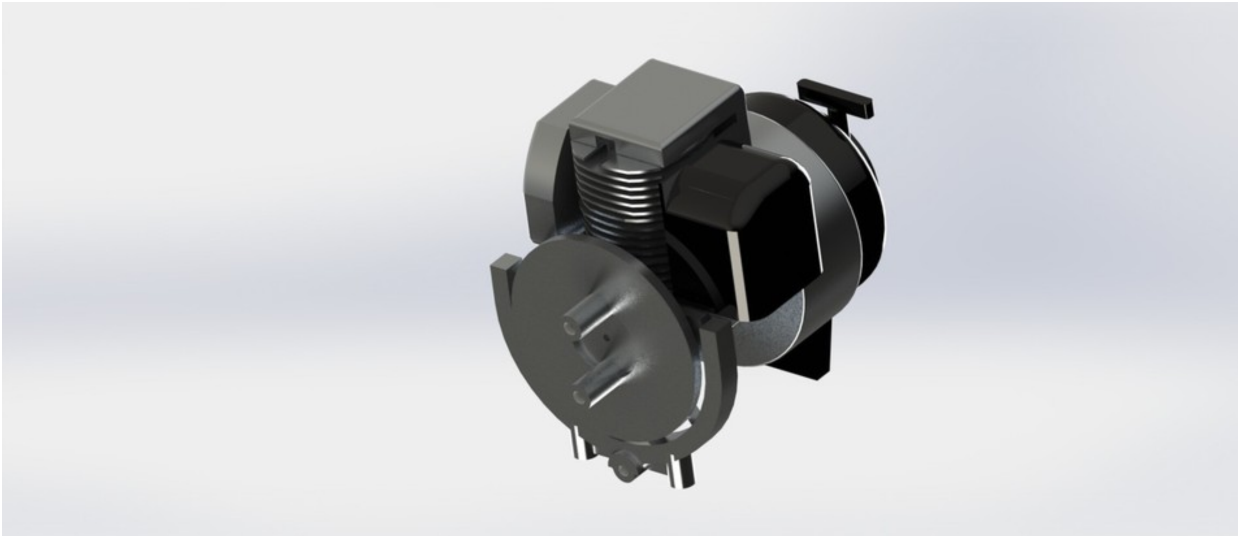

Figure 2: Honda GX25

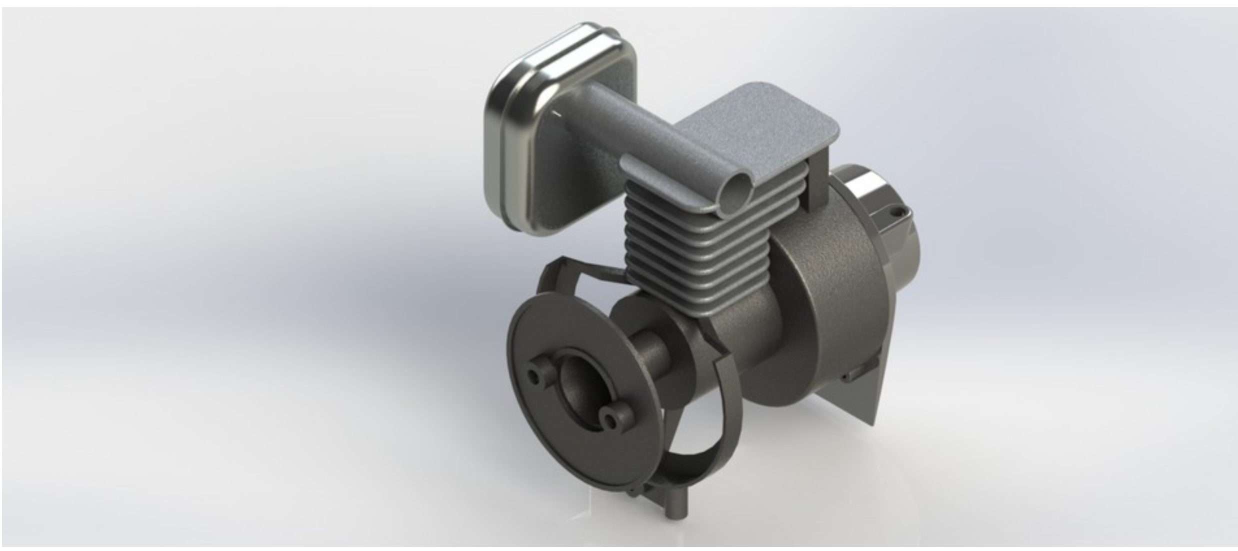

Figure 3: Honda GX35 Engine

Design Considerations

Table 1: Engine Selection Decision Matrix

	Weighted Percentage	**Honda GY6-QMB**	**Honda GX25 25cc**	**Honda GX35 35cc**
Power Output	5%	1	10	5
Compression Ratio	25%	10	1	1
Aftermarket Support	20%	10	1	1
Starter Type	10%	10	1	1
Clutch Type	10%	10	1	1
Initial Fuel Consumption	10%	1	10	5
Cost	20%	1	5	10
Total	100% (10 points)	6.85	3.15	3.4

Power Output

In the category of power output, least is the best. The car will be light, so it will not take a lot of power to achieve the desired speed. The GY6-QMB produces 2.1 kW at 6500 rpm and 3.1 N-m at 5500 rpm, the GX25 produces 0.72 kW at 7000 rpm and 1 N-m at 5000 rpm, and the GX35 produces 1 kW at 7000 rpm and 1.6 N-m at 5000 rpm [1]. The GX25 would produce enough power to move the car, while not producing any more than we need. Consequently, the GX25 scored the highest in this category followed by the GX35 and last was the GY6-QMB.

Compression Ratio

Compression ratio of an engine is an important measure of thermodynamic efficiency: the higher the ratio, the more efficient the motor. Since the motor will be cycled, overall efficiency is just as important as initial fuel consumption. The GY6-QMB starts with a compression ratio of 10.5:1 while the GX25 and GX35 both have compression ratios of 8.0:1 [1]. The GY6-QMB scored the highest possible points in this category while the GX25 and GX35 scored the lowest.

Aftermarket Support

The GY6-QMB is mostly used on scooters and motorized bicycles while the GX series motors are primarily used for applications like lawn and garden equipment. Most people do not modify their gardening tools while many people modify their scooters. The GY6 has considerably more aftermarket parts support than either the GX25 or the GX35. This is important because it makes replacement parts much cheaper. It also means that there is more ability to modify the motor to improve efficiency with off-the-shelf components instead of custom making many parts.

Ignition Type

Using an electric starter would make it possible for the driver to cycle the motor on and off while driving. Since the plan to improve vehicle efficiency is to cycle the motor, having an electric starter is much better than having a magneto starter. The GY6-QMB is the only motor of the 3 considered to have an electric starter, giving it the maximum number of points for the category.

Clutch Type

The GY6 is the only motor of the 3 that includes a clutch setup with the engine assembly. Consequently, it receives the maximum number of points and the GX25 and GX35 receive the minimum number.

Fuel Consumption

This category is for the initial fuel consumption of the motor, not the projected final goal. The measurements are taken at their max power output rpm. As expected, the smallest engine uses the least fuel. The GX25 uses 0.54 L/hr at 7000rpm, the GX35 uses 0.71 L/hr at 7000rpm and the GY6-QMB uses the most fuel at 1.04 L/hr at 6500 rpm [1]. While the engines would be modified to improve the fuel economy, it is a good idea to start with a motor that uses as little fuel as possible. The GX25 receives the maximum number of points and the GY6-QMB receives the fewest.

<u>Cost</u>

The cost category was measured by taking the cost of 2 of each engine. Ordering 2 engines is important so that there is a spare in case one of the engines experiences problems. Cost estimates for the GX25 and GX35 engines were provided by AZ Power and Lawn while the estimate for the GY6 was from e-bay. The GX25 was $537.29 [4], the GX35 was $510.39 [5], and the GY6 was $619.90 [6]. The GX35 received 10 points for being the cheapest, while the GY6 received 1 point for being the most expensive.

Conclusion

As shown in the decision matrix, the GY6 engine is the best fit for our application. While initially it has the lowest fuel consumption, its high compression ratio, strong aftermarket support, electric start, and integrated clutch make it easy to improve efficiency and ease to integrate into the car. The main benefit for the aftermarket support for the GY6 is the ability to switch it to a fuel injected setup. The GY6 offers the best potential for fuel efficiency while offering the easiest ability to integrate it successfully into the vehicle design.

Drivetrain System

Overview

For our vehicle, we came up with three possible drivetrain systems. However, the way of delivering the torque from the engine to the wheels can lead us to our goal which is getting to a high fuel efficiency point for our vehicle. The three types are: shaft & gearbox drivetrain system, CVT belt system, and a chain & sprocket drivetrain system. In order to choose the best possible drivetrain for our vehicle, a decision matrix will show us the advantages and disadvantages for every system.

Shaft & Gearbox Drivetrain System:

This type of drivetrain can be seen in most types of cars. And, it is the best method of delivering highest torque from the engine to the wheel. The engine's torque needs to be delivered to the rear wheel, and the engine will also be in the back of the vehicle. However, we need the best drivetrain that can obtain our requirements, and helps us to get to the highest possible fuel efficiency for our vehicle. Keeping in mind that this drivetrain will increase the weight of our vehicle, and this is a disadvantage point for this drivetrain.

CVT Belt system:

The CVT belt will deliver the needed torque from the engine to the wheels with an advantage of controlling the gear ratio, which will help us with the fuel efficiency. However, the CVT belt will add weight to the vehicle but less than the shaft and gearbox drivetrain. Installing this drivetrain to our vehicle will consume more time.

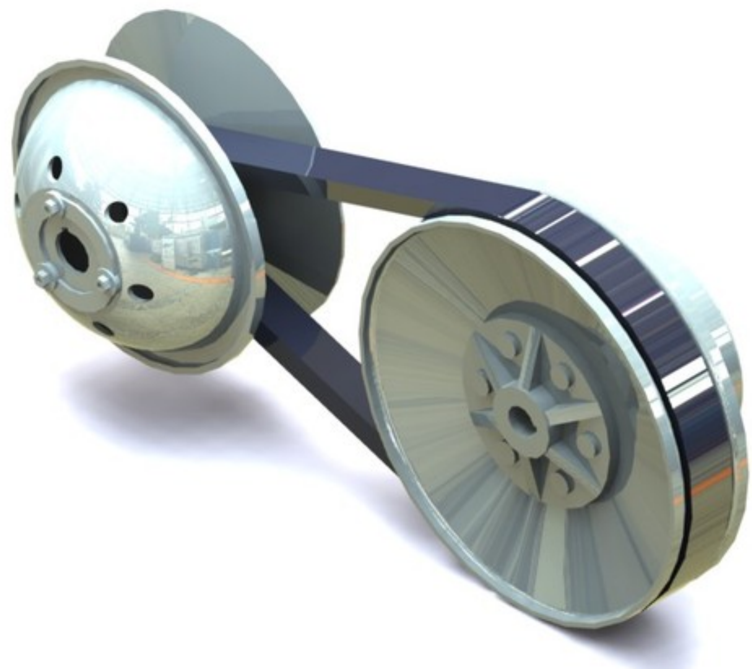

Figure 4 - Example of a CVT Belt System

Roller Chain & Sprocket Drivetrain System:

This drivetrain is the best drivetrain in terms of saving weight and simplicity. As for bicycles, the same chains will be used for this drivetrain. In order to control torque coming from the engine to the rear wheel a small transmission will be used to increase or decrease the speed on the rear wheel. keeping in mind that the maximum average speed needed to be achieved is 17mph.

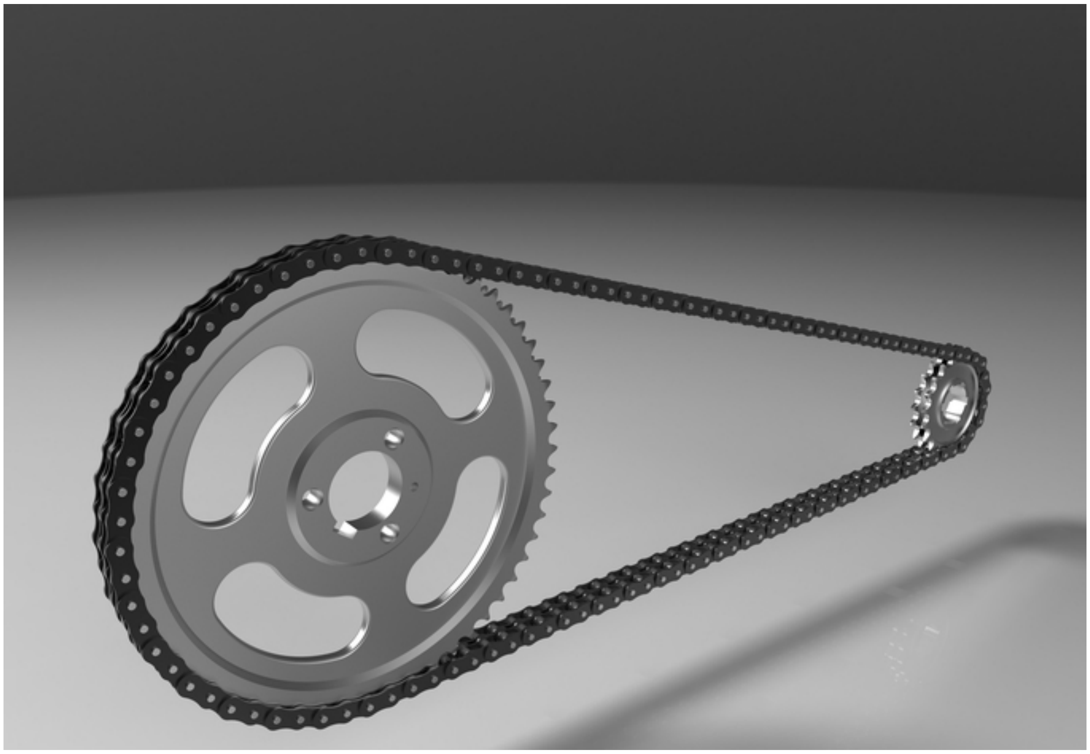

Figure 5 - Example of a Roller Chain Drivetrain System

Design Considerations

Table 2 – Drivetrain Decision Matrix

	Low Weight	High Reliability	High Simplicity	Low Cost	Total
Relative Weight	30%	30%	10%	30%	100%
Shaft & Gearbox Drivetrain System	1	5	2	3	2.9/5
CVT Belt system	4	3	3	3	3.3/5

Roller Chain & Sprocket System	5	3	5	5	4.4/5

"Low weight" is about how light the drivetrain is , for example the lightest drivetrain in the decision matrix is the roller chain & sprocket system. It is important that the weight gets a high percentage, because one of our goals is to achieve a minimum vehicle weight in order to maintain high efficiency. And, the "Low weight" category is measured in pounds. "High reliability" is about how long this drivetrain will stands without any issue. This category should have a high weight percentage, because of its importance in the vehicle. Shaft & gearbox drivetrain gets the highest reliability compare to the other drivetrains. "High simplicity" deals with how long is it going to take the team to implement and install the drivetrain into the vehicle. This category had the lowest weight percentage because our team have the time to install any type of the three possible drivetrains. "Low cost" deals with how much does it cost to get the needed drivetrain. Because of the low available budget, this category will get a high weight percentage same as the first two categories.

Conclusion

As for the drivetrain decision matrix, an estimated numbers were chosen for every aspect. However, the rank for this decision matrix starts from 1 to 5 as a maximum number. According to our decision matrix, the best choice for the drivetrain will be the roller chain & sprocket system (4.4 out of 5), because it satisfy our main goal which is to reach the lowest weight for a drivetrain possible. Also, the roller chain & sprocket system is reliable, simple to build and has a low cost. Therefore, the drivetrain for our vehicle will be the roller chain & sprocket system.

Fuel System

Overview

The team came up with three different concepts for the fuel system. Each one of these concepts is based upon the same idea that the team is limited to gasoline as a fuel source. The team is also limited to many other constraints related to the fuel system. The team must use a Shell Eco-Marathon approved fuel tank of 30mL, 100mL, or 250mL. The team is also limited to certain clear no expansive fuel lines. With all of these constraints in place, there is only a few different concepts related to the fuel system the team considered. These concepts are the use of carburetor, use of fuel injection, and the use of a forced induction fuel injected system.

The first concept is the method of using a carburetor to deliver the fuel in the engine. This is how most small engines are designed. It is a simple delivery system that does not require the need for computer processor or modules. It utilizes the mechanical appendances to deliver fuel. A big problem with carburetors is that they cannot precisely tune a vehicle to the absolute best fuel efficiency. Another disadvantage with carburetors is that they commonly are in need of adjustment. This means decreased reliability and increased maintenance. Figure 7 shows how a carburetor works.

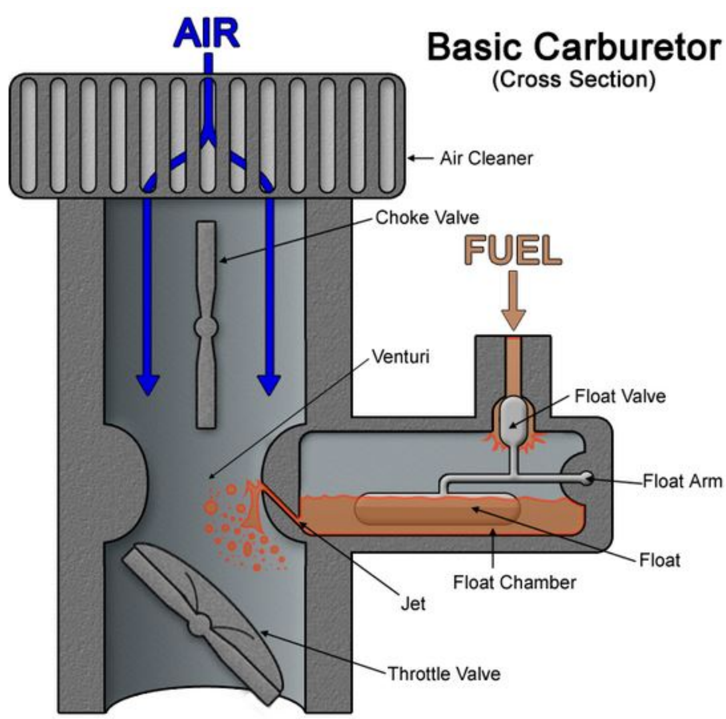

Figure 7: Carburetor Diagram

The second concept is the method of fuel injection. Fuel injection sprays fuel directly into the throttle body or into the cylinder depending on the system. This increases fuel efficiency because the spray is localized where combustion occurs. The system is very reliable once the team integrates it into the engine. Fuel injection also allows for very accurate tuning with the assistance of software and electronics. It does take some time to set up the system and get the system producing the best fuel efficiency results. Figure 8 shows how fuel injection works.

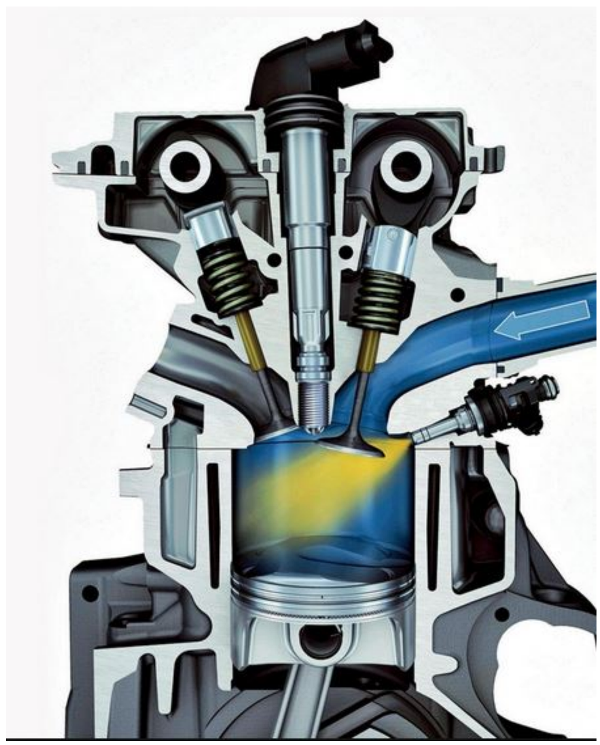

Figure 8: Fuel Injection Diagram

The third concept is the method of having a fuel injected system with the addition of a forced induction system. This is beneficial because it gives massive power increases and fuel efficiency by increasing the compression ratio. The common forced induction methods are turbochargers and superchargers. These forced induction methods require atop of fine tuning to obtain the best results, a compression too high can lead to engine damage. Forced induction methods also require additional integration with the engine atop the fuel injection. Figure 9 shows how forced induction works.

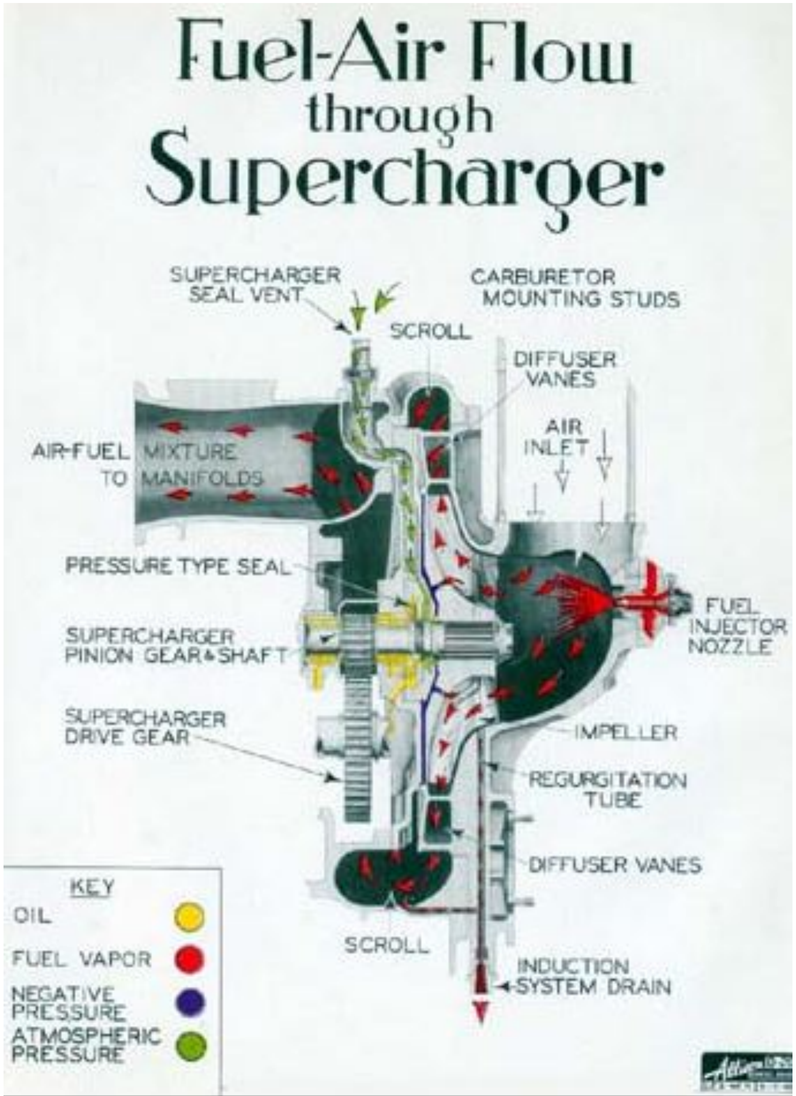

Figure 9: Supercharger Diagram

Design Considerations

The team needed to decide which fuel system was best for the Eco-Marathon competition application. The team determined criteria that would be divided into six sections for the fuel system: fuel efficiency, ease of implementation, precise tuning, reliability, maintenance, and cost. The team defined each of these criterion and gave them a respective weighted percentage based upon importance.

The team defines fuel efficiency as a percentage of fuel that is converted into propulsion energy. This is measured in a percentage. This is the most important to the team because the more fuel efficient the fuel system is the less amount of fuel used to propel the vehicle and overall a lower vehicle fuel efficiency. The team gave fuel efficiency a weighted percentage of 40%.

The team defines ease of implementation as the amount of time it would take to install the fuel system. This is important to the team because the simpler the system is to integrate the more time the team has to test and tune. A simpler system is also easier to find potential problems and fix them. The team assigned ease of implementation with a weighted percentage of 10%

The team defines precise tuning as how accurate the fuel system can be tuned to. This is very important to the team because the more precise the fuel system tuning is, the better the fuel efficiency that can be obtained. The team assigned precise tuning with a weighted percentage of 20%.

The team defines reliability as the time it takes before the system has a problem and needs maintenance. This is important because the team wants a fuel system that will hold true to the tuned characterizes. The team does not want to have to worry about if the fuel system is going to fail during test runs or competition runs. For this reason the team gave reliability a weighted percentage of 15%.

The team defines maintenance as the amount of time spent maintain fluids and retuning to keep best fuel efficiency. This quantity will be measured in minutes. This is important to the team because the team does not want to spend a lot of time in between runs checking and retuning the vehicle at the competition. The team assigned maintenance with a weighted percentage of 10%.

The team defines fuel system cost to be the amount to purchase the fuel system, measured in dollars. This is not as important to the team because the whole objective of this competition is to be as fuel efficient as possible. This means that a good amount of the budget will go into a fuel system. The team assigned fuel system cost to have a weighted percentage of 5%.

The team picked three different fuel system concepts. These fuel system concepts were compared to each other based on the criteria set by the team. The fuel system concepts are displayed in **Table 3.** Each battery was given a score of score of 10, 50, or 100 based on the performance for each different criteria, 10 being the worst and 100 being the best. The scores were then multiplied by the respective criteria weighted importance percentage to give the final score.

Table 3: Fuel System Concept Decision Matrix						
	Carburetor	**Carburetor with Weighted Percentages**	Fuel Injection	**Fuel Injection with Weighted Percentages**	Forced Induction	**Forced Induction with Weighted Percentages**
Fuel Efficiency (%)	10	**4**	50	**20**	100	**40**
Ease of Implementation (mins)	100	**10**	50	**5**	10	**1**
Precise Tuning	10	**2**	100	**20**	50	**10**
Reliability (days)	10	**1.5**	100	**15**	50	**7.5**
Maintenance (mins)	50	**5**	100	**10**	10	**1**
Cost ($)	100	**5**	50	**2.5**	10	**.5**
Total		**27.5**		**72.5**		**60**

Conclusion

After completing the decision matrix, it was clear to the team that the best fuel system for the vehicle was the fuel injection system. The reason behind this is that the fuel injection system is the most fuel efficient, has the best tuning precision, best reliability, and requires the least amount of maintenance.

Electrical System

Overview

The electrical system for the vehicle will be a very simple electrical circuit. The electrical system will be split up into two sub systems. The first sub system will focus on starting the vehicle up and running the vehicle as long as the key ignition switch is in the start or run position. This system will include all of the required kill switches, safety fuses, relays, wiring to the electric starter, and various other components related to the specific chosen engine and fuel injection system. The second sub system will focus on all of the other accessory components such as the horn, speedometer, GPS system, and possible interior lighting for door handle location. The main power source for the electrical system will be generated from a 12V battery.

The reason for the 12V battery is because all of the parts incorporated in the vehicle will be rated for 12V. This battery must have enough power and storage capacity to run the vehicle electrical systems for repeated long periods of time. The team needed to decide which battery was best for the Eco-Marathon competition application. The team determined criteria that would be divided into four sections for the battery: weight, scale, capacity, and cost. The team defined each of these criterion and gave them a respective weighted percentage based upon importance.

Design Considerations

The team defines battery weight to be the overall weight of the battery in kilograms (kg). The reason this is important to the team is because the lighter the battery is, the lighter the overall weight of the vehicle is. For this reason the team assigned battery weight with a weighted percentage of 20%.

The team defines battery scale of the battery to be how much space the battery takes up, measured in cubic centimeters (cm^3). This is important because the team is limited to a certain amount of space on- board the vehicle. The smaller amount of space that is taken up by components will yield a slimmer and lighter vehicle which produces a more fuel efficient vehicle. The team assigned a weighted percentage of 15% to battery scale.

The team defines battery capacity as the amount of power that the battery can provide at the rated voltage. The battery capacity was measured in ampere-hours (Ahr). This is crucial to the electrical system because the vehicle battery must be able to last through several completions of start-up and run the vehicle electrical system for the entire run. The team assigned the battery capacity with a weighted percentage of 40%.

The team defines battery cost to be the amount to purchase the battery, measured in dollars. This is important to the team because the team has limited funds. A battery costing $1000 is just not reasonable. The team assigned battery cost to be a weighted percentage of 25%.

The team picked three different possible battery choices. These battery choices were compared to each other based on the criteria set by the team. The battery choices are displayed in **Table 4.** Each battery was given a score of 10, 50, or 100 based on the performance for each different criteria, 10 being the worst and 100 being the best. The scores were then multiplied by the respective criteria weighted importance percentage to give the final score.

Table 4: Battery Selection Decision Matrix

	Duralast CB series motorcycle	**Choice 1 with Weighted Percentages**	Duralast Lawn & Garden	**Choice 2 with Weighted Percentages**	Optima Yellow Top	**Choice 3 with Weighted Percentages**
Weight (kg)	100	**20**	50	**10**	10	**2**
Scale (cm^3)	100	**15**	50	**7.5**	10	**1.5**
Capacity (A-hr)	50	**20**	10	**4**	100	**40**
Cost ($)	50	**12.5**	100	**25**	10	**2.5**
Total		**67.5**		**46.5**		**46**

Conclusion

After completing the decision matrix, it was clear to the team that the best battery for the vehicle was **the Duralast CB series**. The reason behind this is that **the Duralast CB series** is the lightest, the smallest and still has good capacity and isn't too expensive.

Braking

Overview

The vehicle needs to be able to maneuver through the course and needs to be able to stop abruptly. Three different braking systems were considered for this project: disk brakes, caliper brakes, and drum brakes.

The disk brakes for a bicycle are similar to those used in most automotive applications. The main difference is that bicycle disc brakes are much smaller since they do not need to stop the same amount of mass that disc brakes on cars do. Disc brakes work by pressing a caliper onto a rotor that is attached to the wheel. The rotor has the same angular velocity, such that the kinetic energy of the wheel is changed to thermal energy. A large advantage of using a disc brake system is its location: the brakes are less prone to failure by having debris from the road surface interfere with the caliper compression. An example of this is system is shown in Figure 10.

Figure 10 – Bicycle Disc Brakes

The second evaluated system is the caliper braking system. This is generally the simplest kind of braking system to implement, it is also one of the cheapest. There are several varieties of this system, but the general concept is that there are brake pads attached to arms mounted near the rim of the tire. When the brake lever is squeezed the pads apply force to the rim of the wheel turning some of the kinetic energy of the system into thermal energy. This type of system is very easy to implement because many variations only need one mounting point near the tire and the cable to actuate the mechanism. An example of this type of system is shown in figure 11.

Figure 11 – Caliper Braking System

The third type of braking system evaluated for this project is the drum brake. These kind of brakes are often used on cruiser type bicycles where the rider pedals a short amount in the reverse direction engaging the brake. This kind of brake is not effective for extended duration braking because it does not have a very effective solution for getting rid of the heat created by braking. Drum brakes are generally the same type of system as in cars, however greatly scaled down due to the reduced force required. This type of brake is generally more difficult to service, however due to it being an an enclosed system it is more robust requiring service at longer intervals. An example of this type of brake is shown in figure 12.

Figure 12 – Drum Brake system

Design Considerations

The decision matrix below (Table 5) is rated on a modified scale of 1-10. The scale has 3 positions: 1, 5, and 10. The best being 10 and the worst being 1. The raw scores were multiplied by a weighting factor to get the final score for each potential braking concept.

The categories assessed in the decision matrix are the weight, reliability, cost, and simplicity of the system. The weight of the system is deemed important because it is necessary to have a system that keeps the weight down. A lightweight system will help in the pursuit of higher gas mileage as the less weight that is accelerated during the run of the course the less energy is required. A lighter weight also allows for more weight to be used other places while maintaining the same overall weight. The drum brake system is relatively a very heavy system because of the general size it takes to get the same amount of braking force out of the system. both the caliper and disk systems are very light because there is a relatively small amount of material in both systems.

The reliability of the system deals with how long it is expected to run without issue. This goes both into how well it dissipates heat as well as how well it can be expected to not get gunked up in the course of normal operation. The disk brake system is generally more reliable than the others owing to the fact that it avoids the downfalls of the other two systems. Namely that it is farther removed from the driving surface so it doesn't get nearly as much debris in the system during normal operation, which is the major issue with caliper style brakes, and it also has an open design that is quite good at dissipating heat which is the downfall of drum style brakes.

The simplicity of the system is related to the amount of time, both design and implementation, that it takes to get the system working. The disk and caliper systems are about the same simplicity because all they need is a mounting point and the actuation system, whether that be cable or hydraulics. The disk braking system is more difficult to implement due to the fact that it generally goes inside the hub of the wheel and requires a stationary mounting point on the frame.

The cost of the systems if the most straight-forward part of the system to evaluate. The cost is very important to keep down due to the fact that there are limited funds available to the team for the project. If money was not an issue the team would go with the most effective brakes available, but as it is the team must choose the most effective brakes available for the money that is allotted for braking.

Table 5 – Braking System Decision Matrix

	Relative Weight	Disk	Caliper	Drum
Weight	30%	10	10	1
Reliability	30%	10	1	1
Simplicity	10%	10	10	5

Cost	30%	5	10	5
Total	100%	8.5	7.3	2.6

Conclusion

The decision matrix spells out that the system to go with is the disk brakes. The caliper braking system comes in at a close second place so it is a potential option if disk brakes cannot work out.

Project Planning

Figure 13 shows the Gantt Chart for this project.

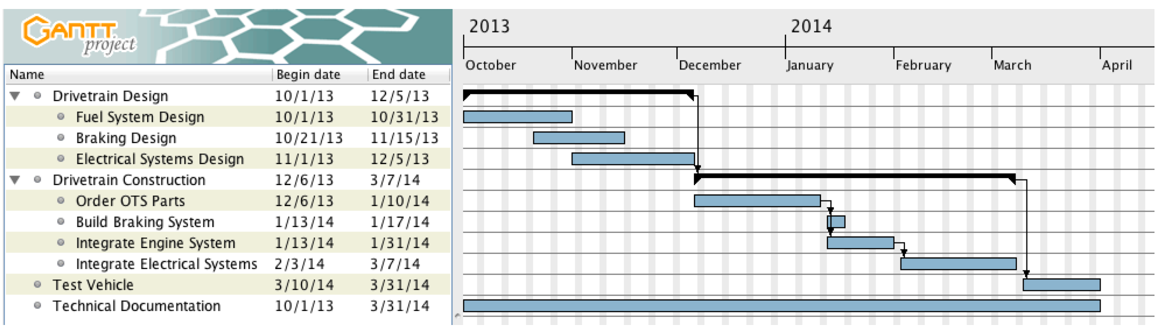

Figure 13 - Project Gantt Chart

Conclusion

Choices for the engine, drivetrain, electrical system, fuel system, and braking system were examined with 3 possibilities, and using decision matrices to decide on a final design solution.

The engine selected was the Honda GY6-QMB for its high compression ratio, strong aftermarket support, and electric start. This engine offers the highest potential for fuel efficiency and a strong balance between cost and performance.

A chain drive system was determined to be the best option for the drive system based on its low weight, cost, and the simple design. Using a chain drive system reduces the overall cost and complexity of the vehicle, increasing the overall reliability of the system.

Fuel injection is the best option for increasing motor efficiency for fuel economy, while still maintaining reliability. Using a carburetor is inefficient, and using forced induction will decrease reliability.

A Duralast motorcycle battery is the best option for powering the vehicle because of its low weight and compact size, while still producing sufficient power and keeping a low cost.

Disc brakes used on a bicycle were selected because of their superior stopping power, low weight, and high reliability.

References

[1] Acosta, B., Betancourt, M., Pinheiro, F., "Shell Eco-Marathon 25% of Final Report," B.S. thesis, Mechanical Engineering Department, Florida International University, Miami, 2012.

[2] Honda Engines, "GX25 Motor Specs," http://engines.honda.com/models/model-detail/gx25, Oct. 2013.

[3] Honda Engines, "GX35 Motor Specs," http://engines.honda.com/models/model-detail/gx35, Oct. 2013.

[4] AZ Power and Lawn. "NAU – SAE ENGINEERING, JOHN Price quote for 25CC ENGINE". 26 Oct 2013.

[5] AZ Power and Lawn. "NAU – SAE ENGINEERING, JOHN Price quote for 35CC ENGINE". 26 Oct 2013.

[6] ebay, "139QMB 50CC 4 STROKE GY6 SCOOTER ENGINE MOTOR AUTO CARB," http://www.ebay.com/itm/139QMB-50CC-4-STROKE-GY6-SCOOTER-ENGINE-MOTOR-AUTO-CARB-/360090949889?pt=Motors_ATV_Parts_Accessories&hash=item53d717d901&vxp=mtr, Oct. 2013.