HPVCP

Final Report

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DISCLAIMER

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EXECUTIVE SUMMARY

The goal of the HPVC (Human Powered Vehicle Competition) team is to create a propulsion system that is different from the typical bicycle drives commonly seen in HPV competitions. Although the original bicycle-style drive system had no problems, it was less efficient and lacked inspiration. In order to improve the existing propulsion system, the HPVCP team aims to create a new drive that will increase efficiency in some way and re-provide kinetic energy for human-powered vehicles. In the new semester, the team decided to refit the existing HPV vehicles to provide a brand new energy recovery system for the existing vehicles.

In order to improve efficiency, deciding on an energy storage system will be a brand new idea and goal. Although the driving loss of the bicycle is small, there is no way to store energy for later use, and there is no way to recover any energy that is not used immediately. In order to solve this problem, in the new semester, the team added a flywheel to the energy regenerative propulsion system to store energy. There are many options for energy storage, but the flywheel is inherently non-destructive and very robust. The team wanted to integrate the flywheel into the drive system, which required a chain drive separate from the bicycle drive system, so the team designed a new chain direction and recreated a new drive above the vehicle.

The main advantage of combining a flywheel is regenerative braking for passive energy storage. Because the flywheel is engaged with the drive shaft, it means it can turn the wheel, or the wheel can turn it. In the starting phase, the wheels can provide energy to the flywheel to turn it. In the energy release stage, the kinetic energy generated when the flywheel rotates is fed back to the wheel drive. There is a friction clutch in the system to allow selective engagement of the flywheel. The advantage of this is that the clutch can be engaged to transfer the stored energy from the flywheel to the axle, or from the axle to the flywheel. The fact that the axle can drive the flywheel means that the flywheel can be used for regenerative braking by engaging the clutch and drag energy from the wheels when sliding downhill. In the new design concept, the team added the design of springs and jaws to provide space for the flywheel to rotate, greatly increasing the safety of the system.

Compared with last semester, the team abandoned the 1:1 gear set, because the gear set is just a device that transmits energy to the design. In actual assembly, the gear set has no specific use, but will reduce efficiency and increase budget. In the design of the new propulsion system, the team does not need to design the frame and vehicle shape, but only needs to focus on improving the energy regeneration propulsion system. This greatly reduces the budget and effort required for the design. On the basis of last semester, the HPVCP team refitted the old vehicles, completed the design goals, and met customer needs and engineering needs. In the latest development, the team has assembled the energy regenerative propulsion system and delivered it for testing.

ACKNOWLEDGEMENTS

Special thanks to Dr. David Willy who has stepped in as our advisor this second semester and provided a great deal of direction to the team. We would also like to acknowledge the NAU machine shop and the employees thereof who have provided much assistance in the completion of our project.

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1 BACKGROUND

1.1 *Introduction*

Human powered vehicle is a vehicle which drives through human power only, requiring no electricity or fossil fuel. Human powered vehicles are being used to reduce the number of motorized vehicles. This vehicle will keep the environment clean as well and it will help the humans to keep themselves active and fit. The HPV uses a light frame, usually in the form of bicycles or tri-cycles. HPV's optimize human performance by isolating muscle groups that generate the most power and cause the least amount of fatigue. In this project the team is going to present a human powered vehicle that will utilize the maximum power from the human and will transmit that human power to the vehicle with maximum efficiency. This energy will then be reclaimed and stored later through the use of a flywheel.

The reason sponsors have shown their interest in this project is that human powered vehicles use no gasoline or electricity, so this is an environmentally friendly vehicle. Furthermore, NAU has a legacy of innovation in the HPV competitions, and the regenerative subsystem would be a great way to keep with this precedent. This project will benefit the sponsors as they will get a creative and optimized vehicle that will utilize the human body and will be of great interest for the public.

1.2 *Project Description*

This project is about the human powered vehicle, and requires research over the exercise science, kinesiology, ergonomics and other related areas where human power can be converted into motive force. In this project the team has to learn about the power generated by bicycle-type systems to use as a comparison.

Normally a human powered vehicle uses the leg muscles to generate the power and that power is transmitted to the vehicle. The original scope sought to examine ways to create more power by including more of the human musculature in the production. This project aims to utilize leg muscles to propel the HPV, design a propulsion system and minimize strain by regaining energy previously expended. In this project the deliverable is a system that can extract power from a human and create motion, but is not solely a typical bike drive.

2 REQUIREMENTS

Requirements of the systems details the needs of the client and what the client is going to desire from the project when it is ready. The requirements determine what the team has to make specifically and they follow those requirements to complete the design.

2.1 *Customer Requirements (CRs)*

Our customer requirements were originally created with Dr. Trevas, who has since left NAU. Changes between the customer requirements from Summer 2021 to this semester are primarily due to the change of our customer. The most significant requirement change is for maximum and efficient use of multiple muscle groups. Originally this entailed the creation of a row bar along with pedals to increase energy created from the body. Additionally, as a stretch goal we planned on displaying more metrics such as the regenerative braking efficiency. Due to scope change and lead times of orders we were unable to do this.

We have also refined our requirements with the help of our current clients. Our customer requirements are as follows:

1. Store Energy to be Used Later ------------------------------------ **High**
2. Achieve Max Usable Energy Storage ---------------------------- **High**
3. Display Bike Speed --- **High**
4. Display Flywheel Speed/Energy Stored in Flywheel ----------- **High**
5. Regenerative Braking Efficiency of 15%------------------------ **Mid**
6. Low Budget -- **Mid**
7. Safe to Operate -- **Low**

Our main objectives are to use and store human powered energy safely and efficiently while also displaying informative metrics to the user. The purpose of storing energy is to set this HPV apart from all the others in the past. That was one of the goals given by our original client. Our new client, Perry Wood, liked the idea of an energy storage/recovery system on an HPV. For this purpose, Energy storage is our main focus now moving forward. Achieving max energy storage and displaying flywheel energy storage and speed go hand in hand as the display metrics will allow us to test our energy storage efficiency. Energy storage capabilities was an original client requirement, but since our client has changed, our priority for attaining max energy storage has increased. As such we planned to spend much effort on testing, calculating, and refining our energy storage capabilities.

Most HPVs do not have a displayed speed, since it is not a very important part of the design. For our design however, this is very important. Displaying speed and energy metrics are a high priority due to its multipurpose use. Calculating and displaying these metrics will not only allow us to test our requirements in an efficient manner but will also allow the user to most efficiently use our HPV. This is an important part of setting our HPV apart from all the others.

2.2 *Engineering Requirements (ERs)*

An important part of any engineering project is the Engineering Requirements. Without these, there is no goal to design to. Our project started with a very unclear set of requirements, since the scope and final product were unclear as well. With the start of the new semester, and the change in client, our scope and requirements became much clearer, however we had to put in more effort to catch up and deliver on our new requirements. Almost all of the following ERs have been updated or added since last semester. The updated engineering requirements have shown below in the following table:

Table 1: Engineering Requirements

Engineering Requirements	Target	Tolerance
1. Optimal Energy Storage	600 J	± 60 J

2. Regenerative Braking Efficiency	15%	± 2.5%
3. Max Speed	20 mph	± 5 mph
4. Display Metrics	Displays correctly	None
5. Usable Energy Threshold	300 J	± 50 J
6. Budget Limit	$1250	± $250

2.3 *Functional Decomposition*

The project was to develop a human powered vehicle that utilized the maximum power from the human body by using different muscles, the scope has since narrowed to just leg muscles. The system uses the human power which counts as mechanical energy and converts that mechanical energy into driving the vehicle. The system uses the efficient way to transform the mechanical energy into driving the vehicle which may consist of a flywheel. This functional decomposition is going to describe what consists of the system's internal functioning and parts, along with the inputs and outputs of the system.

2.3.1 Black Box Model

The black box model defines the inputs and the outputs of the system without investigating into the system. The black box model helps abstract the system and break it down into its base components. For the current project there are three different inputs and outputs, which are categorized as system, energy, and signal. The three inputs are human power, mechanical energy, and on/off, while the three outputs are wheels motion or driving the vehicle, sound, heat and on/off system. There have not been any changes made to the black box model since the input and output of the system did not change when the project scope changed. The ultimate goal is, and has always been, to power a vehicle using only human energy.

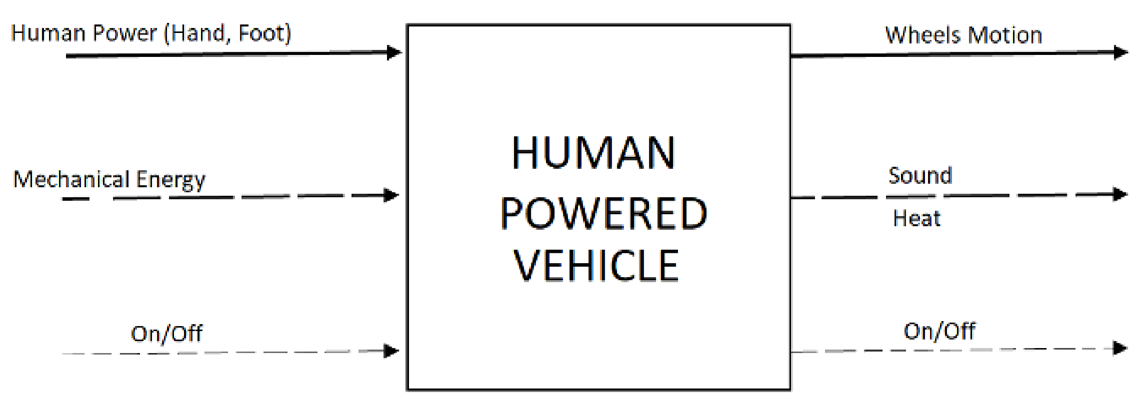

Figure 1: Black Box Model

2.3.2 Functional Model/Work-Process Diagram OR Hierarchical Task Analysis

The functional model is basically a detailed model of the system which defines the complete internal working of the system, like how the inputs drive through different components to reach the outputs. The functional model completely defines the system process, which incorporates with each other and hence it gives the required outputs. The functional model for this project is shown below.

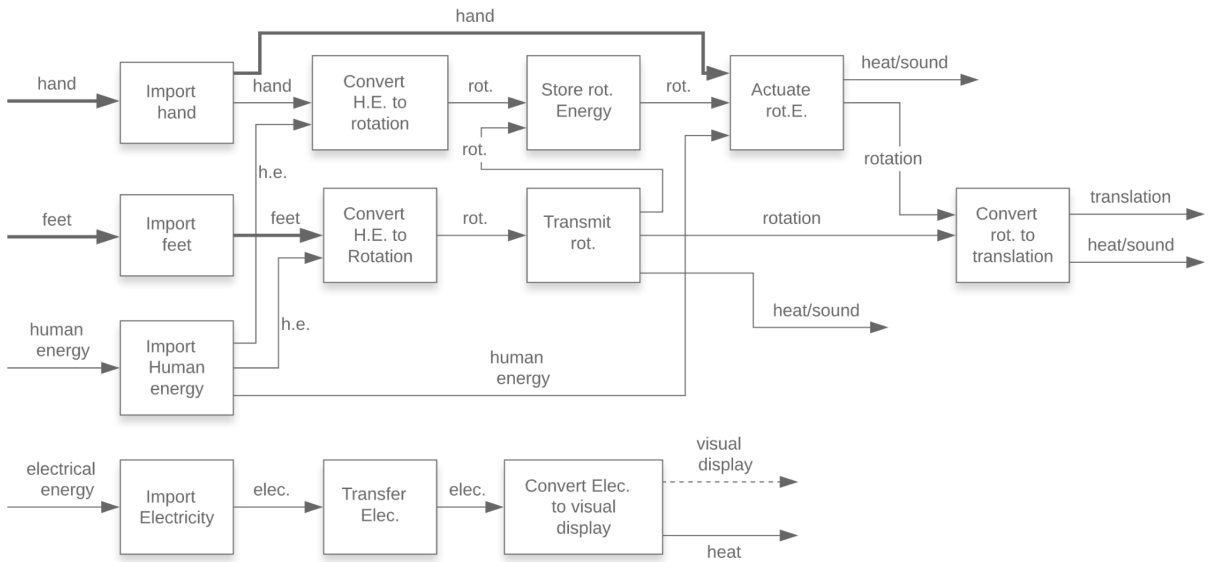

Figure 2: Functional Model

In the given functional model, a crank will take the input from a human, using both legs and hands, and then it transfers that power to the rotational motion that will rotate the gears, pinions, and flywheel depending on which system is being driven. The energy is then transferred via chain and sprocket to a different portion of the vehicle. This is either directly transferred via chain and sprocket, or stored and then transferred via a series of gears and chain-sprocket combinations. This rotational energy is then transferred to translational energy via friction between the wheels and the ground, causing the vehicle to move forward. The stored energy must be transferred using friction. This energy will produce the sound as well as heat during the motion, causing some losses. Finally, to start the vehicle it is driven through pedals, while the flywheel maintains energy from the hands, and then to stop the vehicle there will be a brake system- designed by the team concerned with the entire vehicle.

With the changes in scope, this functional model still fits the new design, but the description above no longer does. In the new design, the only human energy input by the hands is given to actuate the clutch system. Besides that, this functional model is still correct despite large changes in scope. That is because the functionality of the vehicle has largely stayed the same over the course of the project.

2.4 House of Quality (HoQ)

House of Quality is a well-known product development process. Its purpose is to compare the needs of customers for product or process development and find the capabilities and resources to meet these needs. This is a very important process. Translate the customer's wishes into actual engineering goals, determine the priority of the execution steps according to the most important content to the customer, and express the actual plan according to the priority.

Table 2: House of Quality (HoQ)

House of Quality (HoQ)									
Customer Requirement	**Weight**	**Engineering Requirement**	Optimal Energy Storage	Regenerative Braking Efficiency	Max Speed	Display Metrics	Usable Energy Threshold	Budget Limit	
Store Energy to be Used Later	5		9	9	6	6	6	6	
Achieve Max Usable Energy Storage	5		9	9	9	6	6	6	
Display Bike Speed	3		1	6	9	6	3	3	
Display Flywheel Speed/Energy Stored ir	5		3	6	3	9	3	3	
Display Efficiency	4		9	9	9	3	6	6	
Low Budget	3		3	3	3	1	3	9	
Safe to Operate	5		6	6	6	6	3	6	
Absolute Technical Importance (ATI)			183	213	192	168	132	165	
Relative Technical Importance (RTI)			3	1	2	4	6	5	
Target ER values			600J	15%	20mph	none	300J	$1,500	
Tolerances of Ers			60J	3%	5mph	none	50	$250	

The customer of the team is Perry Wood, and we have listed the corresponding CR based on the customer demand information provided by the professor. The new version of human-powered vehicles focuses on energy storage and reuse, so energy storage and efficiency are in large proportions to customer needs. Then, according to the relevance of customer needs and engineering needs, each space is scored in the corresponding project, divided into four scores of 1, 3, 6, and 9. The two parts with high correlation will get high scores, and finally multiply Calculate the absolute technical importance in proportion. According to the above figure, system efficiency and energy storage are the engineering requirements that we need to consider first. In the design process, try to meet high-priority requirements to ensure the best customer satisfaction.

2.5 *Standards, Codes, and Regulations*

The standards and codes that are used in this design project include (but are not limited to):

- American Society of Mechanical Engineering (ASME)
- American Society of Testing and Materials (ASTM)

The codes listed above will be used in the design of this vehicle. Specific standard numbers are listed below in Table 2. Each of these codes help the team to properly design, test, and implement each part of the vehicle. The team will not be limited to the standards listed below, and any further standards that are found will be listed in later reports.

Table 3: Standards of Practice as Applied to this Project

Standard Number or Code	**Title of Standard**	**How it applies to Project**
ASTM A1058	Standard Test Methods for Mechanical Testing of Steel Products—Metric	Gives standards for testing steel components of the vehicle
ASME Y14.5	Dimensioning and Tolerancing	Used for all CAD drawings

3 DESIGN SPACE RESEARCH

In this part of the research, all team members studied a key element of the propulsion system. These concepts are different from the role of independent subsystem components as a single component, which is a key part of considering how they will operate as a complete system. The team members reassembled and designed a brand-new energy recovery propulsion system to make continuous improvements and implementations in the new semester.

3.1 *Literature Review*

This section will summarize the specific research directions of each group member in the last semester. Due to the different design schemes, the research goals between the two semesters are also different. In the last semester, team members studied different parts of the vehicle: gears, clutches, flywheels, sprockets and chains, and circuit components. Team members used a variety of resources to help design the project. When the team members studied gears and chains, they used MATLAB to help calculate and verify the rationality of the components. The main articles are also listed in the corresponding section, and the final article list is included in the reference. The task of the team is to find the right speed sensor, determine the microprocessor and electronics to use, and create a user interface for the digital monitor that will be installed on the front of the HPV. The team also needs to focus on the efficiency of energy transmission and storage, and begin to find ways to effectively meet engineering requirements and customer requirements. The final energy storage method decided is flywheel. Although there are suggestions for hydraulic accumulators and electric collection systems, they are not a viable option for us at all. When the flywheel is almost completely effective, the efficiency of the hydraulic accumulator under ideal conditions is about 87%, excluding the loss of air resistance and load-bearing bearings. In the study of roller chains and sprockets, the team analyzed the relationship between different sprockets in detail. In the final design, this semester, the team members completed the calculation and design of the flywheel and clutch together. In the research of energy recovery propulsion systems, the design of flywheels is particularly critical. The team members added a flywheel to the existing vehicle and reconnected it to the existing engineering vehicle to achieve energy recovery and reuse.

3.2 *Benchmarking*

This section will show the benchmark test information from the previous semester and this semester. The benchmark test last semester was mainly conducted by the client Dr. Trevis, and the design is biased towards the whole vehicle. The benchmark test for this semester is more complete, with the communication of the customer Dr. Perry, and the course instructor Dr.Willy. The goal of the whole project is to design a propulsion system with energy recovery. Under the new project goal, the team members improved and updated the benchmark information.

3.2.1 System Level Benchmarking

This section discusses the product design related to the finished product and the project design in the existing market, and the correlation is mainly judged by the function and appearance. The project design draws on some market products to meet engineering needs.

Existing Design #1: Hydro Rowing Machine

Rowing machines use air or water flowing through the internal flywheel to create resistance. The wheel is connected to the rowing handle by a chain, and when the handle is pulled, the flywheel will rotate. The faster you swipe, the faster the flywheel spins, so the greater the resistance. A water rowing machine will use 86% of the body's muscles, effectively improving lung and muscle function. The row part in the team design refers to the design ideas of the rowing machine.

Existing Design #2: Bicycle

A bicycle is a two-wheel steerable machine pedaled by a person. The wheels of ordinary bicycles are installed in a metal frame, and the front wheels are fixed in a rotatable handle. Riders provide power by pedaling on cycling and turn the handlebars to steer. The pedaling part of the bicycle is the same as the pedaling designed by the group.

Existing Design #3: Race Car

A racing car is a professional car used for vehicle competitions. Has extremely high speed and streamlined body. The chassis of the car is very low to satisfy the grip at high speeds. Our design also has a low chassis in order to reduce the power provided by the human body.

3.2.2 Subsystem Level Benchmarking

This section discusses existing designs that have been considered final design components, most of which are sub-components of existing solutions. Each subsystem is divided into multiple existing designs, which in some way contribute to the current HPV design.

Subsystem #1: Clutch

Existing Design #1: Friction Clutch

A friction clutch is a necessary component for this design, if a flywheel is going to be implemented. This allows the flywheel to be powered up without affecting the vehicle's speed, and then allows that energy to be used when necessary, by engaging the clutch. The friction of the clutch on the flywheel will slow it down, while also transferring some of that energy to the drive axle of the vehicle. Essentially it is a system to allow transfer of angular momentum between the drive axle and the flywheel. This system can also be used for regenerative braking purposes, but will not, however, slow the vehicle to a complete stop.

Existing Design #2: Centrifugal Clutch

A friction clutch is a necessary component for this design, if a flywheel is going to be implemented. This allows the flywheel to be powered up without affecting the vehicle's speed, and then allows that energy to be used when necessary by engaging the clutch. The friction of the clutch on the flywheel will slow it down, while also transferring some of that energy to the drive axle of the vehicle. Essentially it is a system to allow transfer of angular momentum between the drive axle and the flywheel. This system can also be used for regenerative braking purposes, but will not, however, slow the vehicle to a complete stop.

Existing Design #2: Cone Clutch

Cone clutches are similar to plate clutches. Instead of being a flat plate, it is a conical shape with friction pads or a frictional surface that is pressed into a similar but larger shape. It works the same way as a plate clutch in the fact that the frictional surface is not spinning and is pressed into a spinning surface in order to slow it down. This allows for a larger surface area, and in turn, faster energy loss.

Existing Design #3: Plate Clutch

A plate clutch is the most simple form of a friction clutch. Modern friction plate clutches are commonly used in motorcycle transmission systems. A plate clutch consists of a disk or plate made up of a natural or synthesised material having a high coefficient of friction as well as a high heat tolerance. Some designs are a solid plate, while others are a series of friction pads arranged in a circle on a metal plate. These clutches are typically engaged with a type of actuator that presses the plate flat against a spinning surface, thus slowing the surface. This design is very simple and would be easy to implement in our design.

Subsystem #2: Flywheel

The flywheel is the central point of the propulsion system, as it is the most advantageous component to have onboard the vehicle. Not only will this system store energy when powered by the hand crank, but it will be able to store energy from regenerative braking as well. This energy can be utilized at any time it is needed, or found to be advantageous.

Existing Design #1: Rim type

A rimmed type flywheel is one that positions the mass to the outer edge of the flywheel. This style of flywheel operates at lower speeds well, and becomes unsafe at high speed.

Existing Design #2: Disk type

A disk type flywheel is typically an evenly distributed mass, or tapered. This style operates at higher speed, and carries more angular momentum.

Subsystem #3: Speed Sensors

This subsystem will be what calculates the speed of our vehicle. The existing designs are both electro-magnetic sensors.

Existing Design #1: Hall Effect Sensor

Hall effect sensors are electromagnetic sensors that rely on its namesake the Hall Effect which is a developed electric potential between two perpendicular current carrying conductors. HE sensors have both a latching and non-latching style. We will be using the non-latching style as voltage output goes to low when magnet stimulus is removed.

Existing Design #2: Reed Switch

Reed switches are electromagnetic sensors which contain ferromagnetic, flexible reeds that create a circuit when introduced to a magnetic field. Reed switches are versatile, simple, and cheap.

4 CONCEPT GENERATION

4.1 *Full System Concepts*

These full systems are the initial concepts considered. for the reasons stated, they were either altered or rejected entirely. All of these plans were viable options, however they simply weren't ideal.

4.1.1 Full System Design #1: Row Powered Vehicle

This design was inspired by a row machine found at a gym. It uses a simple flywheel system with a rope attached to a handle. The user pulls on the rope to spin and add power to the flywheel and axles. As the flywheel gains speed it carries momentum, pushing the vehicle forward for longer amounts of time than usual. The pull rope will be connected to a spring system to retract it with very minimal user effort.

4.1.2 Full System Design #2: Combined Row and Pedal Propulsion

Originally, the dual powered system was driven by a flywheel, and a pedal drive. These two drives were designed to both go to a common output shaft. This design would function using a clutch to engage and disengage the flywheel from the drives. to ensure that the rotation from the row and the foot pedal are matching, there would be a 1:1 gear mesh between the pedals and the output shaft. The issue with this design is the common output shaft. The reason a common output shaft is bad is that whenever the flywheel is being powered up with the clutch engaged, the chain to the foot pedals is spinning. While this allows for the foot pedals to drive the flywheel as well, it means that when the hand crank is not being used, that chain is then spinning. Either way, one method involves moving more mass, over more parts, leading to faster fatigue times, and a generally lower efficiency system. By making the foot pedals go directly to the drive axle, and the hand crank to the flywheel, these issues are mitigated.

4.1.3 Full System Design #3: Lean Bike

The design is inspired by motorcycle racing, which reduces drag by reducing the friction between the human body and the air. The design uses the movement idea of leaning over and climbing, and the rider lies on the seat and pedals with both feet to provide power. Hold the front grip with both hands and control the direction by rotating it. This design reduces the resistance of the human body and air, and can provide greater power.

4.2 *Subsystem Concepts*

These subsystems are all designs that were considered for implementation into our propulsion system.

The weighting, or validity of use was based primarily on efficiency. Secondly considered, was how easy or difficult it would be to implement the subsystems into the entire system. Ultimately the most usable subsystem would be later chosen for each task. Though they are similar to existing concepts, they differ in most cases by the way they are implemented into our propulsion system, rather than existing as stand alone components.

4.3 *Subsystem #1: Clutch System*

4.3.1 Design #1: Centrifugal Clutch

A centrifugal clutch would passively operate, outside of the user's control, to supply power from the flywheel to the output shaft, and thereby the rear wheels. This would allow the user to not have to actuate it manually, however it also means that its engagement is out of the users control, which could be dangerous. This clutch style would also not operate well at low speed, making it difficult to employ on the HPV. to get it to operate, the angular velocity would be far past what would be safe for the flywheel to be spinning at.

4.3.2 Design #2: Conical Friction Clutch

The conical friction clutch design would yield high performance for a clutch, due to increased friction surface area, and be manually controlled by the user. The downside to using a conical friction clutch is that it would be more labor intensive to machine, or more expensive to buy.

4.3.3 Design #3: Jaw Clutch (Square or Spiral)

While a jaw clutch would provide immediate output from flywheel to output shaft, this design would be uncomfortable for the user upon engagement, as well as rough on the fasteners and other drivetrain components.

4.3.4 Design #4: Standard Friction Plate Clutch

This design is not as effective as a conical friction clutch, in the same amount of space, but can be sized up to have the same surface area. like the conical friction clutch, it can be manually actuated, as well as providing a smooth, even engagement.

4.3.5 Design #5: CVT (Continuously Variable Transmission)

The CVT style transmission was considered as an option, as it would not require the user to manually accentuate the clutch each time. The issue with this system is that it would not be very efficient in such a low power setting. Due to the belts that allow a cvt to operate, as well as the multiple roller weight systems, it would be hard to get the cvt to reliably engage at the low operational speeds of an HPV.

4.4 Subsystem #2: Flywheel

4.4.1 Design #1: Rim type

By positioning the mass to the outer edge of the flywheel, such as ring or hoop, the moment of inertia is a value twice as big, as if it were a standard flywheel of the same weight. The downside is that it will have less momentum than a standard flywheel of the same mass, operating at the same output, meaning that it is less usable due to having a lower speed. it should be noted that at high speeds, rim type flywheels will burst at a lower speed than a disk type, in the same setting.

4.4.2 Design #2: Disk type

While requiring a higher angular speed, due to a reduced moment of inertia when compared to the ring style, this is a more usable design. This flywheel can be directly implemented into the clutch system, and maintain a higher momentum at the same weight and output power of a ring style flywheel.

4.5 Subsystem #3: Hand Crank/ Rowing Mechanism

4.5.1 Design #1: Pull Cord

The pull cord mechanism would rely on a cord wrapped around a central pulley on a shaft. This would take the linear pull and translate it into rotary motion, thereby spinning our output shaft. This design would require a return spring to retract the cord, leading to reduced efficiency.

4.5.2 Design #2: Rack and Pinion

The rack and pinion design would be elegant and strong, and could be very specifically tailored to the exact needs of the system. Using the rack and pinion system would require a track system however, and would have more moving arts than the other systems considered, making a more failure-prone system, that weighs more and is less efficient, as it too would need a return spring, or a heavily sprung ratcheting pinion to allow for return to initial position.

4.5.3 Design #3: Roller Chain and Sprocket

The roller chain and sprocket is a robust design, requiring only two pivot points, one of which being a freewheel, to operate. This will allow for easy return to initial position, with minimal work required, and no inhibition of efficiency on the power stroke.

4.6 Subsystem #4: Speed Sensors

4.6.1 Design #1: Hall Effect Sensor

HE sensors are robust and can withstand wear since they have no moving parts. HE sensors are compatible with high strength magnets to increase the range of the sensor. Hall Effect sensors are low cost and easy to procure, they are also readily made to connect to a board. This design would be the most efficient to implement in our system.

4.6.2 Design #2: Reed Switch

Reed Switches are cheap, simple, and easier to implement than HE sensors. However, due to the moving parts inside a reed switch they are more prone to wear and breakages, as well as false readings. This design should still be sufficient enough for our system but is not the best choice.

5 DESIGN SELECTED – First Semester

This section contains information on the design selected, and a brief introduction to the changes that have been made since the first semester. Along with a general description of the design, in this section we will discuss all subsystems of the design as well as the engineering calculations that were made in order to ensure the safety of the design.

5.1 Design Description

This design contains multiple subsystems which work together to allow the vehicle to function properly and meet all the customer and engineering requirements. Some systems required in depth calculations in order to ensure that they would work properly. The following subsections describe the subsystems of the HPV. All subsystems were modeled in a 1:6 scale prototype shown in Appendix C. The full system design can be seen in appendix A1.

5.1.1 Subsystem 1: Clutch Assembly

The clutch system includes a friction clutch plate as well as a 1:1 gear ratio. The clutch plate will be pressed against the flywheel to transfer energy from the flywheel to the rear axle or vice versa. The gear ratio is necessary in order to reverse the rotational direction so that it is spinning the same direction as the axle. All rotational motion is transferred via chain and sprocket combinations. A design tool was created to calculate the required size of the clutch plate based on flywheel calculations shown in Appendix D. Calculations and material selection were based on equations and tables found in Shigley's Mechanical Engineering Design [23].

After the first semester, the gear system was removed. This was due to a change in scope, which then allowed the flywheel to connect directly to the rear axle, so a change in direction was no longer necessary. A clutch plate has been chosen by recycling parts from a pit bike clutch, and a fixture for the clutch plate has also been designed. A sprocket connects to the back of the clutch plate fixture in order to allow the clutch to be connected to the rear axle.

5.1.2 Subsystem 2: Flywheel

The Flywheel is the energy storage component of the HPV, also shown in Appendix G. The flywheel needs to be able to store as much energy as possible in order to apply the energy when the driver needs a boost. The flywheel was designed to connect to a row bar, but that portion of the design has been removed since last semester.. It will be mounted on bearings to allow it to spin freely with minimal losses due to friction. A flywheel design tool was created to calculate the size and material of the flywheel as shown in Appendix E. Calculations and material selection were based on equations and tables found in Shigley's Mechanical Engineering Design [23]. Bearings were chosen

5.1.3 Subsystem 3: Row Bar

After the start of the new semester, this part of the design was negated due to a change in scope. Here is the original design description. The row bar is the main source of power input for storage purposes. It needs to be a minimum of 2'-0" wide and tall enough to reach the user without being uncomfortable while still allowing maximum power input. At the bottom of the row bar there will be a free-wheel sprocket allowing rotation only in one direction. This allows the user to put power into the flywheel while pulling, and then to easily push the bar forward on the return stroke. After the start of the new semester, this part of the design was negated due to a change in scope.

5.1.4 Subsystem 4: Pedals

The pedals are the most simple and most crucial part of the design. Originally the design was to be a simple "copy" of bicycle pedals, but the team realized during prototyping that that would not work with the selected layout. The pedals will be similar to those found in a paddle boat. They will be a continuous bent rod with foot sized pedals in two locations, to work similar to a crankshaft. A sprocket will be attached on the bar, to the side of the pedals, and a chain will be extended to the rear axle of the vehicle.

As the driver pedals, the vehicle moves forward, quite like a bicycle.These can be seen in Appendices A and B.

5.1.5 Subsystem 5: Speed Sensors

Hall effect sensors will be positioned next to the flywheel and the rear axle. Interrupt signals from the HE sensor will be sent to the Raspberry Pi and converted into RPM, and then further converted into the relevant display metrics- MPH, and Energy Stored in the Flywheel (J), and flywheel efficiency (%). It will also be displayed to the driver on a large LCD with a user interface displaying speed, energy stored, and flywheel efficiency, as well as notifications of when to slow down and when to engage the clutch. All of this will be powered by a 9v battery kept in the electronics housing. See Appendices F and G, as well as Appendix J for relevant code snippets.

5.2 Calculations

5.2.1 Subsystem 1: Clutch

To aid in designing a clutch quickly and efficiently, a design tool was made in excel, see appendix D. One way to calculate the total force is by using the following equation.

$$F = P * A$$

Equation 1: Force Equation

Where P is the total pressure applied and A is the surface area. F has been classified as the application force available through the human grip strength.

$$F_{max} = \frac{F_g * sin\theta_{max} * L}{cos\theta_{max} * h}$$

Equation 2: Max Force Applied

The max force applied can be found using equation 2 above. F_g is the grip strength, h is the height of the lever above the handle and L is the length of the lever. Using this equation we can find the max force applied on the clutch. With that force, friction force is calculated by multiplying the force by the friction coefficient. This ultimately was unknown for the chosen clutch plate, but was useful in early calculations. From the friction force we were able to estimate a torque using the following equation. D_o and D_i are the outer and inner diameters of the clutch plate respectively.

$$T = \frac{F_f}{4} * \frac{D_o + D_i}{4}$$

Equation 3: Torque

5.2.2 Subsystem 2: Flywheel

The flywheel design tool was the most helpful design tool this semester. Using this we were able to roughly estimate the total energy of the vehicle, energy transferred to the flywheel, and total energy transferred back into the vehicle. With a target value of 600J stored and 15% efficiency, this design tool was used to find an optimal flywheel diameter and thickness. This was done using equations 3 and 4 below. A ratio of 5:1between the clutch and rear axle was used in the design tool, though this was never able to be achieved in the final design due to lead times.

$$E = .5 \bullet I \bullet rps^2$$

Equation 4: Flywheel Energy Storage

Where I is inertia and the equation is as follows:

$$I = k \bullet M \bullet R^2$$

Equation 5: Inertia

Where k = 0.5 (inertial constant), M = 20.54 (mass), R = 0.3302 (flywheel radius).

5.3 Prototyping

Near the end of the summer semester, the team designed a small scale "prototype" of the design up until that moment. It was not a working prototype, but more of a proof of concept. This can be seen in appendix C. This design completely changed however at the beginning of the fall semester due to a change in client and therefore scope. The new design was never prototyped, but small components were 3D printed to ensure that they would fit correctly with the rest of the assembly (see figure below).

Figure 3: Friction Plate Fixture - Proof of Concept

6 IMPLEMENTATION – Second Semester

This section will discuss the implementation of the past few weeks and show the problems encountered. The team will make changes to the design during the implementation process, including engineering calculations and revised parts drawings when necessary. The content contains detailed information about all iterations of the design, including failed iterations or minor prototypes, as well as the reasons for failure and improvement measures. In the process of improvement, it will explain in detail why and how to improve, and provide reasons and solutions for improvement.

6.1 *Design Changes in Second Semester*

This section will briefly describe what the original design was and how to make changes to this particular component or subsystem. The content will provide the purpose and reason for the change, and give a solution. Different iterations are responsible for different research directions.

6.1.1 Design Iteration 1: Retrofit Design to New Vehicle

At the start of the second semester, our team received a new client and a new scope. This scope included taking our system and adding it to an existing Human Powered Vehicle. In order to do this, some big changes needed to be made, and some parts had to be added to the design. The vehicle chosen to be retrofitted to was a nearly complete HPV, but it needed some work. The new design included a mounting system for the propulsion system, an intermediate shaft to connect the motion of the wheels to the flywheel, and a screen mounting system. The rowing system, as stated previously, was removed from the design. This was done mostly due to a lack of space and functionality on the new vehicle.

6.1.2 Design Iteration 2: Removed Intermediate Shaft

Nearing the completion of manufacturing, the team realized that the design could be simplified further by removing the intermediate shaft, as long as the clutch/flywheel system was mounted in the correct position. For this reason alone, the intermediate shaft was removed further simplifying the design and speeding up manufacturing and assembly. This design can be seen in appendix A2.

6.1.3 Design Iteration 3: Change in Flywheel Support

While the flywheel was originally intended to be 12 inches in diameter, and an inch and a half thick, it quickly became evident that it would not be feasible. Acquiring the material for such a flywheel would be difficult, and machining it would not be possible at NAU. To remedy the issue, the team planned to make the flywheel modular, by stacking up to 8, 12”x .25” disks on a main carrier in order to create a flywheel. By doing this, the stock would be more readily available and easier to machine. In the end, the team decided to revert back to a single plate flywheel, due to cost and simplicity of manufacturing. This single plate design required two carrier bearings and was 10”x1”.

6.1.4 Design Iteration 5: Change in Board choice and Display

We decided to change the board from a Raspberry Pi to an Arduino due to price and availability. Our team already had an Arduino available from an Elegoo kit purchased (with recommendation from our client) in the first semester. We determined that purchasing an additional board would be an unnecessary expense. Additionally we had to go with a smaller display than originally intended. The purchase for the 128x64 LCD screen was denied and the teammate assigned to completing this subsystem was not informed of this until it was too late to purchase and receive a screen of this size from a different supplier. The team decided to use the 16x2 screen that came in the Elegoo kit purchased last semester and made changes accordingly to the user interface.

7 RISK ANALYSIS AND MITIGATION

The FMEA table is a key part of the team for the reasonable design of the system. The potential threats and failures are listed in sequence and their hazards, severity, and probability of occurrence will be scored. In this section, we will elaborate on whether the system has potential failures and their effects. The cause of the fault and the hazard caused are presented in the FMEA table.

7.1 *Potential Failures Identified First Semester*

This section will show the FMEA form made last semester. We listed some potential threats and possible design failures. In the shortened FMEA, sorted according to the RPN value, we can get the top ten faults. One of the most important faults is the overheating of the clutch, because during the braking process, the clutch and the flywheel forcibly contact friction and cause the flywheel to stop. In this process, a lot of heat will be generated- causing the clutch to overheat- thereby affecting the efficiency of the clutch. If the clutch is damaged as a result, the best solution is to replace it with a new one.

Table 4: Top 10 Failures of first semester

Part # and Functions	Potential Failure Mode	Potential Effect(s) of Failure	Potential Causes and Mechanisms of Failure	RPN	Recommended Action
13	Clutch overheating	May cause damage	cannot be disengaged	405	evaluate clutch assembly, replace parts if necessary
1	Chain stuck	The vehicle won't move	not enough lubricant	384	lubricate chain
12	Flywheel overheating	May cause damage	clutch engaged to long	360	evaluate clutch assembly
11	Pedal off	The vehicle won't move	crash, wrong use	320	Prepare spare parts
13	Clutch damaged	Vehicle out of control	too much use, foreign obje	315	evaluate and replace clutch plate
10	rod deformation	May cause damage	tension, compression, torq	288	evaluate rod. replace if necessary
9	wheel blowout	Vehicle out of control	Sharp on the road, pothole	256	relpace innner tube and tire if necessary
9	wheel overheated	May cause damage	0	240	0
6	sprocket spins too slowly	Power can't transmit	incorrect ratio	240	0
8	Seat overheating	May cause discmfort	friction from flywheel	224	evaluate flywheel mount. Remount if necessary

The principle of overheating of some parts caused by the brake is the same as the overheating of the clutch, so I will not repeat it in the following. Chain jam is the second most common fault, and the chain will jam for many reasons. Without adding lubricating oil, the rider riding too fast can also cause the chain to jam. The solution is to add lubricating oil or replace the stuck chain part.

The most likely cause of the pedal to fall off and the deformation of the rod is collision. In the process of riding, collision is inevitable, from distortion to car crashes and deaths are all possible tragedies. The best solution to a collision is to observe the vehicle and road conditions at all times while riding to avoid collisions. A tire blowout is also a common bicycle problem. The main cause may be sharp objects on the road, or high temperature of the wheels causing gas expansion. To avoid going out in hot weather, our team also prepared spare wheels for easy replacement.

7.2 *Potential Failures Identified This Semester*

The project goals were redesigned this semester, and the overall goal was transformed into the design of a propulsion system with energy recovery. In this process, the importance of the flywheel has been greatly enhanced, and the new design and mount connecting the flywheel will be reassessed for the importance of failure. Compared with the previous semester, the team also added a circuit component system to test the efficiency of the flywheel and to detect the speed of the flywheel. We also identified the electrical system as a point of failure as jostling can always cause unsoldered wires to come out, short circuits, or breakage of the board. Under these brand-new changes, the FMEA form was re-made, and the changes were highlighted. As can be seen from the new table, the importance of the flywheel ranks first.

Table 5: Top 10 Failures of second semester

15	Flywheel canno	Power can't trar	10	tension,	8	3.2	9	720	
15	Flywheel deforr	Power can't trar	9	tension,	8	3.3.	8	576	
15	Flywheel overh	Vehicle out of c	8	too much torque	7	3.2	8	448	
13	Clutch overheat	May cause dam	5	cannot be diser	9	3.7	9	405	evaluate clutch
17	The circuit does	May cause dam	7	Connection erro	8	3.4	7	392	
12	Flywheel overh	May cause dam	5	clutch engaged	9	3.3	8	360	evaluate clutch a
1	Chain stuck	The vehicle wo	6	not enough lubr	8	3.2	8	384	lubricate chain
11	Pedal off	The vehicle wo	8	crash, wrong us	8	3.3	5	320	Prepare spare p
13	Clutch damage	Vehicle out of c	9	too much use,	7	3.7	5	315	evaluate and
10	rod deformation	May cause dam	6	tension,	8	3.6	6	288	evaluate rod.

7.3 *Risk Mitigation*

Under the brand-new propulsion system, the team members ranked the importance of each subsystem and listed possible potential failures. In the new semester, team members shifted their focus to the energy recovery of the propulsion system, which makes the potential failure of the flywheel and clutch more important. It can be seen from the analysis in the above figure that several key faults of the flywheel are in the forefront, which led the team to pay more attention to its safety when redesigning the flywheel system.

A spring system was added to the new design. In order to avoid excessive torque caused by too fast rotation, the team added a spring in the design to cushion the huge torque when the flywheel rotates. This basically eliminates the deformation of the flywheel caused by the rotation speed and the potential failure of the flywheel to rotate too fast.

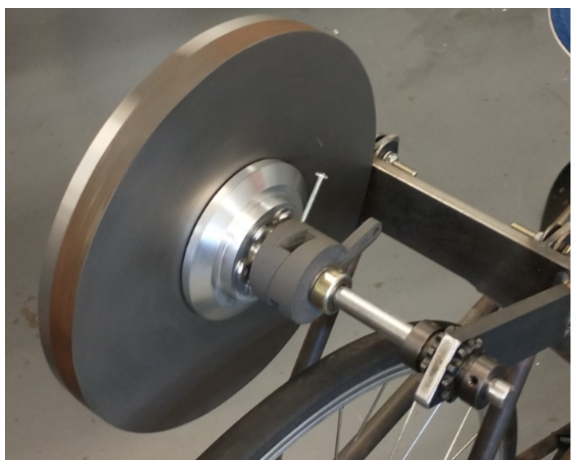

Figure 5: Clutch Subsystem Design

In the clutch design above, there is a jaw design, which will provide a certain buffer space for the flywheel when it rotates. This is a very good design. The flywheel is basically free from serious failures and damage during operation. We adopted a new spring and jaw design to reduce the potential failure of the flywheel, but this has brought new failures. The material hardness of the spring and jaw is not very high, and it may be damaged during the continuous expansion and contraction process. But relative to the possibility of damage to the flywheel and the risks it brings, the team members adopted a new design. Because new potential faults are less likely to occur and are less dangerous.

To mitigate board breakage and wire shortage and disconnection we decided to make our electrical system more robust . During system testing of the completed electrical setup in the housing we discovered that in the installation process a wire shorted out causing dimming of the lettering on the screen and digital read errors associated with the LCD connection wires. We mitigated this by tacking down the board, replacing round-pinned jumper wires, replacing wires that came with the Elegoo kit with more robust wires with soldered square leads, and using appropriately color coded wires instead of the rainbow jumpers for ease of use and for any future repairs.

8 ER Proofs

This section will discuss the proof of engineering requirements developed by the team. For each project requirement certification, it will describe in detail how each project requirement is met. Including the test methods and conclusions used. Provide evidence to prove the reliability and robustness of the system for each engineering requirement. The content will clearly clarify how the team meets engineering needs and how to improve the system to meet design goals and customer needs.

8.1 *ER Proof #1 – Energy Storage*

The first, and most prominent engineering requirement is energy storage. The goal was to be able to store roughly 600J of energy. This has been satisfied by adding a large flywheel to the design which will store mechanical energy with minimal losses. To prove that this has been satisfied the team plans to test the vehicle's clutch system in order to find out how much energy can be stored. We will calculate this using equations 4 and 5 (see section 5.2.2). This has already been predicted to be met using the flywheel design tool shown in appendix E. The estimated amount of energy stored is roughly 750 J which is well above our design requirement. Testing has not yet taken place, as the design has not been completed upon the writing of this report. The team expects to see good results during testing.

8.2 *ER Proof #2 – Efficiency*

The efficiency of the vehicle will be tested much like the energy stored. The energy of the vehicle will be gathered using the following equation:

$$KE = \frac{1}{2}mV^2$$

Equation 6: Kinetic Energy

The energy of the vehicle will be gathered at a given speed, then after the clutch has been engaged, the vehicle stopped, and the clutch re-engaged, the energy will be gathered again. This was simulated in the flywheel design tool in appendix E. The estimated efficiency of the vehicle was calculated to be roughly 13.6%, which is not quite at the 15% needed, but fits within the 2.5% tolerance. Further testing is required to validate these calculations, but this has not been performed upon the writing of this document.

8.3 ER Proof #3 – Max Speed

The max speed deemed safe to operate the vehicle at is 20MPH. Our robust solution to display the speed and warnings to the user when they approach the max speed was first implemented through an equation which takes the interrupts provided, converts it to RPM, and then converts it to MPH (code shown in next section). Through an If-Statement, we can let the user know if they are approaching the max speed. We tested this to ensure this output to our display by testing edge cases such as spinning the wheel at 18-19MPH and 21-22MPH. This test successfully proved our completion of this Engineering Requirement. See Appendix K.

8.4 ER Proof #4 – Display Metrics

We implemented our display metrics (displaying speed [MPH] and flywheel energy storage [J]) through modular functions (Appendix J) and using the Flywheel Energy Storage Equation (section 5.2.2). We tested out results (detailed in section 9.1.2) against a tachometer to ensure our algorithm is correct. Additionally we tested base cases such as speed and energy storage displayed at 0MPH, 1MPH, and 20MPH and detected no anomalies. Lastly, we tested edge cases such as quickly changing speeds and found that our display had about a 1 second delay due to the refresh rate of the screen. Despite a slight delay we found that our electronic and programmatic subsystem satisfies our engineering requirements.

8.5 ER Proof #5 – Usable Energy Threshold

This engineering requirement was based on a stretch goal. The team wanted to be able to display when it would be more efficient to engage the flywheel. Unfortunately, this was not able to be achieved due to late manufacturing and assembly caused by lead times. This would have been done by evaluating the total energy in the vehicle and comparing it to the total energy in the flywheel. If the total energy in the flywheel exceeded that of the vehicle by 300 J, the screen would display to engage the clutch.

8.6 ER Proof #6 – Budget

The calculation of the engineering requirements of the budget uses a simple mathematical model, and the team has agreed with the mechanical engineering department and the instructor for each purchased product and use. Reimbursement is used for the purchase of some materials and originals. The overall budget is $1500. Since the vehicle frame is not designed and some raw materials are from Machine Shop, the total budget is $487.82, which fully meets the engineering needs.

Table 6: Bill of Materials and Budget

Bill of Materials

Team				HPVCP			
Part #	Part Name	Qty	Description	Material	Dimensions	Cost	Link to Cost estimate
1	Elegoo Kit	1	Electronics kit	Various		$59.00	https://www.amazon.com/gp/product/
2	Hall Effect Sensor US1881	3	Latching	Steel	TBD	$10.78	https://www.sparkfun.com/products/9
3	Backlight Graphic LCD	1	Display	Various	75x52.7mm	$23.95	https://www.sparkfun.com/products/7
4	N24 Neodymium Disk Magnet	3		Nickel-plated neodymi	0.250"* 0.200"	$9.75	https://www.magnetshop.com/neodym
5	Manual Clutch Set	1	Clutch	Carbon Steel		$40.39	https://www.amazon.com/GOOFIT-Hea
6	Radial Ball Bearing	1	Bearing	Steel	Outside Dia.1.37	$9.92	https://www.grainger.com/product/TRI
7	Radial Ball Bearing	4	Bearing	Steel	Outside Dia.1.12	$25.80	https://www.grainger.com/product/TRI
8	Thrust Bearing	1	Bearing	Steel	Outside Dia.1.56	$7.28	https://www.grainger.com/product/INA
9	Roller Chain Plate sprocket	2	sprocket	Carbon Steel	24 Teeth 1/2" Bo	$32.48	https://www.amazon.com/KOVPT-Rolle
10	Keyed Shaft	1	Shaft	Steel	1/2" X 36"	$23.00	https://thebigbearingstore.com/1-2-x-
11	11 Tooth Sprocket	2	sprocket	Carbon Steel	11 Teeth	$20.74	https://thebigbearingstore.com/11-too
12	Low-Carbon Steel Disc	1	Flywheel	Carbon Steel	10'' 1''Lg	$76.87	https://www.mcmaster.com/7786T292
13	Thrust Bearing	1	Bearing	Steel	0.5 in Bore	$5.08	https://www.grainger.com/product/INA
14	Rear Disc Hub	1	hub		7.5 x 4 x 3 inche	$59.95	https://www.amazon.com/SHIMANO-F
15	Screen mount	1	3D Print	PLA		$21.42	
16	friction plate fixture	1	3D Print	PLA		$6.21	
17	spiral jaw	1	3D Print	PLA		$19.20	
18	fixture	1	3D Print	PLA		$36.00	
19							
20							
		Total Cost Estimate:				$487.82	

9 LOOKING FORWARD

This section will show the client detailed information about the team's completion of the project and improvement of the project. The content will include observations of the entire project, such as how to improve the experience of future teams or future customers and how to meet customer needs. This section will be divided into two sections, future test procedures and future work.

9.1 *Future Testing Procedures*

This section outlines future tests that should be performed to ensure that the vehicle meets all engineering requirements outlined in section 2.2. These tests only include those which have not been completed prior to the writing of this document.

9.1.1 Testing Procedure 1: Energy Storage/Efficiency

Testing Procedure 1: Objective

This test, as stated in sections 8.1 and 8.2, will test the efficiency of the energy storage system as well as the maximum energy able to be stored in the flywheel. The steps for this test are as follows:

1. Measure vehicle speed using data collected visually from the display screen.
    a. Record Data
    b. Calculate total vehicle kinetic energy
2. Engage clutch to power flywheel
3. Bring the vehicle to a stop
4. Measure flywheel angular velocity
    a. Using sensors
    b. Double Check with tachometer
    c. Record - This helps to meet ER 1.
5. Engage clutch to remove power from flywheel
6. Measure vehicle speed as in step one
    a. Record Data
    b. Calculate total vehicle kinetic energy
7. Calculate efficiency by dividing final KE by initial KE
    a. Record - This helps to meet ER 2.
8. Repeat steps at different speeds
    a. Increments of roughly 5 mph

Testing Procedure 1: Resources Required

The only resource required for this experiment outside of that which is already included in the vehicle design is a tachometer to double check the flywheel velocity. This however, is not necessary if the sensors have been properly calibrated.

Testing Procedure 1: Schedule

This test should only take place after the entire vehicle has been assembled and the sensors and display have been calibrated correctly. Expect to spend roughly 1-2 hours on testing, leaving time for trial repeats if necessary. This is a relatively simple test, and should not take long if done by a group of 2-3 people.

9.1.2 Testing Procedure 2: Electronics and Metrics

Testing Procedure 2: Objective

The objective of this test is to determine that the electronic subsystem (arduino, screen, and hall effect sensors) are working properly and the equations determining MPH and Flywheel energy storage are correct.

First, the tester should turn on the Arduino via the button on the front of the housing while stationary. The display should be lit blue and show MPH and Energy Stored as 0.00. To test the functionality of the speedometer, lift the frame of the rear end of the vehicle, spin the rear tire, and observe that the LED on the Hall Effect Sensor will light up red when the magnet on the wheel passes by. Compare the speed on the screen with the speed taken by an accurate tachometer. This testing procedure will verify the speedometer engineering requirement.

To test the "Maximum Speed of 20MPH" engineering requirement repeat test one, but spin the rear wheel until the tachometer registers a speed of 20MPH. When the speed approaches 20MPH the screen should display "Slow Down" in place of where the speed used to be displayed.

Next the tester should spin the flywheel and again observe that the Hall Effect LED indicator should turn red for each revolution of the flywheel. Test the speed of the flywheel with an accurate tachometer and convert it to rps, and then plug it into the energy storage equation or use an appropriate calculation tool: see section 5.2.2 for the equation. This testing procedure will verify the flywheel energy storage display metric engineering requirement.

Additionally, testing was performed on the code itself by the programmer. Testing included using assert statements to test the validity of the equations by forcing the expected result with a given input. Assert testing was also done on Hall Effect and LED outputs.

Testing Procedure 2: Resources Required

This testing procedure will require a well lighted area large enough to house the HPV, an accurate tachometer, more than eight square feet, two people- one to hold the frame and one to work the tachometer, a calculator, and a flywheel energy calculation tool (if available) or the equation provided above.

Testing Procedure 2: Schedule

This testing procedure should not take more than 10 minutes to complete and can be completed at any time and any tools that may need to be procured (such as calculators and tachometers) should be retrieved ahead of time.

9.2 *Future Work*

In the future, if this team or another team were to continue with this project, the next step would be to refine the existing design. This design is compact and simple as it stands, but there is always room for improvement. It would also be important to add safety features such as a roll cage and a cover for the flywheel and clutch system. These features, along with all the other features that were included in the preexisting design, will make this vehicle very safe for the operator.

Testing results that have not been collected at the writing of this report may show that some ERs were not met. If this happens, more iterations will have to be made on the design. The most likely components to be modified are the sprockets. The size of these could change in order to adjust ratios or derailers could be added to allow for increased energy flow in a chosen direction, either to or from the flywheel. The vehicle that was provided has broken steering, and thereby needs to be repaired, however the drivetrain is salvageable. This will be a very important future step in making this vehicle functional and safe.

10 CONCLUSIONS

In summary, the HPVCP team creatively proposed a novel and unconventional design of a human powered vehicle propulsion system that can recover excess energy and store it. The collected energy can be returned to the vehicle drive system when needed. According to the actual test and the theoretical design of the flywheel, the team can basically complete the customer's needs and engineering design requirements. The maximum speed of the flywheel is less than the designed 20mph, but this also improves the efficiency of energy storage. The budget fully meets the engineering needs, and it only costs less than $500 to install a new energy recovery propulsion system for existing human-powered vehicles. So far, we have completed the design of a brand-new propulsion system and produced the first prototype, putting the regenerative energy storage system, display and electronic self-driving car system into practice.

10.1 Reflection

This section of reflection will discuss how the team applied engineering design principles to our design solutions. Engineering design needs to meet customer needs and engineering needs. The team used a large number of engineering models such as HoQ, Design Matrix, etc. to improve the design of the entire project. The initial project goal was to design a novel propulsion system, and the final goal of this semester was to design a brand new energy recovery system for the existing human powered vehicles. For the team’s design goals, public safety and environmental sanitation are the most important design factors. The team will design a safe and environmentally friendly solution to replace the existing one. In the existing prototype design, the team added the design of springs and clutches to ensure the safety of the flywheel. The entire energy recovery system also greatly improves the efficiency of energy reuse, and increases the interest and promotion of existing human-powered vehicles. If the existing energy recovery system can improve the efficiency of the bicycle, it will be of great help to environmental protection.

10.2 Post Mortem Analysis of Capstone

10.2.1 Contributors to Project Success

The team’s purpose was not completed as originally stated due to a change in client and scope. The team was able to accomplish the goals set forth at the beginning of the project, in the summer term to some degree however. The new client’s requests however, were completed. The goals were initially pretty broad, and focused on overall group success and participation, being that the original client, instructor, and sponsor, had no clear requirements or project needs. There were many parts of this project that contributed to its success. The ability for members who were in person to meet up and work together was the biggest contributor of all, as these members were the driving force of the project.

As a team, we all learned more about machining and designing parts that are easy to machine. This will be useful in our careers in the future, and the knowledge gained was used in the manufacturing and assembly of the final product. We also learned, in a rather unfortunate way, the importance of planning for lead times. The team worked well together for the most part. When the team was able to split up work evenly, everything went very smoothly. Designs and calculations were carried out well until the end and were very helpful in designing, manufacturing, and testing.

10.2.2 Opportunities/areas for improvement

The biggest struggle amongst team members was accountability. Though the team charter defined an environment that required equal participation, and accountability was to be enforced by peer evaluations, this did not go so well. Because the beginning of the semester required a large reevaluation of the project, there was a need for mass team participation. Though there were 5 team members, not all contributed equally throughout the project. The initial redefining of the project allowed for the team leader, and documents manager to distribute tasks to other members based on ability, and all members participated. This worked well because all members had certain strengths, such as specializing in CAD, analysis, manufacturing, or software, and it promoted group activity.

As the semester continued, some members neglected their responsibilities and administrative roles because they got comfortable with the leader and documents manager being the driving force of the project, and simply waiting for tasks to be completed, rather than taking an interactive role. because not all members participated in person, there was not the same sense of urgency and accountability for all. Though the team planned for the peer evaluations to be an inspiration to not neglect duties, this tactic failed to keep all members honest, despite encouragement from other team members.

Past the personal aspects of the project, the team had trouble with lead times throughout the entire semester due to the large period spent redefining the project. Once the scope of the new project was clarified, the design process had to begin again, and this led to delays getting to the manufacturing process. Once the manufacturing processes were able to begin, the issue of lead times began to play a bigger factor than before, as each part integrated into the system depended on the next. This led to Team members having to purchase parts on his or her own, and waiting for reimbursement due to the school taking so long, however due to neglection of administrative rolls, parts were not always ordered.

When the team was able to work around the manufacturing issues, it was brought up to the team leader was informed at the last minute that the vehicle that was being retrofitted was not allowed to be modified in any way. This was an unfortunate development, as the team's entire goal was to alter the vehicle in order to add kinetic energy recapturing capabilities. Because of this, in the final three days of manufacturing, a new mounting system had to be developed, and due to missing components, the propulsion system was also altered.

11 REFERENCES

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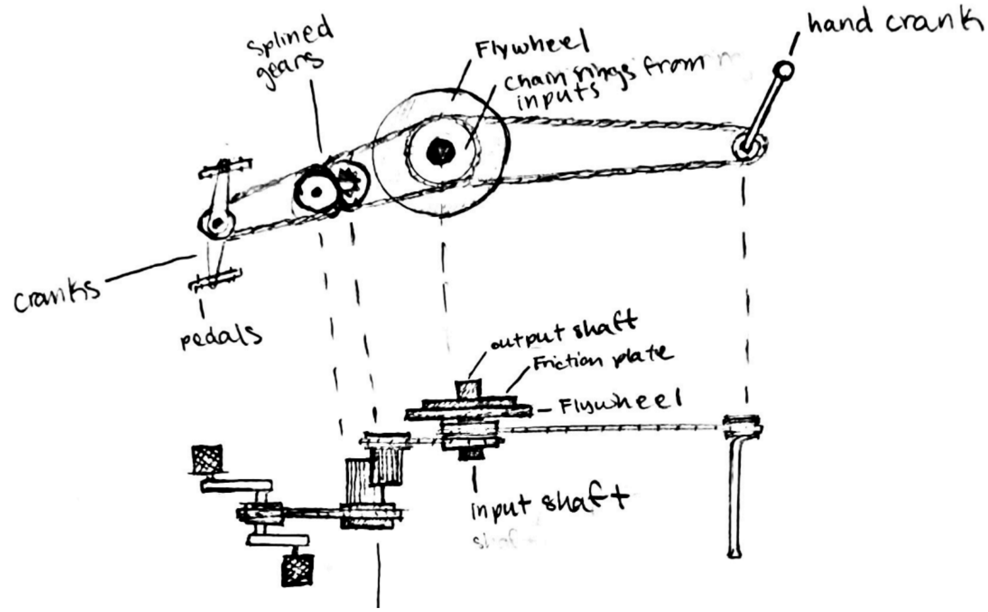
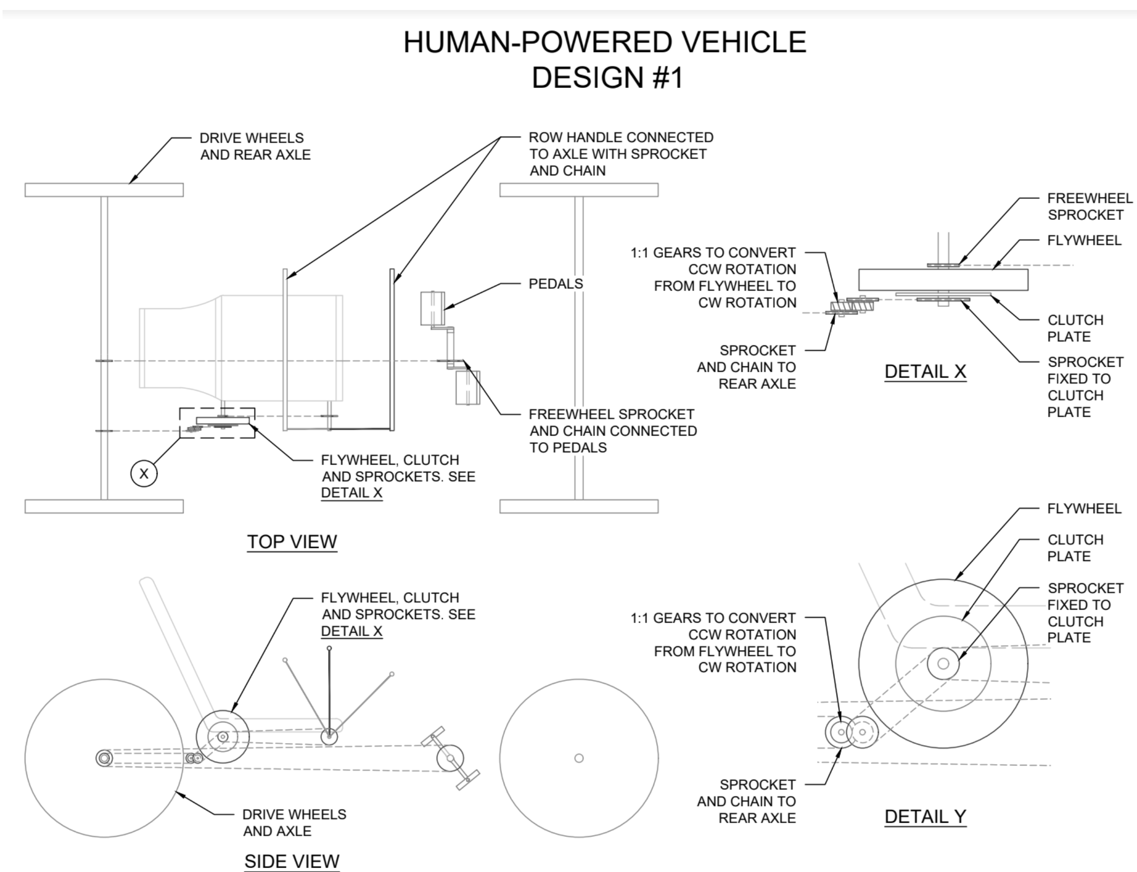
12 APPENDICES

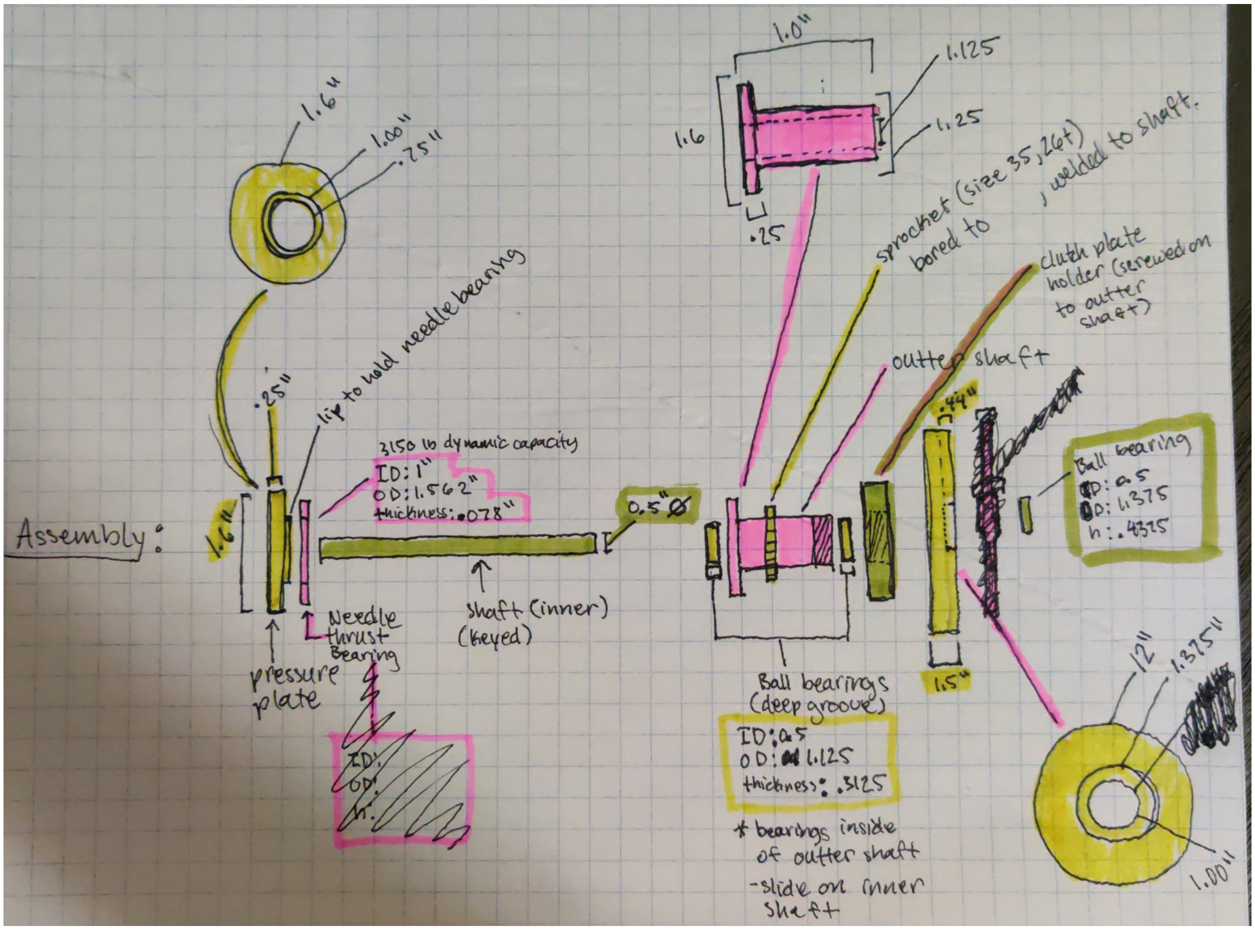
Appendix A: Complete design process

Appendix A1: Original Design





Appendix A2: Updated Design



Appendix A3: Final Design

Appendix B: FMEA sheet

Appendix B.1: FMEA Sheet of First semester

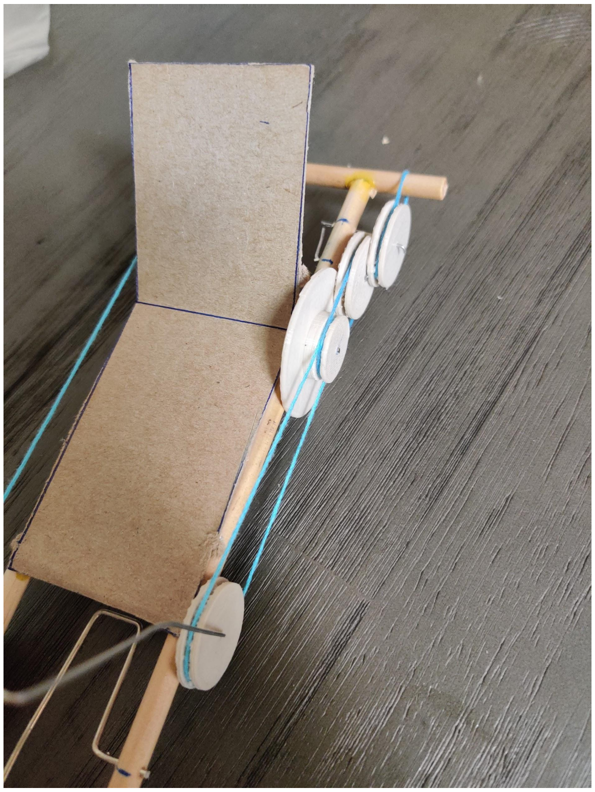
Product Name	HPVCP Team		
System Name			
Subsystem Name		Date	8/3/2021
Component Name			

Part # and Functions	Potential Failure Mode	Potential Effect(s) of Failure	Severity (S)	Potential Causes and Mechanisms of Failure	Occurance (O)	Current Design Controls Test	Detection (D)	RPN	Recommended Action
1	Chain break	The vehicle won't move	8	rusted chain	6	3.6	4	192	replace chain
1	Chain stuck	The vehicle won't move	6	not enough lubricant	8	3.2	8	384	lubricate chain
1	chain falls off	The vehicle won't move	9	Loose chain/sprocket	4	3.1	4	144	tighten chain, increase distance between sprockets
1	Friction overheating	May cause damage	4	not enough lubricant/too little clearance	7	3.2	8	224	lubricate affected area
1	chain is too long	May cause damage	3	too many chain links	3	3.2	6	54	remove chain links
2	Connection error	The vehicle won't move	6	Human error	5	3.2	4	120	
2	Easy to fall	The vehicle won't move	8	Wrong size	3	3.6	5	120	Prepare spare parts
3	Sprocket spinning too fast	May cause damage	5	incorrect ratio	6	3.1	7	210	
3	Sprocket tilt	May cause damage	6	crash	4	3.6	5	120	reset or replace sprocket
3	Cannot engage with the chain	May cause damage	7	impropper measurment	3	3.1	5	105	
6	sprocket spins too slowly	Power can't transmit	5	incorrect ratio	6	3.2	8	240	
5	Complex connection	May cause premature failure	6	Human error	4	3.2	4	96	
5	unalligned axis	The vehicle won't move	6		3	3.3	5	90	
8	Seat angle	operator uncomfortable/harmed	4	crash	6	3.5	8	192	remount the seat
8	seat falls	opperator injury	9	crash	2	3.3	7	126	remount seat. evaluate seat mounts. Replace if necessary
8	Seat overheating	May cause discmfort	4	friction from flywheel	8	3.2	7	224	evaluate flywheel mount. Remount if necessary
9	wheel blowout	Vehicle out of control	4	Sharp on the road, pothole	8	3.1	8	256	relpace innner tube and tire if necessary
9	wheel twist	Vehicle out of control	6	pothole, crash	5	3.1	6	180	replace wheel
9	wheel overheated	May cause damage	5		6	3.2	8	240	
9	Wheel rotation speed is inconsistent	Vehicle out of control	4	Human error	2	3.2	8	64	
9	wheel size is different	May cause damage	4	Manufacturing error	3	3.4	5	60	replace wheel
10	rod twisted	May cause damage	7	too much torque	6	3.6	4	168	evaluate cause of torque, replace if necessary
10	rod break	The vehicle won't move	9	tension, compression, torque, incorrect placement of weight, crash	5	3.6	2	90	replace rod
10	rod deformation	May cause damage	6	tension, compression, torque, incorrect placement of weight, crash	8	3.6	6	288	evaluate rod. replace if necessary
11	pedal cannot be rotated	Vehicle out of control	5	Pedal stuck	6	3.3	4	120	Prepare spare parts
11	Pedal off	The vehicle won't move	8	crash, wrong use	8	3.3	5	320	Prepare spare parts
11	Pedal deformation	May cause damage	4		8	3.3	5	160	
12	Flywheel overheating	May cause damage	5	clutch engaged to long	9	3.3	8	360	evaluate clutch assembly
12	Flywheel disengagement	Vehicle out of control	6		6	3.7	6	216	
13	Clutch overheating	May cause damage	5	cannot be disengaged	9	3.7	9	405	evaluate clutch assembly, replace parts if necessary
13	Clutch damaged	Vehicle out of control	9	too much use, foreign object	7	3.7	5	315	evaluate and replace clutch plate
14	Gears can't mesh	May cause damage	8	Human error	4	3.7	6	192	Prepare spare parts
14	Gear disengaged	The vehicle won't move	6		5	3.2	5	150	Prepare spare parts
14	Gear deformation	May cause damage	6	too much torque	6	3.2	6	216	reevaluate gear calcs. replace gears
14	Gear tilt	Vehicle out of control	4	crash	4	3.4	3	48	remount gear, replace if necessary
15	Screw fall	May cause damage	4	vibration	8	3.2	4	128	evaluate screw location for other damage. replace screw
16	Loose nut	May cause damage	3	vibration	6	3.1	5	90	evaluate nut location for other damage. replace nut
15	Screw is too short	Partially destroyed	5	wrong screw used	4	3.2	5	100	replace with correct screw
15	Screw is too large	Partially destroyed	5	wrong screw used	4	3.2	5	100	replace with correct screw

Appendix B.2: FMEA Sheet of Second semester

15	Flywheel canno	Power can't trar	10	tension,	8	3.2	9	720	
15	Flywheel deforr	Power can't trar	9	tension,	8	3.3.	8	576	
15	Flywheel overh	Vehicle out of c	8	too much torque	7	3.2	8	448	
13	Clutch overhea	May cause dam	5	cannot be diser	9	3.7	9	405	evaluate clutch
17	The circuit does	May cause dam	7	Connection erro	8	3.4	7	392	
12	Flywheel overh	May cause dam	5	clutch engaged	9	3.3	8	360	evaluate clutch
1	Chain stuck	The vehicle wo	6	not enough lubr	8	3.2	8	384	lubricate chain
11	Pedal off	The vehicle wo	8	crash, wrong us	8	3.3	5	320	Prepare spare p
13	Clutch damage	Vehicle out of c	9	too much use,	7	3.7	5	315	evaluate and
10	rod deformation	May cause dam	6	tension,	8	3.6	6	288	evaluate rod.
9	wheel blowout	Vehicle out of c	4	Sharp on the	8	3.1	8	256	relpace innner
6	sprocket spins t	Power can't trar	5	incorrect ratio	6	3.2	8	240	
9	wheel overheat	May cause dam	5		6	3.2	8	240	
1	Friction overhea	May cause dam	4	not enough	7	3.2	8	224	lubricate affecte
12	Flywheel diseng	Vehicle out of c	6		6	3.7	6	216	
14	Gear deformatio	May cause dam	6	too much torque	6	3.2	6	216	reevaluate
17	LED display fail	Unable to obtai	6	tension,	6	3.3	6	216	
3	Sprocket spinni	May cause dam	5	incorrect ratio	6	3.1	7	210	
8	Seat angle	operator uncom	4	crash	6	3.5	8	192	remount the sea
14	Gears can't mes	May cause dam	8	Human error	4	3.7	6	192	Prepare spare p
9	wheel twist	Vehicle out of c	6	pothole, crash	5	3.1	6	180	replace wheel
10	rod twisted	May cause dam	7	too much torque	6	3.6	4	168	evaluate
11	Pedal deformat	May cause dam	4		8	3.3	5	160	
14	Gear disengage	The vehicle wo	6		5	3.2	5	150	Prepare spare p
1	chain falls off	The vehicle wo	9	Loose chain/sp	4	3.1	4	144	tighten chain,
15	Screw fall	May cause dam	4	vibration	8	3.2	4	128	evaluate screw
2	Connection erro	The vehicle wo	6	Human error	5	3.2	4	120	
2	Easy to fall	The vehicle wo	8	Wrong size	3	3.6	5	120	Prepare spare p
3	Sprocket tilt	May cause dam	6	crash	4	3.6	5	120	reset or replace
11	pedal cannot b	Vehicle out of c	5	Pedal stuck	6	3.3	4	120	Prepare spare p
3	Cannot engage	May cause dam	7	impropper mea	3	3.1	5	105	
5	Complex conne	May cause prer	6	Human error	4	3.2	4	96	
5	unalligned axis	The vehicle wo	6		3	3.3	5	90	
10	rod break	The vehicle wo	9	tension,	5	3.6	2	90	replace rod
16	Loose nut	May cause dam	3	vibration	6	3.1	5	90	evaluate nut
9	Wheel rotation	Vehicle out of c	4	Human error	2	3.2	8	64	
9	wheel size is di	May cause dam	4	Manufacturing e	3	3.4	5	60	replace wheel
1	chain is too lon	May cause dam	3	too many chain	3	3.2	6	54	remove chain li

Appendix C: Prototype 1



Appendix D: Clutch Design Tool

Material			cork on steel or cast iron
Surface Finish			
Outer diameter	D	in	4
Inner Diameter	d	in	3
Thickness	th	in	0.25
Actuating Force	F	lb	*200*
Contact Pressure	P	psi	36.37827271
Wear Coefficient (Clutch)	K	in^3*min/(lbf*ft*h)	0.00013
Wear Coefficient (Flywheel)	K	in^3*min/(lbf*ft*h)	0.000017
Coeff. of Friction	u		0.5
Angular Velocity	v_ang	rad/s	0.3912559018
Peripheral Velocity	V	ft/min	2.934419263
time used	t	hour	100
Revolutions		rpm	147.5
Desired Safety Factor			1.5
Max Pressure	P_a	psi	36.37827271
Clutch Wear	w	in	1.387738355
Flywheel Wear	w_	in	0.1814734771
Contact (Normal) Force	F	lbf	171.4285714
Frictional Force	fric	lbf	85.71428571
Torque Capacity	T	lb-ft	12.5
Max Torque	SFT	lb-ft	8.333333333

Appendix E: Flywheel Design Tool

Material			Steel
Angular Velocity	w	rad/s	136.28
Density	p	kg/m^3	8000
Inner Diameter	d	m	0.0127
Outer Diameter	D	m	0.254
Thickness	th	m	0.0254
Flywheel Mass	m_f	kg	10.27
Inertial constant	k	-	0.5
Moment of inertia	I	kg*m^2	0.083
Flywheel KE	E_f	Nm (J)	769.2

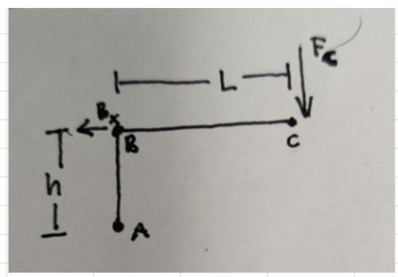
Bike Mass	m_b	kg	35
Bike Speed	v	m/s	9.00
Wheel Diameter	D_b	m	0.6604
Angular Velocity	w_b	rad/s	27.26
Bike KE	E_b	Nm (J)	2835.0

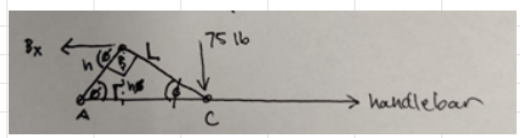
Input Values
Stagnant Values
Calculated Values

Final Speed
% Efficient - 13.57%
3.31 m/s
7.42 mph

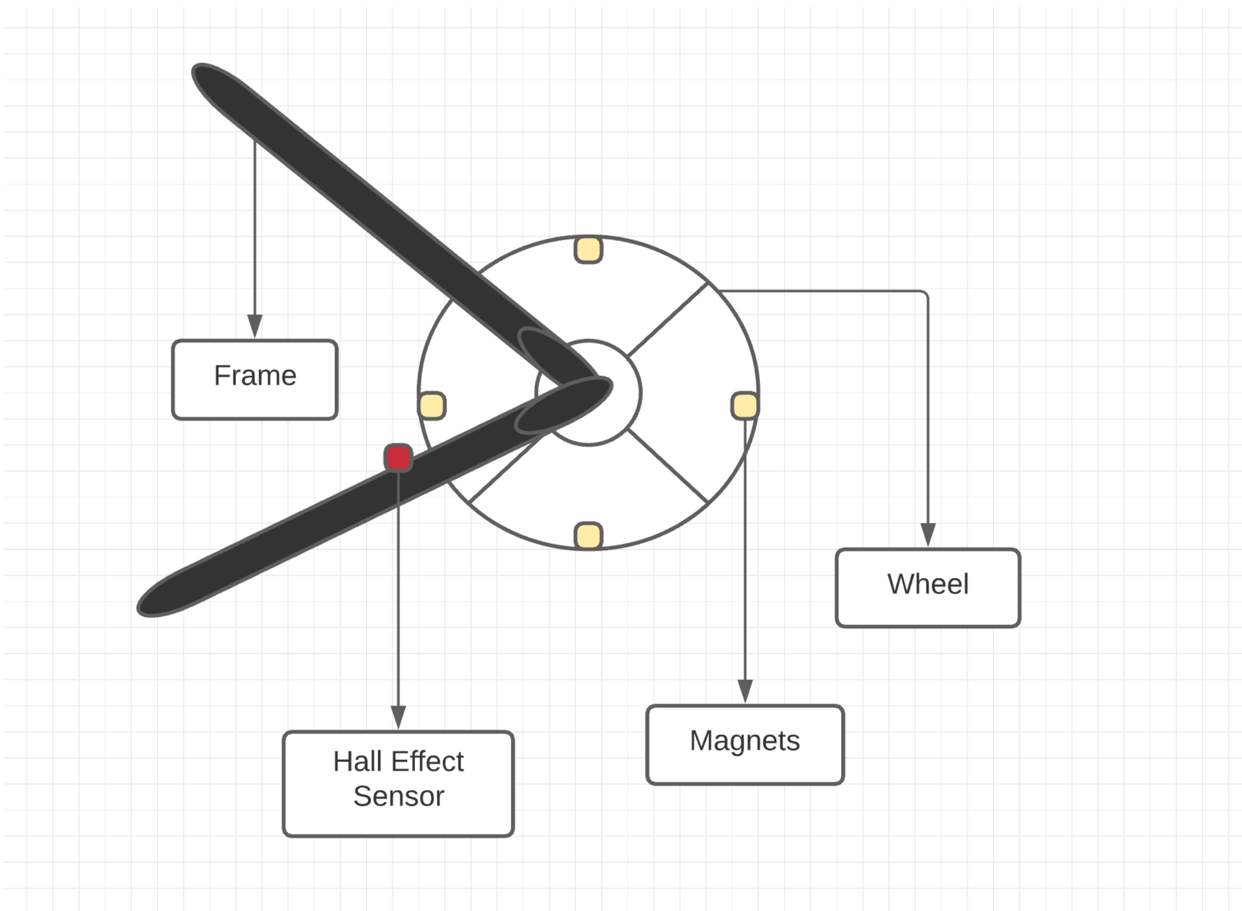
Appendix E2: Clutch application force calculator

force multiplication by lever	actuation force	B_x_o	175	lb
M_a=0=B_x(h)+F(L)	hieght	h	1.5	in
	length	L	3.5	in
	applied grip force	F_c	75	lb
force applied at full squeeze	hypotenuse	hyp	3.807886	
	max angle	θ_h	1.165904	rad
	max angle corrected	θ_h	66.80140	deg
	max force	B_x_m	408.3333	lb

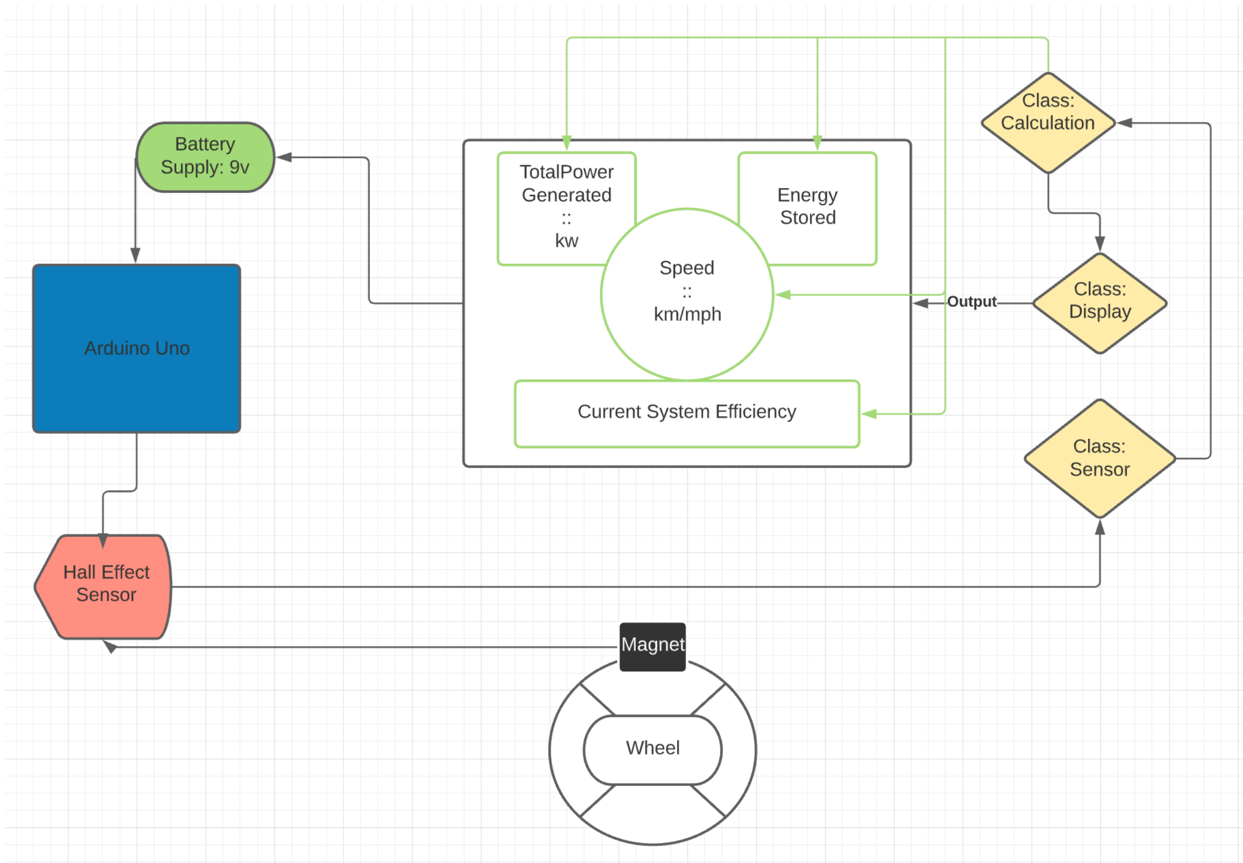




Appendix F: Hall Effect Sensor



Appendix G: Program Flow



Appendix H: House of Quality

House of Quality (HoQ)										
Customer Requirement	**Weight**	**Engineering Requirement**	minimum constant output and storage	Efficiency of system	human power	time to achieve power storage	number of muscle groups to use	degree of freedom	regenerative braking system	
1. attain maximum power from a human	5		3	9	9	3	9	1	3	
2. achieve maximum energy storage and	4		3	6	6	3	6	3	3	
3. high power delivered by propulsion sys	5		6	9	3	6	3	3	3	
4. utilize multiple large muscle groups	2		1	3	6	1	9	3	3	
5. reduce power losses, maintain reliabili	3		9	9	6	9	3	1	9	
6. safe to operate	5		1	1	3	3	6	3	6	
7. lightweight but durable	3		6	3	3	3	6	1	6	
8. high mechanical efficiency	3		9	9	6	3	6	6	6	
Absolute Technical Importance (ATI)			136	188	156	119	177	77	141	
Relative Technical Importance (RTI)			5	1	3	6	2	7	4	
Target ER values			0.5hp	95%	0.5hp	2 s	2	4	10%	
Tolerances of Ers			0.05h	5%	0.05h	0.5s			5%	
Testing Procedure (TP#)			1or3	2	3	4	5	6	7	

Appendix J1: Code - MPH

```
//convert rpm to mph
float rpmToMph(int rpm)
{
  float inches_per_min = WHEEL_CIRCUMFERENCE * rpm;
  float inches_per_hour = inches_per_min * 60;
  float mph = inches_per_hour/63360;
  return mph;
}
```

Appendix J2: Code - RPM

```
  //while the sensor hasn't timed out loop through
  while (currentTime <= sampleTime)
  {
    //check if sensor has been triggered
    if (digitalRead(sensor) == HIGH)
    {
      count_flag = HIGH;
    }

    //if so update the count and flag
    if (digitalRead(sensor) == LOW && count_flag == HIGH)
    {
      count++;
      count_flag=LOW;
    }
    currentTime = millis() - startTime;
  }

  //calculates rpm
  float current_rpm = int(60000/float(sampleTime))*count;
```

Appendix J3: Code - Speed Limit

```
//alerts user if they're approaching max speed
if ( mph >= MAX_MPH)
{
  lcd.begin(16, 2);
  lcd.setCursor(0, 0);
  Serial.println("Slow Down");
  lcd.print("Slow Down");
}
```

Appendix J4: Code - Flywheel Energy Storage

```
float getFlyEnergy(float rps)
{
  float k = 0.5; //inertial constant
  float M = 20.54; //mass
  float R = 0.3302; //flywheel radius
  float I = k * M * (pow(R, 2)); //inertia
  float E = (.5) * I * (pow(rps, 2)); //energy equation
  return E;

}
```

Appendix K: Bill of Materials

Bill of Materials							
	Team			HPVCP			
Part #	Part Name	Qty	Description	Material	Dimensions	Cost	Link to Cost estimate
1	Elegoo Kit	1	Electronics kit	Various		$59.00	https://www.amazon.com/gp/product/
2	Hall Effect Sensor US1881	3	Latching	Steel	TBD	$10.78	https://www.sparkfun.com/products/9
3	Backlight Graphic LCD	1	Display	Various	75x52.7mm	$23.95	https://www.sparkfun.com/products/7
4	N24 Neodymium Disk Magnet	3		Nickel-plated neodymi	0.250"* 0.200"	$9.75	https://www.magnetshop.com/neodym
5	Manual Clutch Set	1	Clutch	Carbon Steel		$40.39	https://www.amazon.com/GOOFIT-Hea
6	Radial Ball Bearing	1	Bearing	Steel	Outside Dia.1.37	$9.92	https://www.grainger.com/product/TRI
7	Radial Ball Bearing	4	Bearing	Steel	Outside Dia.1.12	$25.80	https://www.grainger.com/product/TRI
8	Thrust Bearing	1	Bearing	Steel	Outside Dia.1.56	$7.28	https://www.grainger.com/product/INA
9	Roller Chain Plate sprocket	2	sprocket	Carbon Steel	24 Teeth 1/2" Bo	$32.48	https://www.amazon.com/KOVPT-Rolle
10	Keyed Shaft	1	Shaft	Steel	1/2" X 36"	$23.00	https://thebigbearingstore.com/1-2-x-
11	11 Tooth Sprocket	2	sprocket	Carbon Steel	11 Teeth	$20.74	https://thebigbearingstore.com/11-too
12	Low-Carbon Steel Disc	1	Flywheel	Carbon Steel	10" 1"Lg	$76.87	https://www.mcmaster.com/7786T292
13	Thrust Bearing	1	Bearing	Steel	0.5 in Bore	$5.08	https://www.grainger.com/product/INA
14	Rear Disc Hub	1	hub		7.5 x 4 x 3 inche	$59.95	https://www.amazon.com/SHIMANO-F
15	Screen mount	1	3D Print	PLA		$21.42	
16	friction plate fixture	1	3D Print	PLA		$6.21	
17	spiral jaw	1	3D Print	PLA		$19.20	
18	fixture	1	3D Print	PLA		$36.00	
19							
20							
		Total Cost Estimate:				$487.82	

Budget remain: $1500 - $487.82 = $1012.18