High Efficiency Moped

A MQP Proposal

Submitted to the Faculty of the

WORCESTER POLYTECHNIC INSTITUTE

in partial fulfillment of the requirements for the

Degree of Bachelor of Science

in Mechanical Engineering

by

_____________________________

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Abstract
The objective of this MQP was to design, build and test a high efficiency moped. This moped would be an alternative solution to current mopeds available. The purpose of this moped project was not only to achieve high fuel efficiency, but also to fully utilize the bicycle components, use an alternative fuel, and keep the design simple enough to be easily made from a standard bicycle as a kit. A propane engine, the use of the existing bicycle drive train, and a dog clutch were the main parameters made at the beginning of the project. All three of those parameters were met along with the fuel efficiency specification at a mile per gallon rating of over 200.
Acknowledgements
I would like to acknowledge the following people and organizations for the help throughout the course of my project:

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- Esprit for providing the CAM software.

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- John Wyatt and John Ellsworth for transportation during testing.

- ME 1800 for the use of “Y” blocks
Executive Summary

A major topic of discussion lately seems to be that of alternative transportation, a concern for the price and availability of petroleum, and the effect that emissions from transportation have on the environment. While these forms of transportation have improved our standard of living, and in some ways cleaned up our environment in other ways, such as horse manure in the streets, there are still areas of improvement for transportation today. There are three potential areas that I believe can be dealt with. The first is size of the vehicle. I fell that most cars, motorcycles, and even mopeds are larger than they need to be to get the job done. The second is the fuel type used. Most alternative energies that are proposed do not take into account the adoptability gap between the current forms of transportation. There are generally alternatives that are cheaper and more serviceable already in existence. The third would be the utilization of technologies that are currently available that can be used to improve the transportation vehicle that are currently in use.

The purpose of this project is to design, build, and test a high efficiency moped that balances efficiency in terms of environmental impact versus cost, and in the greater scheme energy consumption. Current energy sources for mopeds are either not very mindful of the environment, go too far while not looking at the real source of pollution or are not examined in relation to cost. In addition, there seems to be an inflation of energy use due to new “environmentally friendly” technologies in most sectors of energy consumption especially transportation. This moped would help reduce that inflation by not offsetting the energy use but reducing it. It would do it by making moped transportation more attractive and practical. Fuel efficiency would be addressed by designing a better control system for the moped that would
allow for more efficient riding. The constraints placed on the project are to use an existing unmodified bicycle frame, use the existing bicycle drive train, keep a certain overall kit weight, and achieve an efficiency and performance that is better than a similar moped kit on the market currently. This project would develop a kit that can be used to build the actual moped from the average bicycle. The main components that were chosen based on these parameters were a 25 cc propane motor, a compact planetary reduction system, a dog clutch system, and a pedal crank freewheel adapter.

With the completion of the design and machining of the moped, the testing phase of the project demonstrated that the moped met most of the specifications that we outlined in the beginning. If a specification was not met a solution was proposed for the future. The following table lists the specifications and provides a green box for “met” and a red box for “not met”. With further testing and refinement of the design and manufacturing process, the propane moped could be a viable form of cheap efficient transportation. The high efficiency moped may be a more attractive alternative to current mopeds on the market for its cleaner emissions, quieter sound, fuel efficiency, and options that other mopeds do not currently combine.

Table 1. Original Specifications and their status

<table>
<thead>
<tr>
<th>Specification</th>
<th>Status</th>
</tr>
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<tbody>
<tr>
<td>No need to modify bicycle frame</td>
<td>Met</td>
</tr>
<tr>
<td>Uses existing bicycle transmission with a crank freewheel conversion kit</td>
<td>Met</td>
</tr>
<tr>
<td>Easy to install with common tools</td>
<td>Met</td>
</tr>
<tr>
<td>For average adult bicycles without frame suspension (Mountain, Road, Utility, etcetera)</td>
<td>Met</td>
</tr>
<tr>
<td>Feature</td>
<td>Description</td>
</tr>
<tr>
<td>---------</td>
<td>-------------</td>
</tr>
<tr>
<td>LEHR 25cc 1 hp Propane 4 cycle OHV</td>
<td></td>
</tr>
<tr>
<td>200 MPG + equivalent (50 mile on one 16.4 oz bottle)</td>
<td></td>
</tr>
<tr>
<td>Manual hand lever activated clutch system</td>
<td></td>
</tr>
<tr>
<td>Pedal or use power assist option</td>
<td></td>
</tr>
<tr>
<td>Pedal start and Coast start</td>
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<td>$1,000 approximate limit</td>
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<tr>
<td>9kg approximate maximum for kit</td>
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<tr>
<td>Achieve 30mph by engine power alone</td>
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<td>Maximum speed of 5 mph for pedal starting</td>
<td></td>
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<tr>
<td>No bicycle components will be critically changed so it can operate just as a normal bicycle</td>
<td></td>
</tr>
<tr>
<td>Lower emissions on average than equivalent gasoline engine</td>
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Introduction

A major topic of discussion lately seems to be that of alternative transportation, a concern for the price and availability of petroleum, and the effect that emissions from transportation have on the environment. While these forms of transportation have improved our standard of living, and in some ways cleaned up our environment in other ways, such as horse manure in the streets, there are still areas of improvement for transportation today. There are three potential areas that I believe can be dealt with. The first is size of the vehicle. I fell that most cars, motorcycles, and even mopeds are larger than they need to be to get the job done. The second is the fuel type used. Most alternative energies that are proposed do not take into account the adoptability gap between the current forms of transportation. There are generally alternatives that are cheaper and more serviceable already in existence. The third would be the utilization of technologies that are currently available that can be used to improve the transportation vehicle that are currently in use. This paper is my proposed solution to some of the problems with transportation that I just raised.

Objective

The purpose of this project is to design, build and test a high efficiency moped that balances efficiency in terms of environmental impact versus cost, and in the greater scheme energy consumption. Current energy sources for mopeds are either not very mindful of the environment, go too far while not looking at the real source of pollution or are not examined in relation to cost. In addition, there seems to be an inflation of energy use due to new “environmentally friendly” technologies in most sectors of energy consumption especially transportation. This moped would help reduce that inflation by not offsetting the energy use but
reducing it. It would do it by making moped transportation more attractive and practical. Fuel efficiency would be addressed by designing a better control system for the moped that would allow for more efficient riding. The constraints placed on the project are to use an existing unmodified bicycle frame, use the existing bicycle drive train, keep a certain overall kit weight, and achieve an efficiency and performance that is better than a similar moped kit on the market currently. This project would develop a kit that can be used to build the actual moped from the average bicycle. The main components that were chosen based on these parameters were a 25 cc propane motor, a compact planetary reduction system, a dog clutch system, and a pedal crank freewheel adapter.

**History**

Before starting the project, research was performed to see what innovations already exist in the field of mopeds. The research was focused on mopeds that utilized alternative fuels, and mopeds that used the existing drive train of the bicycle. The main alternative fuel types found were diesel, propane and electric.

The research started with diesel because it was the first choice for a fuel type but there was not a lot of information to be found. In the 1950s the Lohmann Company produced 18cc diesel engines for mopeds (Practica, 2010). They are no longer produced by any company but, the organization, Practica is using the basic plans of the Lohmann engine to create a small diesel engine to be used in irrigation pumping in third world countries (Practica, 2010). As of right now, the activity of that project seems to have stopped due to problems with engine performance (Practica, 2010).
There was more information to be found about propane engine use in mopeds and more modern use as well. There were a few small friction wheel set ups that people were building on their own that were found on blog sites but there did not appear to be a professionally built moped kit for propane engines. There is a scooter company called GO-PED that builds stand up scooters and one of their models uses a 25cc LEHR propane motor (GO-PED, 2004). Although it is not an actual moped it is very similar in function.

Currently a Polish company is selling a power assisted bicycle that has very similar power train as the moped proposed in this project. The company, Bimoto, has a Honda GX25 25cc engine, uses the existing transmission of the bicycle, and has a free-wheel on the crank to allow for the use of the bicycle transmission (Bimoto, 2009). What this power assisted bicycle does not account for is allowing the engine to run “wide open” to achieve maximum efficiency. The gearing would therefore need to be geared different to permit that.

Figure 1 Bimoto Design 1

Figure 2 Bimoto Design 2

Component Selection

Specifications

- Specifications
- No need to modify bicycle frame
- Uses existing bicycle transmission with a crank freewheel conversion kit
- Easy to install with common tools
- For average adult bicycles without frame suspension (Mountain, Road, Utility, et cetera)
- LEHR 25cc 1 hp Propane 4 cycle OHV
- 200 MPG + equivalent (50 mile on one 16.4 oz bottle)
- Manual hand lever activated clutch system
- Pedal or use power assist option
- Pedal start and Coast start
- $1,000 approximate limit
- 9kg approximate maximum for kit
- Achieve 30mph by engine power alone
- Maximum speed of 5 mph for pedal starting
- No bicycle components will be critically changed so it can operate just as a normal bicycle
- Lower emissions on average than equivalent gasoline engine

Specifications Defined

The first parameter is to utilize an unmodified bicycle frame. Modified is used in the sense that there will be no cutting, welding, bending, drilling et cetera strictly the frame. There will be modifications to the components of the bicycle but nothing that cannot be easily returned to its original state. The reasoning for this is simply to make it easier on the consumer who might not have the needed tools to modify a bicycle frame. The goal of the project is simple efficient transportation for the average person which means everyone including people without the proper tools and people who are not experience in metal working. In addition, leaving the frame unmodified allows the bicycle to be returned to its original condition if desired.

The second parameter is the use of the existing bicycle transmission. This includes any existing transmission system whether it is an internal hub or a derailleur system. The use of the
existing transmission allows for shifting with riding which is currently not available with most moped kits. It also allows for fewer modifications to the bicycle and allows the bicycle to be pedaled normally. One aspect that should be considered is the legality of using a manual transmission on a moped, of which, using the existing transmission would be. The Connecticut DMV, for example, clearly states that a moped must have an automatic transmission regardless of its maximum speed or maximum engine capacity (DMV.org, 2012).

Another parameter is environmental friendliness or alternative fuel use. This parameter involves choices relating to the environment that are not quantitative such as an amount of an emission. It would take into account other political, economic, or environmental decisions that would not come about in calculations or analysis. For example if a diesel engine was chosen which actually was not as efficient as the gasoline equivalent the potential use of biodiesel would need to be taken into account. In the example of a propane engine, the fact that the majority of propane is produced domestically without much foreign importation would also need to be taken into account.

The cost of the kit is another parameter to consider. The moped kit would need to be kept somewhat inexpensive so that the people who it is designed for can afford it. It should be a cheaper alternative to other less efficient form of transportation. There are too aspects of the cost that should be considered when comparing different forms of transportation: the initial cost and the operation cost including maintenance, fuel et cetera. The initial costs will be discussed first and the operational cost will be discussed later and presented in a table format.
The initial cost of the moped kit cannot be compared to one cost of a moped kit but to similar ones that have some of the characteristics of it. The first would be the Bimoto kit. According to the Bimoto website, the entire gasoline 25cc kit would cost about $900 not including the cost of the bicycle or the shipping (Bimoto, 2009). Another similar kit to the proposed moped is the Sick Bike Parts conversion kit (Sick Bike Parts, 2012). The kit appears to be used for the 50cc engine and it does allow for the use of the existing transmission (Sick Bike Parts, 2012). The cost of the transmission conversion kit alone is about $190 (Sick Bike Parts, 2012). The GOPED scooter (although not a moped it can use the LEHR propane engine) ranges in cost from approximately $600 to $900 (Goped, 2004). Even though the GOPED is a scooter the majority of the parts are the same and the cost of the scooter itself is comparable to a bicycle cost. Out of all of these kits, the Bimoto and the GOPED scooter appear to have the most in common with the proposed moped kit. This would mean an overall cost limit of $900 to $1000 dollars.

<table>
<thead>
<tr>
<th>Description</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sick Bike Parts</td>
<td>$190</td>
</tr>
<tr>
<td>GOPED</td>
<td>$600-$900</td>
</tr>
<tr>
<td>Bimoto</td>
<td>$900</td>
</tr>
</tbody>
</table>

The next quantitative parameter is the overall weight of the kit. The weight of the Bimoto kit without the engine is 6kg and the Honda GX25 is 2.7kg. This means an overall 8.7kg not
including the bicycle. The entire GOPED scooter is 9kg. This would mean that the weight of the proposed moped kit would need to be about 9kg or less.

Table 3. Moped Kit Weight

<table>
<thead>
<tr>
<th>Description</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>GOPED</td>
<td>9kg</td>
</tr>
<tr>
<td>Bimoto</td>
<td>8.7kg</td>
</tr>
</tbody>
</table>

Fuel consumption is one of the most important factors in this project and also one of the hardest to compare when dealing with alternative fuels. According to the Bimoto website, their kit can achieve about 235 mpg (Bimoto, 2009). Some of the 2 stroke moped kit companies claim to get about 150 mpg. The Golden Eagle company, which makes power assist friction kits claims they can get around 225 mpg (Golden Eagle Bike Engines, 2012).

One aspect of fuel consumption that needs to be analyzed is the cost different between fuel types. The real measure of efficiency in regards to the consumer is not the actual fuel consumption but the cost of that fuel consumption. One way to make this comparison is the use of the “miles per dollar” (MPD) unit. The formula for this unit multiplies the miles-per-unit-of-fuel rating of the vehicle by the inverse of the cost per unit of fuel. The shows how many miles can be driven on one dollar. The higher the MPD the more miles you can drive on a dollar. Table compares the MPG ratings and MPD ratings of the Bimoto moped and the proposed High Efficiency Moped if were to use the LEHR 25cc propane motor.

Table 4: Miles Per Dollar Comparison
<table>
<thead>
<tr>
<th>Product</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bimoto</td>
<td>59</td>
</tr>
<tr>
<td>HEM (16.4 oz bottle)</td>
<td>16</td>
</tr>
<tr>
<td>HEM (20 lb refill store)</td>
<td>49</td>
</tr>
<tr>
<td>HEM (20 lb refill camp)</td>
<td>60</td>
</tr>
<tr>
<td>HEM (National price)</td>
<td>72</td>
</tr>
<tr>
<td>Toyota Prius</td>
<td>11</td>
</tr>
<tr>
<td>Average automobile</td>
<td>9</td>
</tr>
</tbody>
</table>

The maximum speed of the moped kit will be determined mainly by law. Since the law varies from state to state the maximum speed of 30mph was determined based on the majority of state maximum moped speeds. For example, Massachusetts state law says that a moped must have a maximum speed no higher than 30 mph but it must not be driven faster than 25 mph (Mass DOT, 2012). Connecticut DMV on the other hand sets a maximum speed of 30 mph but does not specify the maximum driving speed (DMV.org, 2012). California is one of the few states that have a maximum speed limit of 20 mph according to the California DMV website (CA.gov, 2011). In terms of the potential sale of the moped kit in the future, the design could be adjusted for use in such states that have a lower maximum speed limit or they could simply not be sold there.
Engine

Gasoline (two-stroke vs. four-stroke)

The most practical engine that would work in the moped that is gasoline is the Honda GX25. It matches the required power to the pedals; it is four-stroke and OHC which helps with lowering the noise level; and it is compact so it will fit well behind the seat as opposed to in the triangle of the bicycle frame. This type of engine is also forgiving in how it positioned with regards to the oil reservoir.

Smell and emissions is a consideration when looking at small gasoline engines. The two-stroke engines that are include in most moped kits currently smoky and load when compared to four-stroke engines. This is undesirable especially when the moped is used in more densely populated. Since this is exactly where most mopeds are used a four-stroke engine is a better option.

The majority of motorized bicycle kits that do include four-stroke engines with kits have engines that are larger than needed. The website Bicycle Engines sells a kit that is a two horse power motor as opposed to the proposed one horse power motor for this project. There is only the company, Bimoto, which includes the GX25 in its kits. The two-stroke moped kits do not go below 50cc as well in fact a lot are higher than 50cc.

Diesel

A diesel engine was an option that was looked into but there does not appear to be a production model engine of such a size as to power a moped. All current small diesel engine manufacturers’ engines are too large to even be adapted to work on a moped. The Practica Organization appears to be the only recent experimenter with small diesel engines (Practica,
The Practica organization, as mentioned above, has experimented with building a small diesel engine but they do not appear to be producing them (Practica, 2010).

**Electric Motor**
While some electric moped kits were looked while researching different types of mopeds, an electric option was eliminated due to weight of batteries and the lack of real benefits. The only area where an electric system might have benefit in the area of energy efficiency is if regenerative braking was to be implemented. It was decided that this was too far out of the scope of the project for the time allotted.

**Propane/Natural Gas**
One potential option for an alternative fuel that is a clean burning alternative to gasoline or diesel is propane or natural gas. The University Of North Dakota did a small project called “HOW A MOPED CAN RUN ON PROPANE GAS” which looked at problems that arise when trying to run a two stroke moped (scooter in their case) on propane and how those problems can be avoided (UND). Although this looks like a potentially viable option in the future in might be two involved for the amount of time to work on it.

The use of a four-stroke propane motor would be easier than using a two-stroke motor. GOPED is a company that utilizes four stroke propane motors in the small stand up scooters and go-carts that it sells (Goped, 2004). The engines that they use are made by LEHR which sells them as “environmentally friendly” (LEHR, 2012). The company claims lower fuel costs, lower maintenance costs, zero evaporative emissions, zero ozone depleting hydrocarbons, they are non-toxic to ground water and soil, they produce 97% fewer particulates, 96% fewer carcinogens, over
85% of propane used in this country is produced domestically, and it exceeds 2011 EPA emission standards (LEHR, 2012).

According to the website, Amazon.com, a weed-whacker equipped with the LEHR 25cc propane motor costs $160 not including shipping (Amazon, 2012). This is cheaper than the Honda GX25 (Brand New Engines, 2012). The engines tend to be more expensive when purchased alone and the Honda GX25 is not available on a cheap appliance such as a weed-whacker. The LEHR propane engine is available on two different weed-whackers and a leaf-blower (LEHR, 2012). All of the appliances are cheaper than the Honda GX25.

Selection
The power required for the moped will be entirely based on the performance of an average healthy human’s performance on a bicycle. The goal of the project is not to build a high power racing motorcycle, it is too closely match the performance of a human body and analyze its efficiency. The first objective is therefore to analyze the power required for different situations and durations in cycling and find an engine and power transmission system that will best match it.

The book “Bicycling Science” by David Gordon Wilson gives detailed analysis of power required by a cyclist in various conditions and situations. The first important graph provided is a maximum sustainable power versus duration time. This graph, figure, has various curves for different levels of cyclists. The first curve that will be the most important to this project is the “NASA curve for a ‘healthy man’”. This graph shows the maximum power for the shortest duration of a “healthy man” to be approximately 750 Watts. This level of power might be necessary in quick acceleration or to maintain higher speeds even if though that speed is unachievable by that particular cyclist. This graph also has an area of the curve where it levels off in the 300 Watt to 400
Watt range. This is the range of power that can be held for the greatest duration. After this range the power level can be held for an almost infinite amount of time. According to Wilson, this is referred to as the Critical Power (Wilson 2004 p. 43). Wilson specifically defines critical power as “the greatest power level that short-term tests suggest could be sustained ‘forever’” (Wilson 2004 p. 43).

The Critical Power level will most likely be the power required for level and calm moped riding conditions. Another graph from Wilson’s book, see figure, compares power versus riding speed for various headwind conditions (Wilson, p. 127, 2004). For 0 m/s headwind a cyclist would need to produce approximately 450 Watts for the maximum moped speed of 13 m/s (Wilson, p. 127, 2004). Assuming that the rider would not be maxing out the moped for long periods of time, the power level would fall down in the 300 Watt to 400 Watt range. As mentioned about, this is in the range of the Critical Power for the average cyclist.

Another graph from Wilson’s book, see figure, shows the different power levels for different styles of bicycles (Wilson, p. 140, 2004). Assuming that the average bicycle would fall in between a Sports bicycle and a Utility Cycle, the power level would once again be approximately 450 Watts for the maximum moped speed (Wilson, p. 140, 2004). Once again assume that the moped will run slightly lower than the maximum possible speed on average and the power level would fall into the 300 Watt to 400 Watt range.

Figure 5 Power Required for Various Bicycle Types

![Figure 5 Power Required for Various Bicycle Types](image)


One important aspect that needs to be considered when looking at the power required for a bicycle is the effect of slope on power. Using both information from Wilson’s book and on online
cycling calculator from the website Analytic Cycling, a graph was creating, see figure 6, to compare power versus slope for various speeds (The minimum speed being zero, and the maximum speed 12 m/s). According to an Utah.gov document on road grades, the maximum road grade (slope) is 8% with some exceptions (State of Utah). If a parameter is set that states that no less than 75% of the maximum speed can still be maintained driving up an 8 % grade, then the power required to maintain that speed on the grade would be about 700 Watts. Although this power level can only be maintained for a short period of time by a healthy man according to Wilson’s first graph, an engine with a maximum power rating of 700 Watts can hold that power level for a much longer time.

Figure 6 Interpretation of Utah.gov and Wilson’s Data
From this data it can be concluded that an engine with a maximum power of about 700 Watts while still being able to produce 300 Watts to 400 Watts at a somewhat efficient speed is desired for this project. Three engines that come as close as possible to these requirements are the Robin Subaru 1.1 hp micro engine, the Honda GX25, and the LEHR 25cc propane motor. Their performance curves are provided in figures 7 and 8. The maximum power is about 750 Watts with the Honda and about 800 Watts with the Robin Subaru. The LEHR motor does not have a performance curve at this moment. Considering the additional benefit of lower emissions and initial cost the LEHR Propane engine has been chosen for this project.
Figure 7 Honda GX25 Power and Torque Curve

http://engines.honda.com/models/model-detail/gx25
**Drive Train**

*Figure 8 Subaru Power and Torque Curve*

http://www.brandnewengines.com/eh025a0299.aspx

**Table 5: Drive train Decision Matrix**

<table>
<thead>
<tr>
<th>Power</th>
<th>Power</th>
<th>Clutch</th>
<th>Efficiency</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transmission 1</td>
<td>Transmission 2</td>
<td>Ratios</td>
<td>Reduction</td>
<td></td>
</tr>
<tr>
<td>------------------------</td>
<td>------------------------</td>
<td>--------</td>
<td>-----------</td>
<td></td>
</tr>
<tr>
<td>Harmonic drive</td>
<td>chain</td>
<td>Varies</td>
<td>70</td>
<td>2000</td>
</tr>
<tr>
<td>All chain</td>
<td>Manual</td>
<td>94-96</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>Single stage gear</td>
<td>chain (Bimoto)</td>
<td>Centrifugal</td>
<td>96</td>
<td>326</td>
</tr>
<tr>
<td>Compound reverted</td>
<td>chain</td>
<td>Varies</td>
<td>94</td>
<td>?</td>
</tr>
<tr>
<td>Single stage gear</td>
<td>belt</td>
<td>Belt</td>
<td>93</td>
<td>326</td>
</tr>
<tr>
<td>Compound reverted</td>
<td>belt</td>
<td>Belt</td>
<td>91</td>
<td>?</td>
</tr>
<tr>
<td>Planetary Gear box</td>
<td>chain</td>
<td>Varies</td>
<td>96</td>
<td>400</td>
</tr>
<tr>
<td>Planetary Gear box</td>
<td>belt</td>
<td>Belt</td>
<td>93</td>
<td>400</td>
</tr>
<tr>
<td>Planetary gear box</td>
<td>chain</td>
<td>integrated band</td>
<td>96</td>
<td>100</td>
</tr>
</tbody>
</table>

**Harmonic Drive**

Harmonic drive speed reducers are compact reduction systems that can achieve 100:1 reduction in one pass. This ratio is ideal for the moped which would have an engine output rpm of around 7000 rpm assuming maximum power output for maximum efficiency, and a bicycle crank average rpm of about 70 rpm. Besides the ideal reduction ratio the harmonic drive is also much lighter and more compact than other common reduction systems.
Although the reduction ratio is very high for one step, most harmonic drives have a max rpm of around 3000rpm. This became evident after talking to NAC Harmonic Drive and looking at the Harmonic Drive (Canada) website (Harmonic Drive, 2012). In addition NAC Harmonic Drive quoted a cost of approximately $2000 for a harmonic drive close to the specifications that are required for the high efficiency moped (NAC Harmonic, 2012). This is compared to a cost of around $200 for most other moped power transmission systems.

One issue with using a harmonic drive reduction system on the moped is that while most harmonic drives are very efficient at normal speeds and ratios for the amount of reduction, at higher speeds the efficiency goes down very quickly. The NAC Harmonic Drive website provided two graphs that showed the efficiency versus the speed and the ratio as can be seen in figure (NAC Harmonic, 2012). The efficiency is already in the 70% range at 3000 rpm which is half the speed that one on the moped would need to be operating at. Even the lowest ratio and speed are lower than most of the other drive trains researched (NAC Harmonic, 2012).
Jack Shaft

The Jack Shaft system is a cheap method of converting existing moped kits to multiple speed mopeds by utilizing the existing drive train. The system uses a shaft that redirects the power to the other side of the bicycle (the normal bicycle drive side) and uses adapter gears and a free-wheel to supply power to the bicycle crank. After power is supplied to the crank the bicycle can be shifted normally while riding. This system uses all chains instead of gear-to-gear reduction systems. The efficiency would be around 94% which is close to other reduction systems but the chains would take up a lot of room on the moped. One advantage to using an all chain reduction system is its low cost. Sick Parts sells the jackshaft kit for approximately $190. The way that this system would most likely be broken down into ratios is 1:4, 1:3, and finally 1:6 to the pedal crank.
Single Stage Spur gear and chain combination

The single stage gear spur gear reduction and chain is the current system used on the Bimoto moped kit discussed earlier. According to Norton in the book “Machine Design,” the efficiency of a two spur gear reduction is approximately 98% and a single stage chain reduction is also 98% (Norton, p. 488, 2008). This would mean that the system would have an overall efficiency of 96%.

This system is much more compact than the all chain option but not as much as the harmonic drive or other reduction systems that will be mentioned. Due to the high ratio of 12:1 that is required for the two spur gears, the second gear needs to be much larger than any other gear in other reduction systems. This takes up extra space on the moped and it can even mean more weight. The final ratio would be 1:6 achieved by a chain.

The cost of this reduction system is somewhat average for the reduction systems researched. The Bimoto website has the individual gearbox for sale for $326 (Bimoto, 2009).

Compound reverted and chain

The compound reverted reduction system would involve two smaller spur gear reductions to break up the 1:12 ratio of the single. It would most likely be a 1:4 and a 1:3 with the final 1:6 taken care of by the chain. The advantage to using a compound reverted as opposed to the single spur gear reduction is that it would require less space or at the very least better used space. The two gear sets would be able to double-back on each other making the entire system shorter but wider.

Although this system might mean a conservation of space, due to the extra spur gear reduction, the power transfer efficiency might go down. This might mean an overall efficiency,
including the chain, of 94%. In addition a compound reverted gearbox cannot be located so a potential cost cannot be determined.

**Planetary Gear Train**

One of the most efficient and compact of all of the research drive trains so far is the planetary system. The planetary gearbox can theoretically be more efficient than a spur gearbox of the same ratio according to Norton (Norton, p. 511, 2008). They are also rather inexpensive when compared to the other reduction systems. When looking on robotics supply websites the price range seemed to average around $100 for gearboxes around the needed size.

One key advantage that planetary gears have over the other types of gears is there variety of speeds using the same gears in different orders. The one key set up of a planetary system that is ideal for a moped is the ability to achieve a neutral gear by allowing the ring gear to spin. This keeps the output planets from spinning at all. A simple band brake clutching system can be built into the gearbox. It can then be controlled by a hand lever and cable. This helps avoid a bulky manual clutch located somewhere else on the moped. Although this set up is most likely more compact than a planetary gearbox and a separate clutching mechanism, the time constraints of this project do not allow for the design and building of such a drive system.

The Banebot website sells P80 planetary gearboxes that are available with a 12:1 reduction ratio (Banebots, 2012). They cost $102 and are set up in a way that allows them to be adapted to different systems. In the description they specify a maximum of 85 ft-lbs of torque that should not be exceeded (Banebots, 2012). This well exceeds the requirements for the output of the motor but it also is a size that is workable on the moped and is very close in size to the bolt plate on the
motor. Further specifications are given in table and the actual gearbox can be seen in figure. Given the cost and size of this gearbox, it has been chosen for this moped project.

<table>
<thead>
<tr>
<th>Physical Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
</tr>
<tr>
<td>Reduction</td>
</tr>
<tr>
<td>Stages</td>
</tr>
<tr>
<td>Gear Material</td>
</tr>
<tr>
<td>Weight</td>
</tr>
<tr>
<td>Length</td>
</tr>
<tr>
<td>Width (Square)</td>
</tr>
<tr>
<td>Shaft Diameter</td>
</tr>
<tr>
<td>Shaft Length</td>
</tr>
<tr>
<td>Shaft Key</td>
</tr>
<tr>
<td>Shaft End Tap</td>
</tr>
<tr>
<td>Mounting Holes (12)</td>
</tr>
</tbody>
</table>
Figure 11 Banebot P80

Engine to Planetary

Due to the direction of rotation of the motor and the width of the moped if the gearbox was attached directly to the output of the motor, a power transmission system that allows for the reversal of the engine was needed. After considering gear, chain and belt systems to achieve this, a #25 chain was decided upon because of its compactness, its efficient power transfer, and its easy machining and use. This system was originally designed around 8mm shaft but due to a lack of tooling it was redesigned for 3/8 in shaft. The system simply transfers the engine output to the gearbox input with two #25 chain sprockets. The number of teeth on the sprockets was determined by data shown in the following figure. As can be seen the number of teeth needed for approximately one horse power at 7000 rpm (the engine maximum output) is 15 (Martin). From
the key at the bottom it can be seen that this requires an oil bath (Martin). For the testing oil will simply be applied regularly.

Figure 12 25 Chain Power Chart

<table>
<thead>
<tr>
<th>Pitch No. 25</th>
</tr>
</thead>
<tbody>
<tr>
<td>REVOLUTIONS PER MINUTE — SMALL SPROCKET</td>
</tr>
<tr>
<td>100</td>
</tr>
<tr>
<td>11</td>
</tr>
<tr>
<td>12</td>
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<td>13</td>
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<td>22</td>
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<tr>
<td>23</td>
</tr>
</tbody>
</table>

Lubrication: Type A Manual Lubrication, Type B Bath or Disc Lubrication, Type C Oil Stream Lubrication


Dog Clutch Mechanism

The clutching mechanism is a critical part of the design of the moped. It allows for better control of the moped and efficient riding. The main requirement of the clutch is that it needs to be operational whether it is being moved by the bicycle pedal crank or by the motor. This allows the
rider to start the engine from the pedals as well as have the engine drive the pedal crank. The following are the different types of clutch systems that were considered.

**Dog Clutch**
A dog clutch is a clutch that uses teeth that engage with one another to transfer rotational motion. In addition, it allows the rotational motion to come from either shaft of the clutch. This type of clutch is simple and cheap.

**Belt**
The belt clutching system is a common manual clutch that is used on many moped kits. These clutches average approximately $30 and are manually operated as opposed to centrifugally operated. This allows for more control while driving. Although belt clutching systems are cheap and relatively easy to design and build, they can be bulky and less efficient when compared to other clutching mechanisms. The book “Design of Machinery” by Norton says that belts can achieve an efficiency of about 95% to 98% and 93% if there is wear or slippage compared to a spur gear efficiency of 98-99% (Norton, p. 488, 491, 2008).

**Friction Disc**
A friction disc clutching system was the next possible choice after a dog clutch. Such a clutch system could probably fit in the same space that the dog clutch occupies and it would function in a very similar fashion. The reason why it was not chosen is because a dog clutch would be easier to manufacture compared to a friction disc clutch. The main area of concern was in finding the right friction material and attaching it to the clutch system. In addition the differences in speeds were low enough from initial estimates therefore a friction disc clutch would too much for the application.
Basket
A basket clutch is a type of friction clutch that uses multiple smaller friction discs that have a smaller diameter than a single equivalent friction disc. Even with a smaller diameter and more compact design, basket clutches on the market were too large and designing one would be more challenging than a dog clutch.

Electronic
Electronically activated clutches are widely available and small enough to be used on a moped but with a lack of a suitable power source on the moped to use for activation it was eliminated.

Band Brake Planetary
One possible way to achieve a clutching system would be to put a band brake on the ring of a planetary gear system. This would allow a neutral gear when the brake is released. The problem with this system is the enormous complexity in designing and manufacturing it.

Pneumatic
A pneumatic clutch system would operate in the same way as the electronic clutch system. This system would have the same problem of a lack of power for activation.

Centrifugal
The centrifugal clutch is what is used for convenience in most moped kits currently. The problem with the centrifugal clutch is that once the engine has stopped there is no way of restarting it through the pedals. The engine would need to be restarted at a stop.

Freewheels
There are currently two freewheels in the drive train of the moped. The first is at the pedal crank between the crank and the front sprockets; the second freewheel is the one on the rear
cassette which came with the bicycle. The purpose of the front freewheel is to allow the running of the engine without the movement of the pedals. If this freewheel was not here the pedals would spin when the engine is running and the engine would spin if the rider was pedaling. The front freewheel was sold as a kit which other current moped kits use to redirect the power through the existing bicycle drive train. The rear freewheel was fixed by placing small ball bearings behind the ratchet arms of the freewheel. This kept the ratchet arm from clearing the teeth of the receiver of the freewheel, therefore allowing the freewheel to be driven in both directions. This would therefore enable the rider to back drive the drive train while riding to start the engine while coasting.

The freewheel kit that was ultimately chosen was one sold by Cycle eBikes of Taiwan (Cyclone, 2004). According to research, this company appears to be the only main source for the particular type of adapter kit for the bicycle chosen (Cyclone, 2004). Other suppliers get their supply from this company. The one that was chosen (48T, 48T, and 34T) allowed for the greatest possible ratio between the 10T planetary output sprocket and the crank.

**Bicycle**

The bicycle that will be used as the base for the moped kit for this project should be simple, generic, and inexpensive. The only requirements for the design of the bicycle is that it has a multiple speed transmission system that occurs after the pedaling crank (most commonly a derailleur system), that it has a three piece pedaling crank, and that it has a standard triangular frame that represents the average bicycle on the market. The bicycle should be generic to represent the average style of bicycle and the most popular bicycle on the market. The simple and generic traits of the bicycle will probably coincide with the most inexpensive bicycle as well. The
goal of the project is after all to create an efficient and inexpensive form of transportation. Most of the bikes that were looked at were road bikes because most other style bicycles (mountain bikes and cruisers) were not consistent in the frame designs, or overbuilt for the purpose. The following are various bicycle models that are available for the lowest price although another option is to base the moped on a used bicycle to save money.

**GMC Denali**

The GMC Denali seems to be a popular low end road bike that sells for around $160 according to Walmart.com (Wal-Mart, 2012). As you can see in Figure 1 the frame is a mostly standard triangular frame and the pedal crank is a three piece.

![Figure 13 GMC](image)

**Roadmaster Granite Peak**

One mountain style bicycle that had a triangular frame was the Roadmaster Granite Peak. This bicycle is also considerably cheaper than most road bicycles that were researched. It costs $88 according to Walmart.com (Wal-Mart, 2012). In addition the crank appears to be a three piece setup. The frame style can be seen in Figure 2.
Of these two bicycles, the GMC was chosen because of its thinner tires. The Roadmaster has bigger mountain bicycle tires that are not ideal for creating an efficient commuting vehicle. They would create undesired friction while never being used for their intended purpose. The 32mm wide GMC tires are not too thin that they cannot handle bumps in the road or the occasional off-road adventure but they are also not too wide as to create excessive friction.
Design

Preliminary Designs

Much of the preliminary designs involved initial stress, static or dynamic analysis. This preliminary analysis can be found in the appendix at the end of the paper.

Design Iteration 1

The initial design is based on the Banebot P80 12:1 planetary gearbox and it utilizes a dog clutch. The goal of this initial design was to get a visualization of the spacing on the shaft of the gearbox and how the dog clutch might be engaged. The following figures demonstrate the overall design concept.

Figure 15 Design Iteration 1
In this design, the lever on a swivel (1) can push or pull the male dog component (3) to engage it with the female dog component (2). The male dog component can slide along the shaft (4) while still being engaged by the key slot in the shaft. The female dog component is allowed to spin freely but would remain in its position on the shaft due to stops which were not included in this design. The lever could potentially be activated by a hand control cable to engage and disengage the dog. There would be a thrust bushing or bearing on the dog in between the dog and the lever to cut down on friction.

Possible improvements to this design include, a trigger activated and spring loaded dog, reversing of the entire mechanism on the shaft to avoid excessive forces on the shaft, the width of the slots in the receiver to facilitate engagement, the elimination of the chamfer in the teeth and
receiver to avoid unwanted disengagement, the addition of fluting to facilitate the sliding of the dog along the shaft, stops for the drive gear and, a box enclosure for safety and to reinforce the plate that holds the lever.

For analysis the teeth can be considered cantilever beams in a static situation, the engagement will need to be analyzed for impact forces, and any forces along the shaft would need to be analyzed as well. Because this is not the final design the actual analysis will wait until the final design.

**Design Iteration 2**

The second major design included a crude trigger mechanism to engage and disengage the dog under a spring load. As can be seen in figures 17 and 18, there were two springs attached to the lever and to a sliding plate on the top plate that pulled the lever forward or backward depending on the position of the sliding plate. This design would require either a mechanical control rod system or a two cable control system due to the need for pushing and pulling.
Figure 17 Design Iteration 2

Figure 18 Design Iteration 2
Possible improvements to this design include moving the trigger mechanism under the top plate, replacing the two spring trigger mechanism with a linear spring on the shaft with a trigger spring in the control, making the dog and receiver smaller to save weight and space, and add a better sliding surface for the dog.

One thing to note is that the springs would need to apply a force in their minimum extension position that is enough to engage and keep the dog engaged. Also the surface between the sliding plate and the top plate would need a bearing of some kind to reduce friction to make it easier to control. In addition the sliding plate is not properly sized in this model and there would be a stopping mechanism for the dog that is not shown. Once again analysis will not be shown until the final design is decided upon.

**Design Iteration 3**

The third design iteration made the dog and receiver smaller to conserve weight, utilized a linear spring to engage the dog, and used a hex shaft to guide the dog. Possible improvements include the addition of bushings, a control system, a way to remove the lever and yoke bushing, and a way to easily change out the sprocket. The overall design can be seen in figures 19, 20, 21, and 22.
Figure 21 Design Iteration 3

Figure 22 Design Iteration 3
Design Iteration 4

The purpose of this design was to include bushings, a way to easily remove the yoke and yoke lever, add removal system for the sprocket, and improve the hex dog slide system. The way that the design made the sprocket interchangeable was by using a similar design to coaster brake sprocket systems. Three round nibs were made on the inside of the sprocket that was guided by a spline on the dog receiver. In order to install a bushing and improve the dog sliding system the dog and receiver were made larger again to accommodate them. A three square-key system was used instead of the hex shaft. In order to make the yoke and lever removable the yoke itself was split into two pieces and the lever pins were replaced with screw holes. The yoke parts were flanged at the ends and screw holes were added. The flanges needed to be on an angle to clear the lever arm. The section views show how all of the different parts are assembled on the shaft.

Figure 23 Design Iteration 4
Figure 24 Design Iteration

Figure 25 Design Iteration 4
### Figure 26 Design Iteration 4

![Design Iteration 4](image)

### Figure 27 Sprocket Design

**Sprocket Design**

<table>
<thead>
<tr>
<th>![Sprocket Design 1]</th>
<th>![Sprocket Design 2]</th>
</tr>
</thead>
<tbody>
<tr>
<td>![Image 1]</td>
<td>![Image 2]</td>
</tr>
<tr>
<td>![Image 3]</td>
<td>![Image 4]</td>
</tr>
<tr>
<td>![Image 5]</td>
<td>![Image 6]</td>
</tr>
</tbody>
</table>
The first critical support part was the engine plate which allowed the engine to be bolted to the gear box. It would have been at a 45 degree angle to allow for the easy insertion of the mounting bolts. Before the oversight of the engine rotation, the engine output was to be bolted directly to the gearbox using an adapter plate as can be seen in the figures below.
After the redesign of the system, only a flat plate on the bottom of the engine was need to bolt to the top of the gearbox. This permitted the use of a chain drive system on the output of the engine to the input of the gearbox as can be seen in the following pictures.

**Final Design**

**Controls**

All of the controls on the moped consist of standard bicycle cables. The shifters and the brakes are stock from the manufacturer. The clutch and throttle system needed to be fabricated. The throttle system consisted of a standard bicycle brake lever, a standard bicycle brake cable, and the standard fitting on the engine. The handle was installed on the drop handle bars in a position that was easily in reach for the rider but was also out of the way of the brake as to not confuse the two levers. The short cable that was supplied with the weedwacker engine was
removed from the retainer on the needle valve body and replaced with the longer cable end. The clutch system was more involved than the throttle system and therefore required more fabrication. The clutch lever was positioned on the top tube of the bicycle which did not allow for the use of a standard brake lever. The reasoning for the placement was due to overcrowding of controls on the handle bars and the lack of a mechanism that could be placed on the handle bars that was not bulky or difficult to fabricate. An initial lever was fabricated for the top tube of the bicycle but was too small and overly complex. Another lever system was made that only comprised of a few parts and operated without any trouble. The latching mechanism which allowed the clutch to stay out without holding the lever consisted of a screw and a spring. When the lever is pushed up the screw is pushed in so that it catches on the mount body for the lever. The spring force at the clutch pulls back on the lever and keeps the screw in place. When the lever is pushed up again, the force is relieved and the screw retracts allowing the lever to move back. This mechanism design was taken from similar clutch levers for other moped kits currently on the market. The following pictures show the initial design in CAD and the actual lever system that was used on the moped.
Another part of the controls that was not mechanical in nature was the kill switch for the engine. The kill switch was mounted on the opposite side of the top tube that the clutch was mounted on. It was mounted to the same support that the clutch was mounted to. The reason that the kill switch and the clutch were mounted next to each other was based on the nature of their use. The engine will most likely need to be turned off and disengaged either when coming to a stop or coasting. The wires that originally connected to the weedwacker kill switch were extended and another switch was chosen that would stay either on or off (the weedwacker switch was normally closed) and was easy to mount. A picture of the kill switch can be seen below.
Support Brackets

Supports were used heavily throughout the moped with varying uses. They consisted of the engine plate, the main engine mount, Y-block mounts, and the upright tubes.

The engine and gearbox mount is the major support on the moped. It connects to the side of the gearbox and the seat stays of the bicycle. The gearbox side is bolted using the existing gearbox mounting holes and quarter inch steels plates with slots to adjust the position of the output sprocket relative to the pedal crank sprocket. The bicycle side bolts through the triangular shape of the frame with another plate on the other side to clamp the frame. A one inch diameter steel tube was welded between the plates on both sides to connect them. The support can be seen in the following pictures.
A support system that was used throughout the moped was the use of ME 1800 Y-blocks. These blocks were modified to hold such components as the chain tensioner, the propane tank, the clutch and kill switch controls, and the chain guide. These blocks were ideal for bolting components to round tubes. They can be seen in most pictures of the moped including the one below.
The last support system was the upright 3/8” diameter steel tubes that were mounted to the rear of the gearbox. The purpose of these supports was to keep the bicycle mount bracket from deflecting given its length and the weight of the engine assembly. The ends of the tubes were simply flattened and drilled to fit between the gearbox and the accessory bolt holes on the bicycle dropouts. The moped was initially test without these supports in place but the movement of the engine assembly proved to be too much for the chain to stay on the sprocket. In addition, rubber was initially used between the bicycle frame and the engine mount bracket but that allowed for extra movement which the upright tubes could not fix alone. The rubber was therefore changed to a stiffer cardboard. The pictures below show the upright tubes.
Figure 39 Brackets

Figure 40 Brackets
**Engine to Gearbox Chain System**

The top sprocket is supported by the flywheel adapter on the engine and a bearing is supported by a plate which bolts to the engine housing. The bottom sprocket has two bearings for support because there is not support from the planetary gearbox. Set screws are used throughout the system to keep the shafts from wandering out of the bearings. All of the parts that need to be rotating are keyed with 3/32 key ways.

*Figure 41 Gearbox 1*
Figure 42 Gearbox 2

Figure 43 Gearbox 3
The following figures show the final design and assembly of the #25 chain system. It is important to note that the first figure shows the chain before a guard was installed. It is also worth mentioning that the sheet metal stop for the bottom 3/8 was installed in the later figures.

Figure 44 24 chain
Figure 45 25 Chain

Figure 46 25 Chain
Dog Clutch

The next set of figures show the final design and construction of the dog clutch assembly. There may be subtle changes due to manufacturing. The redesigned yoke that moves the dog can clearly be seen to compare to the earlier design iterations.

Figure 49 Dog Clutch

Figure 50 Dog Clutch
A major part and time consumer of this project was the manufacturing of the moped itself. The machining of the parts consisted of two main categories: manual machining and CNC (computer numeric control). Most of the machining was done manually to save time due to the need for only one-off parts. This minimized time spent on CAM software. Although the majority of the machining was done manually, a few parts were machined using CNC machines due to their complexity. The time spent manually machining them would have been more that the time spent using CAM software. In the future, if the moped was to be mass produced, CNC would be used in place of manual machining and other forms of mass production would be used as well including sheet metal presses for chain guards and the clutch lever mechanism; plastic injection molding of the polycarbonate chain guides; and possibly a mass production welding system for the supports.
The following two sections will give explanations of a few of the more involved machining procedures that were used in the building of this moped.

**Manual**

The manual machining for this project consisted of five main methods or fixturing setups. They were turning with a three-jaw-chuck; turning with a four-jaw-chuck; end milling; boring (with a mill); the flywheel fixturing method; and the sprocket and dog fixturing method. Two lathes were used for the turning operations. They were the Haas TL-1 manual/CNC lathe in The Washburn Shops and the DoAll 13 in the Higgins machine shop. The Haas TL-1 was used for its easy to use interface and the DoAll 13 was used because it was setup for four jaw machining.

Three-jaw-chuck turning was used heavily throughout the project. All of the round parts in the dog clutch mechanism were turned in this way for at least one operation; the shaft and sprockets on the output of the engine were turned this way for some of their operations; and parts of the clutch lever mechanism were also turned this way. Because turning with a three-jaw-chuck was the easiest and fastest method of machining for this project, some of the parts were redesigned to be manually turned this way instead of using a CNC mill. This cut down on CAM time.

Turning with a four-jaw-chuck was also used instead of a CNC mill or a manual milling machine boring. There reason why this method was chosen was because it was only needed for one operation and creating CAM files would have used more time. The operation that it was used on was the outer round surface of the engine output shaft bearing plate. A circular shape was needed to align the bearing with the output shaft using the existing engine housing. The manual
mill boring head proved to be too time consuming for such a large radius based on similar parts that were made.

End milling was the second easiest method for machining after three-jaw-chuck turning. This method was used for the engine to gearbox bearing plates, and the clutch mechanism plates. The mills that were used were a Millrite and a DoAll. The operations that they were used for was the face milling, slotting and drilling of the bearing plates, the clutch plates, and the engine support plates. The drilling operations on the mill were a much more accurate alternative to using a drill press. The following picture shows the slot in the outer gearbox bearing plate that was created using an end mill on the manual mill.

Figure 52 Machining
The use of the boring head on the manual mill was the next main machining method. This was used on the bearing plates for their large diameter holes. This is the one manual method used that might have been quicker if done on a CNC mill. The reason that it was used was because the manual mill had already been used extensively and adjusting to another machine would have wasted time. The following pictures show some of the boring head machining.

Figure 53 Machining
The final manual machining method was the flywheel fixturing method. The existing engine flywheel needed to be bored out to receive the shaft adapter. Because the flywheel was roughly cast and the only machined surface was a tapered hole, a fixture needed to be made. This fixture consisted of an aluminum shaft with a taper at one end and a bolt hole at that same end. The flywheel was bolted to the tapered end to allow it to be mounted in a three-jaw-chuck in a lathe. The hole was then easily bored out. The following picture shows the aluminum shaft with the taper and the bolt that held the flywheel.
The CNC machine that was used was a Haas Mini Mill located in The Washburn Shops. There were two different operations that the Mini Mill was used for. The first was the dog jaw on both dogs and the teeth on the gearbox output sprocket. The fixture that was used to secure the dogs was a 1.5” machinable collet. The dogs first underwent the lathe operations to cut them to length which allowed them to easily be mounted in the collet. A CAM file was created using Esprit, the NC code was created from that file on the Mini Mill, and the program was run for both dogs without having to reload the NC code. The output sprocket required more fixturing than the dogs. Because the sprocket was so thin, a collet was out of the question for a fixture. An aluminum plate was machined on a manual mill that held the sprocket with a tight bolt circle that allowed the profile to be machined. Bolts were also added on the outside which allowed for the machining of the inside spline on a manual mill. The aluminum plate could be easily clamped in a standard 6” milling vise. The following picture shows the fixture with a plastic model of the finished sprocket being held by the outer bolts. The inner bolt circle can also be seen. The acrylic sprocket was created to see how the fixture would hold the sprocket after the different machining operations. This fixture allowed the modification of the inside of the sprocket later on.
Design for Manufacturability

In addition to explaining the machining process of the design, the impact of the manufacturing process on the design needs to be taken into account. Several areas of the design were altered to make the machining process easier and faster. This included making the dog fork part out of a ring on a lathe instead of milling it, threading the fork lever instead of using a pin, and making the yoke out of a ring on a lathe instead of milling it. Turning those two pieces instead of milling them was easier because it did not involve CAM software, simpler tooling, and simpler fixturing. Other less important part designs were influenced in this way especially the mount brackets for the controls and guides. They were made from recycled ME 1800 parts as was mentioned in the support bracket section.
Results and Testing

Robustness Testing

Although this moped was only a prototype, the robustness of the design was documented for potential improvement in the future and to analyze the cause of the various failures.

Motor mount movement

After some initial testing of the mopeds drive train without the extra rear engine stabilizing tubes the engine mount proved to be too flexible and allowed the derailment of the engine drive train. The solution to this problem involved replacing the rubber used between the bicycle frame and the main motor mount with cardboard. The original purpose of this rubber was simply to protect the frame. This cardboard protects the frame while being less compressible than the rubber. It is important to note that although the stabilizing tubes were part of the design, it was expecting to at least operate without them. They were meant to be insurance of a sort. The fact that the main motor mount did not work was concerning.

Planetary output sprocket failure

After the moped was assembled and running, a failure occurred with the sprocket assembly, making it fall off of the dog. The retaining ring that held back the sprocket and the spline dowel pins popped out of the groove seat allowing the sprocket to wander. The reason why the retaining ring failed was due to it not being properly made, improper alignment of the chain tensioner, and an improper groove seat for the retaining ring. This problem was solved by adjusting the chain tensioner and redesigning the fixturing of the sprocket on the dog. A second spline was machined 30 degrees out of phase from the first one between the dog and the sprocket. At the bottom of the new spline on the dog, screw holes were added that allowed the
sprocket to be bolted to the dog. Because the end of the dog and the side of the sprocket are not on the same level, a ring was inserted between them to make them level. A thin sheet metal ring was inserted over the end of the dog to retain the dowel pins and the screws were installed with a thread sealant to prevent them from backing out. A picture of the assembly can be viewed below. Also note that the flange of the bushing needed to be machined away in the pattern of the spline to make room for the screw heads.

![Figure 58 Sprocket Design](image)

**Motor to crank derailment and alignment problem**

Only a few problems occurred in the area of the drive train that was not directly related to the front or rear freewheels. The first was the derailment of the chain on the front freewheel sprocket to the outside of the sprocket. This was due to the length of the chain going to the front sprocket and the slight misalignment of the gearbox sprocket to the front crank sprocket. The way that this was resolved was by installing a chain guide that helped keep the chain from going off the
outside edge of the front sprocket. The second problem was the jamming of the chain on the inside of the sprocket assembly or simply between the outer most sprockets of the assembly. The solution to this problem was to attach an additional chain guide to the inside of the previous one to prevent the chain from falling off in that direction. This can be seen in the following figure.

Due to the tight clearance between the chain and the frame of the bicycle, a guard was developed to keep the chain from marring the paint on the bicycle frame. This guard consisted of a strip of black polycarbonate plastic that was fastened to the right hand seat stay of the bicycle
using zip ties. In the future this could be replaced with a molded piece of plastic that is glued to
the bicycle frame. Adjustment of the sprockets on both ends of the chain system would be
possible but very difficult. Because the chain only hits the frame when slack or when going over
bumps (as most conventional bicycle chains do already) a guard seems to be the best alternative
in the long run as well as the short run.

**Improperly installed 3/8 drive shafts**

The 3/8 inch drive shafts that held the #25 chain sprockets were not being fastened
properly by the set screws. The top shaft simply needed the set screws re-tapped and retightened.
The bottom shaft was not fixed using this method therefore a retaining plate was installed over
the end of the shaft to prevent it from wandering out. This system appears to be working well.

**Engine to Planetary Issues**

After initial testing of the machined and assembly system problems began to present
themselves. The set screws were not properly holding the shafts in the bearings. The top set screw
was simply not tightened in the beginning but the bottom shaft still wandered after being
tightened. The problem appeared to be a miss aligned set screw hole after dismantling and
examining the parts. To fix the problem quickly, a piece of sheet metal was bolted over the end of
the shaft using the bearing plate bolts. Although not a failure, a polycarbonate shield was bolted
on using the top plate bolt pattern to cover the exposed parts of the chain. This will prevent
clothing and fingers from getting caught in the chain as well as keep oil from spraying off of the
chain. The following figures show the construction of the chain system and the fixes that were
made after testing. Note that the chain is not shown in the Solidworks models and the teeth are
not shown on the sprockets.
**Failure of #25 1:1 chain**

During the fuel economy testing runs, the #25 chain that transfers the rotational motion of the engine to the planetary gearbox with a 1:1 reduction ratio failed. Upon inspection of the chain, the master link appears to have failed. There are three hypotheses for the reason why it failed. The first is a lack of lubrication as the chain was found to be dry after approximately every five miles of run time. The second is that the master link was not properly installed and simply fell apart. The third potential reason for the failure is that the chain caught on one of the aluminum plates or a broken sprocket tooth. Upon examination of the components, the reason for the failure appears to be mainly the failure of the master link as the chain appears to be in good condition besides the missing master link. What caused the master link to fail is most likely excessive slack in the chain. There do not appear to be any edges or areas of the surrounding parts that the chain caught on. There was however wearing from the chain being too loose. The only damage incurred was a scratch around the upper sprocket. This was probably caused immediately after the chain broke when it left the sprocket. In addition there does not appear to be any damage or noticeable wearing of the sprocket teeth.

In conclusion there does not seem to be a violation of the design or the properties of the chain conditions. The chain did run dry of oil but oil was immediately reapplied. The problem was not a manufacturing problem either, but improper use of the tension adjustment system at hand. The bolts attaching the motor to the planetary gear box were not tightened properly. The only unknown factor is whether the master link was properly installed in the beginning.
Power Estimation

Test Plan

The purpose of finding the power output of the moped, besides interest, was to find the torque and therefore the maximum torque. The maximum torque was required because theoretically the maximum efficiency of the engine is at maximum torque. The engine RPM at the maximum torque was found which was used in conjunction with the speed limit to find the ideal sprocket combination to ride the moped in for the fuel economy test. Ideally the power of the moped was to be measured using a dynamometer of the appropriate size. Because a dynamometer that small was not easily available, an alternative power test plan was developed. This plan included riding the moped and recording the maximum speed achieved in each sprocket combination when the moped was under load. The equivalent engine rpm could be obtained by back calculating through the power train and referencing the cadence table created using the Machars.net cadence calculator using this specific bicycle’s specifications (see figure 52.). It is important to note that only the 48T sprocket data was analyzed as the testing was done in this speed range. It is also important to note that due to time constraints only one run in each sprocket combination was performed.
After obtaining the rpm for the given speeds, the power needed to be estimated. This was done using the bicycle power curve used when designing the moped. The relevant speeds from the testing were compared to the power required to go that speed on a bicycle. There were many variables and sources of error using this method such as error in extracting data from the graph in the book; the weight, aerodynamics, and style of bicycle used to make that graph; environment conditions of the road test; the number of runs; and riding style of the rider. Although there were many sources of error, this was the best option available. After plotting the power versus engine RPM the torque curve could be derived and the ideal RPM found.
Figure 61 Engine Speed from Cadence

<table>
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<tr>
<th>Engine Speed</th>
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<tbody>
<tr>
<td>RPM</td>
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</tr>
<tr>
<td>10</td>
<td>15</td>
</tr>
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<td>15</td>
<td>100</td>
</tr>
<tr>
<td>10</td>
<td>100</td>
</tr>
</tbody>
</table>

In finding the engine speed from the cadence each cadence was multiplied by the ratio of the power train back to the engine. This number was 58.14 as can be seen in figure 53. The original ratio was designed at approximately 72:1 but due to the difficulty in machining a sprocket that small for the planetary output the sprocket size was increased. The next graph shows an interpretation of the bicycle power curve from earlier in the paper. The purpose of making a curve to fit from the books graph was to find the equation of the curve. This formula was then used to find the specific power at a speed not specified on the graph. The formula can also be seen in the graph in figure 54. It is important to note that the Sports Bicycle curve was used to estimate this curve because it seemed to be the best estimation of the bicycle used to build the moped. The table below the Figure 54. is the data used to make the graph. The powers were found using the equation on the curve and the mph intervals on the engine rpm chart were converted to meters per second as that was the unit used by Wilson.
Adapted from “Bicycling Science,” by David Gordon Wilson, p. 140.

Table 6. Power Required to Propel a Bicycle Data

<table>
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<tr>
<th>Speed (mph)</th>
<th>Speed (mps)</th>
<th>Power (Watts)</th>
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<td>123</td>
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<td>17</td>
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<td>18</td>
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<td>19</td>
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<td>21</td>
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<td>22</td>
<td>9.8</td>
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<td>779</td>
</tr>
<tr>
<td>35</td>
<td>16</td>
<td>903</td>
</tr>
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</table>

**Results and Analysis**

The following table shows the data collected during the power road test as well as the conditions of the test. The conditions were recorded to aid in any replication of the test. The fuel consumption was also recorded as a stepping stone for the fuel economy testing. The figure after the table shows the map of the road that the test was performed on. This was Reservoir Street which crosses over the Worcester border in the Holden area. The distance covered during testing is between the two red dots. It is important to note that the weather was sunny and dry during testing.
### Table 7. Power Road Test Data

<table>
<thead>
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<td>Date</td>
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<tr>
<td>Temperature</td>
<td>64 degrees</td>
</tr>
<tr>
<td>Weather</td>
<td>Sunny (dry)</td>
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<tr>
<td>Tire Pressure</td>
<td>30 psi</td>
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<tr>
<td>Total Distance</td>
<td>4.9 miles</td>
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<tr>
<td>Average Speed</td>
<td>14 mph</td>
</tr>
<tr>
<td>Time (duration)</td>
<td>21:06</td>
</tr>
<tr>
<td>Mileage Weight</td>
<td>49 mp(lb) (propane)</td>
</tr>
<tr>
<td>Mileage Volume</td>
<td>200 mpg (propane)</td>
</tr>
<tr>
<td>Total Fuel Consumption</td>
<td>0.10 oz</td>
</tr>
<tr>
<td>Top Speed</td>
<td>31 mph</td>
</tr>
<tr>
<td>Rider Weight</td>
<td>178 lbs</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Testing Results</th>
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</thead>
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<tr>
<td>4</td>
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<tr>
<td>5</td>
</tr>
<tr>
<td>6</td>
</tr>
<tr>
<td>7</td>
</tr>
</tbody>
</table>

Figure 63 Map of Power Testing Road

SearchBox&oe=&q=worcester&um=1&ie=UTF-
After analyzing the data obtained in this test, it was found that the only valid data points were from run six and seven. This is because these two runs were the only two different sprocket combinations that the moped went the same speed in. What this means is that the engine did not reach maximum power in the rest of the sprocket combinations. The moped was expected to have more air resistance than was actually the case. Due to time restraints the testing was not repeated. In order to salvage the two valid data points that were obtained, the two points were correlated to the Honda GX25 engine power curve because this engine was similar in size, power output, and construction. It is also important to note that in addition to not being able to repeat the data, the amount of data was not as great as initially intended. Six sets of seven runs was initially planned to calculate the variance and standard deviation to see if it would fall within three standard deviations. Once again this was not possible due to time constraints.

**Comparison to Honda GX25 power curve**

In comparing the LEHR Propane engine to the Honda GX25 engine, an assumption needed to be made. This was that there is an approximate 14% loss in efficiency between the engine output and the crank of the bicycle. This is made up of two chains at an approximate 2% loss for each chain, and an approximate 10% loss in efficiency of the planetary gearbox. These assumptions are based on individuals with experience in machine design and on machine design books such as “Design of Machinery” by Robert L. Norton (Norton 2008). In making this assumption a theoretical 750 Watts can be derived by multiplying the 660 Watts needed to go 31 mph by 114%. This assumption sounds reasonable given that the stated power output of the LEHR
engine is 750 Watts as mentioned earlier in the paper. After making the assumption that the power is 750 Watts at 31 mph, an interpretation of the Honda GX25 curve needs to be made in order to obtain the equation of the curve. This equation can then be used to calculate the LEHR curve by shifting it accordingly. It yields the same power data points as the Honda engine except shifted 1000 rpms lower. This can be seen in figure 56.

Figure 64 Power vs. Engine RPM Comparison of Honda and LEHR

After the power curve of the LEHR was found, the torque curve was derived. This was done by using the formula Torque=HP*(5252)+RPM. The following Figure 57. shows the graph of this data. The torque is much higher with the LEHR engine because the maximum power of the LEHR engine occurs at a lower rpm.
Conclusion

From this graph it can be determined that the ideal rpm to run the engine at would be approximately 4025 rpm. Given that the speed limit for the road test is 25 mph the ideal sprocket combination would be 48X13 because the engine rpm required is 4884 rpm. Although this is not exact it is the best that can be determined using the existing gearing of the moped and the power data available for the engine. This conclusion was then used to perform the fuel economy test.
Fuel Economy Testing

Test plan

Some initial rough calculations using MathCAD were performed to estimate the efficiency of the engine and the potential fuel economy (see appendix). The fuel economy test plan consists of six runs that cover five miles each. This would mean that using the theoretical specification of two hours per tank of propane from LEHR mentioned earlier in the paper, the total distance that can be covered is 50 (approximately 50 mp(lb)) given the speed limit of 25 mph. It was decided that multiple short runs of about five miles each would make it easy to check the engine and mechanics constantly, allow a break for the rider, and the ability to salvage data if there was to be a break down in the middle of a set of runs. Six runs were planned which would mean a theoretical 30 miles to be covered or 60% of the fuel. This would be a large enough sample to determine that the data is within three standard deviations of the mean. A scale made by Escali with an accuracy of 0.1 oz would be used to measure the tanks in between each run. The bicycle computer on the moped would provide the necessary distance and other important data. The road that was used to do the testing, Reservoir Street in Holden, MA, can be seen if figure 58. and the red dots indicate the stretch of road that was used to do the testing. It is important to note that one single run on the road is 2.5 miles. A full five mile run required a turnaround at the lower dot.
Figure 66 Map of the Fuel Economy Testing Run

http://maps.google.com/maps?rls=com.microsoft:en-us:IE-SearchBox&oe=&q=worcester&um=1&ie=UTF-8&qh=&hnear=0x89e406585a2a8b0d:0x9e137dd87fca4d6d,Worcester,+MA&gl=us&sa=X&ei=SvttUlajF-WM0QGZ-YG4AQ&ved=0CIkBELYD
**Results and Analysis**

The following table shows the conditions during testing and the data gathered during testing. The table after the conditions table presents the fuel economy data that was recorded. There are some major discrepancies with much of the data in this table. There are several reasons for these differences. The first reason is that during the second run the moped went faster on the downhill toward Olean Street (see map). The second is that the #25 chain broke on the third run which cut the testing short (see robustness testing for information about #25 chain failure). The third run was highlighted in red to indicate this. Due to time constraints the testing was not repeated or completed. The third run was disregarded when performing analysis on the data. In addition it is important to note that the propane canister was measured in ounces but converted to pounds to relate to the original hypothesis of two hours of run time per pound of propane and the size of the propane canister used.

<table>
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<td>Temperature</td>
<td>60 degrees</td>
</tr>
<tr>
<td>Weather</td>
<td>Rainy (wet)</td>
</tr>
<tr>
<td>Tire Pressure</td>
<td>50 psi</td>
</tr>
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<td>Total Distance</td>
<td>12 miles</td>
</tr>
<tr>
<td>Average Speed</td>
<td>17 mph</td>
</tr>
<tr>
<td>Time (duration)</td>
<td>45:50</td>
</tr>
<tr>
<td>Top Speed</td>
<td>33 mph</td>
</tr>
</tbody>
</table>
Table 9. Fuel Economy Testing Data

<table>
<thead>
<tr>
<th>Run</th>
<th>Distance (miles)</th>
<th>Fuel Consumption (pounds)</th>
<th>Miles per pound propane</th>
<th>Miles per gallon propane</th>
<th>Maximum Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5.1</td>
<td>0.088</td>
<td>58</td>
<td>240</td>
<td>n/a</td>
</tr>
<tr>
<td>2</td>
<td>5.1</td>
<td>0.11</td>
<td>46*</td>
<td>190</td>
<td>33</td>
</tr>
<tr>
<td>3**</td>
<td>1.6</td>
<td>0.056</td>
<td>29</td>
<td>120</td>
<td>n/a</td>
</tr>
<tr>
<td>Avg. of 1,2</td>
<td>5.1</td>
<td>0.10</td>
<td>51</td>
<td>210</td>
<td>n/a</td>
</tr>
</tbody>
</table>

* Average speed was faster than the first run in the same sprocket

** #25 chain failure

Conclusion

From this data analysis it can be concluded that the fuel economy does meet the fuel economy specification from the initial data collected. More testing would need to be done to confirm this in the future. It can be seen clearly that the testing was not completed to the specifications in the testing plan. The average fuel economy in miles per gallon of propane was found to be 210 mpg while the original specification was 200 mpg.
Specifications Results

The purpose of this section is to examine the remaining specifications and discuss whether they were met, how they were met, and if they were not met why. The previous sections discussed physical testing that was carried out with data collection and analysis. This section deals more with the qualitative aspects of the design. Each specification that was stated in the beginning of the paper (except the ones covered in testing) will be discussed in the same order that they were originally stated in.

No need to modify bicycle frame

This specification was met easily. The design worked around modifying the frame and instead is based on a series of brackets. The most that happened to the bicycle frame was the application of tape to minimize the damage of the frame paint from the brackets.

Uses existing bicycle transmission with a crank freewheel conversion kit

This specification was met by using an easily obtainable freewheel adaption kit from Cyclone Cycle (Cyclone, 2004). In addition the design allowed for a chain from the motor to reach the adaption kit without impeding the rider in any way.

Easy to install with common tools

The kit was easy to install using common tools such as Allan keys, an adjustable wrench, pliers, and screw driver. The only potential exceptions could be the crank puller tool that was used to remove the standard bicycle crank and a bicycle chain tool that might be used to adjust the motor drive chain. Although these tools are not standard tools they can be cheaply purchased at a
local bicycle shop. Another option to avoid problems with tool availability would be to include the tools in the kit if the kit were to be sold.

**For average adult bicycles without frame suspension (Mountain, Road, Utility, et cetera)**

The bicycle that was chosen to test the kit on was easy to work on and is a standard popular bicycle currently on the market. All of the critical areas where brackets attach to the bicycle are the same as any similar bicycle. Attaching the kit to another standard bicycle should not be a problem. All components that might need adjustment on a different bicycle are easily changeable with standard tools.

**LEHR 25cc 1 hp Propane 4 cycle OHV**

This was easily met by simply purchasing the engine. In the long run if the kit were to be produced supply might be an issue. LEHR is the only company that makes this engine and if it were to discontinue the motor there would be no alternatives. A gasoline engine would have to be modified which might be more costly.

**Manual hand lever activated clutch system**

Although the original manual clutch lever system was scratched after an initial prototype was made, a sturdy replacement was designed and built allowing the specification to be met. The lever is ergonomically shaped and is easy to use the while riding the moped.

**Pedal or use power assist option (the engine)**

This specification was met by the inclusion of the dog clutch into the design. This allows the rider to bypass the motor and pedal normally. The crank adaption kit also helps this specification to get met. It allows the motor chain to run without issue during pedaling.
**Pedal start and Coast start**

This specification was not met. The original design included the locking of the bicycle freewheel. After the freewheel was locked it was found that the bicycle shifting system did not accommodate a load being applied to the chain in the opposite direction. The power assist system still works but the ability to start the motor while riding without pedaling was lost. It is important to note however that this concept would still work if an internal hub style bicycle was used as opposed to a derailleur style bicycle.

**$1,000 approximate limit**

This specification was easily met as can be seen by the budget in the appendix. One point that needs to be made about this specification is that the cost of machining time is not factored in and the potential cost if the parts were to be mass produced was not calculated.

**9kg approximate maximum for kit**

This parameter was not met. The weight of the kit was 9.5 kg. Although this specification was not met there is room for material removal of the current components. The main components that can have extra material removed are the aluminum bearing plates, the aluminum adaptor plates, and the steel main support bracket. In addition the main support bracket could be made out of aluminum instead of steel.

**Achieve 30mph by engine power alone**

This specification was met twice, first in the power testing and then in the fuel economy testing. A speed of 31 mph was reached in the power testing and a speed of 32.6 mph was reached in the fuel economy testing.
Maximum speed of 5 mph for pedal starting

This was met easily. The actual speed was approximately 3 mph to start the motor. The purpose of this specification was simply to not require the rider to achieve a high rate of speed before being able to start the engine.

No bicycle components will be critically changed so it can operate just as a normal bicycle

No bicycle components were modified besides the exchange of the crank mechanism. The crank can be easily replaced if necessary.

Lower emissions on average than equivalent gasoline engine

As mentioned in the Propane section under Engine in the beginning of the paper propane is generally cleaner to burn than gasoline. According to the EIA.gov website, propane for transportation use yields about 12.66 pounds of CO$_2$ per gallon (EIA.gov, 2007). This is compared to 19.54 pounds of CO$_2$ created when burning gasoline for transportation use (EIA.gov, 2007). Since CO$_2$ was a major concern as most other emissions are lower than gasoline engines on average this specification was met.
**Conclusion**

To conclude the paper most of the specifications that were detailed at the beginning of the paper were met with the exception of the coast start specification. The following table lists the specifications and provides a green box for “met” and a red box for “not met”. With further testing and refinement of the design and manufacturing process, the propane moped could be a viable form of cheap efficient transportation. The high efficiency moped may be a more attractive alternative to current mopeds on the market for its cleaner emissions, quieter sound, fuel efficiency, and options that other mopeds do not currently combine.

<table>
<thead>
<tr>
<th>Specification</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>No need to modify bicycle frame</td>
<td>Met</td>
</tr>
<tr>
<td>Uses existing bicycle transmission with a crank freewheel conversion kit</td>
<td></td>
</tr>
<tr>
<td>Easy to install with common tools</td>
<td></td>
</tr>
<tr>
<td>For average adult bicycles without frame suspension (Mountain, Road, Utility, etc.)</td>
<td></td>
</tr>
<tr>
<td>LEHR 25cc 1 hp Propane 4 cycle OHV</td>
<td></td>
</tr>
<tr>
<td>200 MPG + equivalent (50 mile on one 16.4 oz bottle)</td>
<td></td>
</tr>
<tr>
<td>Manual hand lever activated clutch system</td>
<td></td>
</tr>
<tr>
<td>Pedal or use power assist option</td>
<td></td>
</tr>
<tr>
<td>Pedal start and Coast start</td>
<td></td>
</tr>
<tr>
<td>$1,000 approximate limit</td>
<td></td>
</tr>
<tr>
<td>9kg approximate maximum for kit</td>
<td></td>
</tr>
<tr>
<td>Achieve 30mph by engine power alone</td>
<td></td>
</tr>
<tr>
<td>Maximum speed of 5 mph for pedal starting</td>
<td></td>
</tr>
<tr>
<td>-----------------------------------------</td>
<td></td>
</tr>
<tr>
<td>No bicycle components will be critically changed so it can operate just as a normal bicycle</td>
<td></td>
</tr>
<tr>
<td>Lower emissions on average than equivalent gasoline engine</td>
<td></td>
</tr>
</tbody>
</table>
Appendix

Operations Manual

HEM Operations Manual

Tim Ellsworth

1. Description
   a. Insert diagram of the moped
   b. Label the different parts and briefly explain their purpose

2. Initial Procedures
   a. Fuel and oil
   b. Adjustments

3. Maintenance
   a. Changing fluids
   b. Adjustments
   c. Changing tires
   d. Chain wear inspection

4. Safety
   a. Helmet

5. Flow Chart of Operations

6. Before Starting
   a. Make sure that the dog is disengaged (the clutch lever is locked in the forward position)
   b. Make sure that the bike is safe and in good working condition
   c. Make sure that the bike is in its lowest possible gear combination
      i. If it is not pedal it normally or spin the rear wheel while shifting to get it into its lowest gear

7. Starting
   a. Mount the bike and pedal normally up to about 5 mph
   b. At this point engage the clutch using the clutch lever
      i. It will automatically be pulled to the engaged position once unlocked from the disengaged position
   c. Continue to pedal once up to starting speed
   d. Use the throttle to speed up the engine
   e. Once you feel the engine take over you can stop pedaling

8. Shifting
   a. Once you have started and you are comfortably cruising in the lowest gear you can begin to shift to higher gears to gain speed
b. The clutch does not need to be disengaged when shifting but the engine should not be under a load

c. Once in the next gear the throttle can be used to accelerate

d. Down shifting can be used when slowing down
   i. Only one or two gears should be shifted at a time to avoid jamming and derailment
   ii. If stopping the bike should be in its lowest gear

9. Coasting
   a. When in downhill situations or in situations that do not require power from the engine for extended periods of time the motor can be disengaged
      i. The engine can be turned off to save fuel
      ii. The clutch lever has an electronic switch that kills the engine every time the dog is disengaged
   b. The engine can be engaged again if the bike is going faster than 5 mph (pedaling would be required below that) and the bike would need to be in a reasonable gear for the speed

10. Braking and Stopping
   a. The bike is equipped with front and rear brakes
   b. Braking when dog is engaged:
      i. braking is short
      ii. When it does not slow the bike below 5 mph
      iii. you will return to cruising immediately after braking
   c. Braking when dog is disengaged:
      i. When coming to a normal stop
      ii. At speeds below 5 mph
      iii. After or during coasting
   d. Emergency Braking
      i. If you need to come to a quick stop do not worry about disengaging the clutch if you cannot
      ii. Use the amount of braking force that you feel you need with the throttle off and simply kill the engine while stopping
      iii. Using the kill switch to turn off the engine in an emergency stop will help as well
      iv. The way you plan on stopping in an emergency is up to you but have a plan before you ever ride the bike
Calculations

Figure 67 Fuel Economy

Propane Engine Efficiency and Fuel Consumption Analysis

Engine Efficiency

\[ C_{\text{propane}} = 1.675 \] \( \frac{\text{kJ}}{\text{Kg}} \)

\[ C_{\text{u}} = 1.480 \] \( \frac{\text{kJ}}{\text{Kg}} \)

\[ \eta_{\text{propane}} = \frac{C_{\text{propane}}}{C_{\text{u}}} \]

\[ \eta_{\text{propane}} = 1.126 \]

\[ V_{\text{maxpropane}} = 8 \]

\[ V_{\text{minpropane}} = 1 \]

\[ f_{\text{propane}} = \frac{V_{\text{maxpropane}}}{V_{\text{minpropane}}} \]

\[ f_{\text{propane}} = 8 \]

\[ \eta_{\text{th.propane}} = 1 - \left( \frac{1}{f_{\text{propane}}} \right)^{\text{th.propane}} \]

\[ \eta_{\text{th.propane}} = 0.231 \]

Figure 68 Fuel Economy

Fuel Consumption

\[ p_{\text{propane}} = 0.0073 \] \( \text{MW} \)

\[ LHV_{\text{propane}} = 46.35 \] \( \frac{\text{MJ}}{\text{kg}} \)

\[ \text{fuelcon}_{\text{propane}} = p_{\text{propane}} \left( \frac{1}{\eta_{\text{th.propane}} - LHV_{\text{propane}}} \right) \]

\[ \text{fuelcon}_{\text{propane}} = 6.999 \times 10^{-5} \] \( \text{kg/s} \)

\[ \text{fuelcon}_{\text{propane}} = \text{fuelcon}_{\text{propane}}1000 \]

\[ \text{fuelcon}_{\text{propane}} = 0.07 \] \( \text{lb/hr} \)

\[ \text{fuelcon}_{\text{propane}} = \text{fuelcon}_{\text{propane}}3600 - 0.00220462253 \]

\[ \text{fuelcon}_{\text{propane}} = 0.355 \]
**Dog Clutch**
Diameter determined by torque in relation to the minimum cross section surface area for the specified material.

**Figure 69 Dog Clutch Calculation**

\[ T = F \times r \]

\[ F = \frac{T}{r} = \frac{12 \text{ Nm}}{0.00635 \text{ m}} = 1889.76 \text{ N} \]

\[ T = \frac{(J \times \tau)}{r} \]

\[ J = 2.25 \times a^4 \]

\[ T = \frac{(2.25 \times a^4)(25 \text{ ksi})}{a \times \sqrt{2}} \]

\[ T = \frac{(2.25 \times a^3)(25 \text{ ksi})}{\sqrt{2}} \]

\[ a = \text{cube root}((12 \times \sqrt{2})/(172368932.33 \times (2.25))) = 0.0035238567 \text{ m} \]

FOS of 3: 0.139~0.417
Steel

$T_{ai}=25\text{ksi} \rightarrow \text{with FOS of 3} \rightarrow \tau_{ai}=8.33\text{ksi}$

$57433328.25 \text{N/m}^2 = 0.5(h)((12\text{Nm}/0.00635)/4)/(0.00635*0.00635)$

$\Sigma Fx = N=0$

$\Sigma Fy = -0.5(74401)*(0.0085)-(74401)*(0.00635)+V=0$

$V=788.65\text{N}$

$\Sigma Fy = -24800*h-37201*h+V=0$

$\Sigma Fy = -62001*h+V=0$

$V=62001*h$

$\tau=V/A=62001*h/A=62001*h/(b*t)$

$h=0.00635\text{m}$

$b=0.00635\text{m}$

$t=\text{the thickness of the tooth (finding)}$

$\tau_{ai}\text{FOS}=57433328.25 \text{N/m}^2 = 62001*(h/(b*t))$

$t=926.33\text{m}$
Dog Tangential Velocity

Figure 71 Dog Tangential Velocity Calculation

7000rpm/60=117Hz

ω=2πf

ω=2π(117Hz)

ω=733rad/sec

ω=Vtan/r

Vtan= ω*r

r=0.5in

Vtan=366m/s
Control Spring Force Analysis

Figure 72 Control Spring Force Analysis

9N ~ 2 lbs
M=0=(*0.04826)-Fc(0.5)
Fc=9*(0.04826)/0.5
Fc=34.2N
M=0=(34.2)*(0.01905)-(Fs)*(0.035052)
Fs=(34.2*0.01905)/0.035052
Fs=18.59N ~ 4.18 lbs

Timeline

The following Gantt charts show a rough timeline that the project was completed in. It is important to note that they were changing constantly during the project and are not an accurate portrayal of what happened.
Research background and components
Select components based on analysis of the...
Design Individual Components using CAD
Assembly of the designed components in CAD...
Preliminary analysis of the CAD model
Present the design along with any analysis

Order Parts
Machining of components
Assembly of completed components
Complete machining and assembly
Preliminary testing of the prototype
Present the completed prototype along with...
Submit draft of report
Test and analyze the engine
Test and analyze the drive train
Test and analyze the handling and ergonomics
Test and analyze the overall power...
Test and analyze the fuel consumption
Finish writing the parts of the final paper
Compile and review the final paper
Present the final project
Submit the final report

Test and analyze the fuel consumption
Finish writing the parts of the final paper
Compile and review the final paper
Present the final project
Submit the final report
Costs

This was the purchases made during the project. The green rows indicate major purchases made. The ME budget was maxed out and included all of the stock and hardware used. It is important to note that this total cost does not include the labor of building the moped.

Table 1. Costs

<table>
<thead>
<tr>
<th>Description</th>
<th>Size</th>
<th>Quantity</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>ME Budget</td>
<td></td>
<td></td>
<td>$160.00</td>
</tr>
<tr>
<td>Speedometer</td>
<td></td>
<td>1</td>
<td>$8.33</td>
</tr>
<tr>
<td>Secondary Chains</td>
<td></td>
<td>2</td>
<td>$14.00</td>
</tr>
<tr>
<td>Banebot planetary</td>
<td>12:1</td>
<td>1</td>
<td>$102.75</td>
</tr>
<tr>
<td>LEHR Propane engine</td>
<td>25cc 1hp</td>
<td>1</td>
<td>$123.51</td>
</tr>
<tr>
<td>3 piece freewheel kit</td>
<td>48T48T34T</td>
<td>1</td>
<td>$170.00</td>
</tr>
<tr>
<td>GMC Denali bicycle</td>
<td>700c</td>
<td>1</td>
<td>$171.99</td>
</tr>
</tbody>
</table>

$750.58
Works Cited


