



# WPI

## Human Powered Recreation Vehicle

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Bachelor of Science Degree in Mechanical Engineering

Submitted by:

Nolan Bell  
Alex Gallant  
Michael Munroe  
Katherine Schweikert

Approved by:  
Professor Cobb

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Nolan Bell

Alex Gallant

Michael Munroe

Katherine Schweikert

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# **Abstract**

The motivation for this project was to design and build a human powered vehicle for the main purpose of recreation. The target clients for the project are adult victims of stroke who now suffer from hemiparesis. After researching the current market and resources for recreation, the team developed four preliminary concepts, used a morph chart to select the best features from each, and designed a final prototype. The prototype was built using the frame from a Mobo Trike and incorporating modifications such that the tricycle is operated with the right side of the body exclusively. The final prototype meets all functional requirements outlined at the start of the project.

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# 1.0 Introduction

Stroke is a leading cause of death in the United States, affecting 795,000 lives each year. Strokes impact brain function and often result in limited mobility. Hemiparesis, or one-sided weakness, affects approximately 80% of stroke victims on either the left or right side of their bodies. This condition greatly impacts mobility and ability to participate in recreation. Recreation is an important part of stroke recovery, and recreational activities improve quality of life. People, regardless of disability from stroke, should be able to participate in recreation they find fun and engaging.

Human powered vehicles, such as bicycles, are a way to participate in recreation. Hemiparesis often makes it difficult or impossible to power a bicycle due to muscle weakness and limited mobility. The current options for recreation for adults with disabilities and hemiparesis are limited or expensive. Recreation options for victims of stroke need to be expanded.

The goal of this Major Qualifying Project (MQP) is to design and build a recreational device which is human powered for adults with impaired mobility, particularly victims of stroke who now suffer from hemiparesis. The project team hopes to adapt what is on the market currently and design a human powered vehicle that is accessible for victims of stroke who now experience hemiparesis.

The report illustrates each step the team took to develop the final prototype. The report contains background research, initial designs, design processes, prototyping, building, and testing. The data and information used to guide design decisions is included to illustrate the process that led the project team to the final prototype. The report also includes recommendations for future

work on this research and prototype. The project is referred to as Human Powered Recreation Vehicle throughout the report.

## **2.0 Background**

In order to achieve the goal of this MQP, an understanding of strokes, hemiparesis, and recreation for people with disabilities is required. To guide functional requirements and ultimately design decisions, an understanding of the mechanics of human powered vehicles is required and explained herein.

### **2.1 Stroke**

A stroke is a medical condition which occurs when there is a block in blood flow to the brain, caused by blood clots or burst blood vessels [1, 2]. This kind of blockage can cause lifelong brain damage, disability, and in extreme cases, death [2]. The brain is able to function because of oxygen-rich blood flow through the arteries and vessels [1], so when oxygen-rich blood is blocked from moving through the brain, brain cells are unable to get oxygen and die as a result.

There are two main types of stroke: ischemic and hemorrhagic. Ischemic strokes are more common than hemorrhagic stroke [1] and occur when there is a blood clot in an artery responsible for delivering blood to the brain [2]. Hemorrhagic strokes occur when blood vessels in the brain burst [2]. Regardless of the type, both result in the brain not functioning effectively and are serious medical conditions.

#### **2.1.1 Prevalence**

Stroke is the fifth leading cause of death for adults in the United States [2] and the leading cause of disability [3]. According to the American Stroke Association, stroke accounted for 11.8% of deaths worldwide in 2015 [3].

## 2.1.2 Recovery

Recovery from stroke varies from patient to patient; it could be a short recovery time of days or weeks or in some cases, a long recovery time of months or years [1]. Brain damage from stroke has many different forms, and depending on where and what kind of stroke occurred, there can be varied disabilities. Language, speech, memory, muscle function, bladder control, swallowing, and eating can all be affected by stroke [2]. Therapies such as speech, physical, and occupational can help patients adjust to life after experiencing a stroke. Physicians recommend making healthy lifestyle choices to prevent another stroke in the future [2] and seek a balanced life of work and recreation.

Hemiparesis is defined as “muscular weakness or partial paralysis restricted to one side of the body” [4] and affects about 80% of stroke victims [5]. This can make it difficult for people recovering from stroke to return to their normal lives. People with hemiparesis can experience loss of balance, difficulty walking, difficulty in grasping objects, fatigue, and lack of coordination, among other effects [5]. The opposite side in which the stroke occurred in the brain is likely to be affected by hemiparesis. Stroke in the left hemisphere of the brain can result in weakness on the right side of the body, difficulty in speech, and difficulty learning. Stroke in the right hemisphere of the brain can result in weakness on the left side of the body, difficulty recognizing familiar objects, mood swings, poor judgement, and difficulty with spatial reasoning. Hemiparesis is chronic but not typically progressive [6], and a lack of mobility and failure to stay active can result in a plethora of complications [7]. More often than not, survivors of stroke experience battles with their mental health. Recreation can help reduce the risk of developing mental illness and help survivors of stroke stay active.

## **2.2 Recreation & Quality of Life**

Recreational activities have been shown to significantly improve quality of life for all people [8, 9, 10]. Recreation can be summarized as physical activities that are engaged in for leisure rather than primarily exercise or rehabilitation.

### **2.2.1 Benefits of Recreation**

Recreation has many benefits for people from all walks of life, and professional recommend participating in recreation to improve quality of life, general health, and job satisfaction [8,9,10,11,12]. Recreation has been shown to reduce risks of obesity, heart disease, cancer, diabetes, and osteoporosis [11]. Heart disease is a leading cause of death [11], and risk of heart disease can be decreased with recreational activities, such as walking, jogging, swimming, or biking [10,11]. In addition to these physical health factors, recreation can also reduce the risk of mental illness, such as depression and anxiety [11, 12]. Recreation improves self-esteem, personal growth, and life and job satisfaction [8]. People who participate in recreation have a good or satisfactory quality of life [10].

Aside from personal benefits, there are social benefits to recreation as well. Recreational activities allow people to connect with their communities. As a result, communities are strengthened and experience more volunteerism and less crime [11].

## **2.2.2 Recreation & Disabilities**

For a person with disabilities, opportunities for recreation can be restricted due to limited mobility. Many people with disabilities need assistive or adaptive devices in order to enjoy recreation such as playing sports, walking, jogging, biking, or swimming.

Children often have access to adaptive devices to allow them to participate in recreation, but there is a disparity in this space for adults. There are many organizations that exist to help people with disabilities and specifically hemiparesis, but many of these organizations are targeted towards getting children active rather than adults. There are grants and foundations to support the purchase of adaptive devices, but being under the age of 18 is often an eligibility requirement [14,15,16]. The funding for adults with disabilities does not exist in the same way it does for children, mostly because of initiatives geared towards encouraging children to be active. Once children with disabilities reach adulthood, however, opportunities and encourage for an active lifestyle significantly decrease. For adults who are veterans, the U.S. Department of Veterans Affairs does a good job of providing veterans with resources and devices for them to continue an active lifestyle, but unfortunately this service does not cover every adult with disabilities. It is important for adults as well as children to be able to access recreation, as it provide opportunities to learn from and connect with others.

Disabled Sports USA conducted a study and found that adults with disabilities involved in sports are twice as likely to be employed in comparison with adults with disabilities who are not involved [13]. Additionally, 81% of participants with Disabled Sports USA are more satisfied with their lives as a result from their involvement [13].

Recreation has a plethora of benefits, and disabilities should not hold people back from being able to take advantage of such benefits. There is an opportunity here to develop affordable, adaptive devices for adults with disabilities, particularly survivors of stroke.

## **2.3 Assistive Devices**

### **2.3.1 Regulations for People with Disabilities**

The American Disability Act (ADA) became a law in 1990 prohibiting discrimination against individuals with disabilities in all areas of public life. The specific section deals with the public accommodations of this act. When looking this act, there will be a need to look into curb ramps and pedestrian crossing. The curb ramps will be necessary to know for dimensioning purposes and what a vehicle needs to be capable of. The ADA states that running slopes must use less than a 8.33 percent slope if constructed before January 26, 1992 [16]. There are several other standards dealing with the rise and running slope that will be taken into account.

The ADA also has regulations on assistive devices such as wheelchairs, Mobility Aids and other power-driven Mobility Devices (OPDMD). It is important to look into this area of the ADA to see what accommodations are necessary for these Mobility aids and OPDMDs. This vehicle is referenced as a recreational vehicle, not a Mobility device or aid, so it will include some but not all ADA regulations.

The Occupational Safety and Health Administration (OSHA) is an administration created by Congress through the Occupational Safety and Health Act of 1970 [17]. It assures safe and healthful working conditions for working men and women. The reason to look into the OSHA is specifically Industry 3751 and 3799 which deal with Motorcycles, Bicycles, parts and personnel carriers. Industry 3751 deals with the manufacturing of bicycles and similar equipment. The



recreational vehicle that is being designed is not intended to be manufactured but these still can be useful guidelines and a good reference tool when creating the design specifications.

### **2.3.2 Mobility Aids**

Assistive Mobility vehicles for stroke or hemiparesis victims vary from electric powered scooters to a much more simple wheelchair. Accommodations for people with disabilities is the main focus when looking into these Mobility Aids. The wheelchair provides means of easy transportation without much effort, yet this is almost unattainable for hemiparesis victims. A wheelchair is intended for users with leg injuries or inability to use their legs. It also requires the use of both arms in order to spin the ring around the wheels as seen in the figure below.



*Figure 1: Wheelchair.*

A substitute to that is an electric scooter. It provides easy mobility through electric power and is capable of steering with a singular hand. This may not be a human-powered vehicle but it still exists as a mobility aid for people with disabilities .The electric scooter is a more common mobility device.

A walker is also another mobility aid for people with disabilities. As show below in Figure 2, it is a fairly simple device with the purpose of providing balance and supporting the legs by allowing the weight of the body to be distributed by legs and arms. A device like this is one of the simplest mobility aids besides the cane. Another device very similar to this is a pool walker. It is

essentially the same device but some are made from PVC piping and help the user float in the water. The pool walker is commonly used as a recreational rehabilitative device.



*Figure 2: Walker.*

## **2.4 Human Powered Recreation Vehicles**

### **2.4.1 Standards**

The World Human Powered Vehicle Association (WHPVA) defines a Human Powered Vehicle as any and all vehicles that are powered only by muscular-strength [18]. The only power supplied to the vehicles is through human strength and that is translated to the motion of the vehicle. Common examples of this are bicycles and canoes where human power is needed to move the vehicle. The World Human Powered Vehicle Association is an association of national associations monitoring HPVs. WHPVA is promoting the improvement, innovation and creativity

of HPV's (Human Powered Vehicle) mostly in the design and development phases [19]. Currently there is no organization for the United States but there are many members across the globe spanning from Australia to France. They support and regulate competitions and promote the design and evolution of land water and air HPVs.

## **2.4.2 Existing Recreational Devices**

When looking into human powered vehicles, there are lots of devices that come to mind. Bicycles, canoes, skateboards and scooters are common examples that most people think of, yet there are so many more. It is impressive to see how many different human powered vehicle have been created. This is truly a massive category and started the brainstorming for ideation. There are a few devices that are viewed in depth, such as the tricycle, bicycle, green machine, scooter, Lopifit and more. These all incorporate different methods of power some pedal others require walking. Essentially, all of these standard HPVs were unsuitable because of one shortcoming they all shared. They were unsupportive of Hemiparesis users.

Now when searching for Hemiparesis supportive HPVs there is Hase Bike that comes with assistive equipment. A Simple leg sling is all that is used by this bike to support the affected leg. These are mainly recumbent bikes allowing for better mounting and balance.



*Figure 3: Hase Bike with Leg Sling.*

The Glidecycle is a two wheeled Human Powered Vehicle that essentially suspends the user and allows them to run or walk. Below is an image of a glidecycle showing the frame and the intended method of use. The user is suspended from the frame of the bike allowing for less impact with the ground. This vehicle allows for “weightless running” [20] that is created for easier movement. Unfortunately, this would not be fully supportive for hemiparesis users due to the lack of stability and difficulty mounting. This vehicle slightly resembles an Anti-gravity treadmill which also allows for this type of “weightless running” for rehabilitation purposes. The Glidecycle is considered a recreational vehicle, unlike the Anti-gravity Treadmill, which is used for rehabilitation.



*Figure 4: Glidecycle.*

## **2.5 Road Safety**

### **2.5.1 Non-motorized Vehicle Laws**

The Human Powered Recreation Vehicle must be compliant with state laws to be a viable method of recreation. The focus of this report was in the state of Massachusetts because we are producing the vehicle with the intent that the product will be used in the Worcester area. Bicycle laws in Massachusetts provide a similar set of guidelines to use in the creation of the Human Powered Recreation Vehicle.

In Massachusetts, bicyclists receive rights of the road for the users' own safety including regulations on the operator. For example, if a bicycle rider is under sixteen years of age, the operator is legally required to wear a helmet [18]. Bicyclists may take their vehicle on any public road, street, or bikeway. Normally, bicycles are not permitted to be ridden on sidewalks in Massachusetts. However, they can be ridden on sidewalks if they are outside of business districts

and that they use the sidewalk in the event of safety concerns or by local laws [17]. For recreation purposes, the Human Powered Recreation Vehicle would not be used in business districts, but rather on terrain with less activity. Bicyclists also have to use hand signals unless they require both hands for safety concerns, which may be the case in the Human Powered Recreation Vehicle. Cyclists are obligated to obey traffic laws and give pedestrians the right of way. In the production of the Human Powered Recreation Vehicle, the maximum distance to stop would need to be considered for the safety of the pedestrian and the operator of the vehicle. The vehicle must not be modified where the user's hands are placed higher than his or her shoulders on the handlebars [18]. In order for the bicycle to be used at night, Massachusetts State Law requires a white light facing forwards and a red light facing backwards. The pedals of the bicycle also needed reflectors on its front and back sides unless the operator wore reflective material around his or her ankles [17].

In addition to where and how the vehicle must be used, there are requirements on how the bicycle must be equipped. The bicycle must have a permanent and regular seat attached to it. The brakes of the vehicle are required to be sufficient enough to stop the vehicle within 30 feet from a speed of fifteen miles per hour on a dry, clean, hard, and level surface [18]. Traveling at night, the headlight of the vehicle must emit a white light, which has to be visible at least 500 feet away. The taillight of the vehicle must be red and visible from 600 feet away. The pedal reflectors must also be visible from 600 feet through the low beams of a car's headlights [18]. By Massachusetts State Law, the vehicle is required to satisfy these conditions in order for it to be recognized as a roadworthy recreation vehicle.

## 2.6 Mechanics of Vehicular Motion

In order to analyze the different ranges of motion that our Human Powered Recreation Vehicle might undergo, we must first understand different concepts of mechanics. Mechanics is the study of the relationship between motion, forces, and energy. Mechanics can be broken down into three categories of analysis: statics, stress, and dynamics [20]. In a later chapter, we will analyze statics and stress and how they occur within, or on, our vehicle. Here we will analyze dynamics, which is the branch of mechanics that analyzes forces and how they lead to motion within a system.

Motion can be found in three major forms as well. First is *translation*, which is motion in which an object moves. For a two-dimensional analysis, the object can move anywhere along the x or y-axis. Second is *rotational*, which is any motion in which one point of the object is stationary, while the rest of the object spins. The point of rotation or *axis* is not always in the center of the body. The third form of motion is a *combination*, in which the object moves around in a two or three dimensional plane while also rotating [20]. It is likely that in any design for our vehicle, all three of these motions will be found in a combination of ways.

### 2.6.1 Drivetrain/Propulsion

According to Newton's First Law, any object will remain at rest unless acted upon by an outside force. In the Human Powered Recreation Vehicle, all forces to produce motion will come directly from the rider. The rider will use their energy to apply a force, doing work on the propulsion system.



There are numerous forms of propulsion to analyze, without looking into the use of motors or control systems and other electronics. The use of chain and sprocket, torque from the rider's hips, and stepping motions are just a few forms of propulsion that can all be incorporated into a Human Powered Recreation Vehicle.

*Chain and sprocket* systems connect two gears or sprockets using a chain to transfer a torque from one sprocket to the other. Some advantages of using this system is its relative durability under human power, cheap cost, flexibility, and ability to operate under different lengths [21].

*Torque from the rider's hips* allows the rider to utilize the full weight of their body to power the vehicle. Many systems on the market currently utilize this method to propel their systems, despite not being suitable for a rider with hemiparesis. Common examples are the Ripstik and the Trikke Bike.



*Figure 5: Ripstik powered by torque from the hip.*



*Figure 6: Trikke bike powered by torque from the hip.*

Both systems are also similar to the motions of skiing or snowboarding. If incorporated into a vehicle safe for a rider with hemiparesis, the motion would allow the rider to shift weight and use their whole body during the recreational activity.

*Stepping motions* utilize the normal gait and motion of walking, while on a vehicle. This form of motion would also require some sort of pedal or device for the rider's force to push on, producing the force necessary to power the vehicle. This form of power can come in a motion similar to walking up the stairs, on a stair stepper, translating the foot up and down. It can also come in the motion of a treadmill, where the foot travels front and back.



*Figure 7: Stair-stepper.*

## 2.6.2 Shifting

Shifting on a bike, or other vehicle, allows the rider to pick a speed and intensity for their ride. From a chain sprocket system, like mentioned in the last system, there are two sets of sprockets. The first is attached to the pedals, and called the *chain ring*, The second set is called the *cassette* and is found on the rear wheels [23]. The Chain Ring receives all of the torque produced by the rider, transferring it to the cassette via the chain, to power the vehicle.

Positioning is key with these systems. Both the Chain Ring and the Cassette are positioned largest diameter to smallest. While both are found on the right side of a bike, the smallest Chain Ring and the Largest Cog will be closest to the frame. As can be seen in Figure 7 below, the position of the chain in relation to the two sprockets is key for a smooth ride.

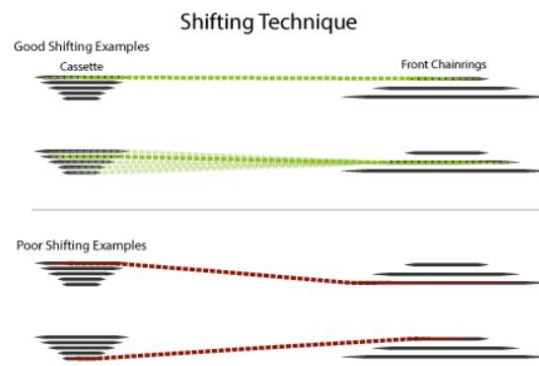


Figure 8: Shifting Techniques in a Chain and Sprocket Propulsion System [23].

Improper shifting, like the red chain in the image above, can be detrimental and result in a dropped, lose, or even broken chain [23]. At the same time, proper positioning can help produce a great workout on a recreational vehicle. The easiest ride on the rider will be when the rider's foot has to travel the smallest distance, around the smallest gear on the Chain Ring, being translated

back to the largest ring on the Cassette. The opposite combination of gears will result in the ride requiring the rider to put in the most work [23].

In order to get to these locations, there are multiple forms of shifting. The most common forms of shifters are incorporated on the handlebars. Two advantages of this location, on the vehicle, are that they are within the reach of the rider, while maintaining stability over the vehicle, and they are also within the rider's field of vision, so that they do not have to take their eyes off of the road. One type is a lever incorporated into the brake lever, a second utilizes a separate lever to be used by the rider's thumb, and the third utilizes a twisting motion of a grip on the handle bar [23]. The three types can be seen in the figure below.



*Figure 9: Brake lever.*



*Figure 10: Thumb lever.*



*Figure 11: Twist grip.*

### 2.6.3 Braking

Brakes on a bicycle, and other recreational vehicle, use calipers to impede the motion of the vehicle. This is done with tension and friction between the caliper and the wheel, slowing down the system as a whole.

There are three major parts in a brake system: 1) the lever, 2) the cable, and 3) the calipers. Both rim brakes and disk brakes utilize these components [22].

On a *rim brake* system, the calipers are mounted just over the rim of the bike. The calipers are then connected back to the handlebar levers using the brake cable. Then, when the rider squeezes the cable, to brake, they are putting the cable under tension, pulling the calipers together, tightening them against the rim of the wheel, and increasing the friction [22].



*Figure 12: Rim brake system on a bike.*

The other form of brakes are *disk brakes*. In this type of system, a disc is mounted so that it rotates with the wheel. The calipers are then mounted over the disc, so when the rider brakes, the cable still pulls the calipers together in tension, but instead of applying friction to the rim of

the wheel, all of the friction is applied between the disk and caliper pads, slowing down the vehicle [22].



*Figure 13: Disk brake system.*

## **2.6.4 Steering**

In vehicles, with anywhere from two to four wheels there are a number of combinations of wheel placement. Different designs incorporate an even number of wheels in the front and rear, while others stagger the relationship by putting more in the rear or the front. With that comes the decision of which wheels will be used to steer the vehicle. Common recreational vehicles like a simple bicycle often utilize the front wheel because of comfort, location, and handling. When the rider gets onto a standard bike, leaning forward to grab the handle bars, they shift the center of gravity, closer to the front wheel, making it the steering wheel.

On a two wheeled vehicle, such as a bike, the equations for the turning radius are as follows:

$$R = \frac{W}{\sin \phi} \text{ and } r = \frac{W}{\tan \phi}$$

These equations are for the turning wheel (R) and the fixed wheel (r). In these equations, W represents the distance between the centers of the two wheels and  $\phi$  is the angle the wheel is turned from a straightened position. For all instances, the radius of the turning wheels (R) will always be larger than its fixed counterpart.

Now, with a vehicle such as a recumbent tricycle we will analyze a design of one wheel in the front and two wheels in the rear, with the rider sitting just in front of the rear wheels. We will also consider that the wheels stand straight up and down while turning, not leaning. In this setup, the center of gravity of the rider has shifted back significantly toward the rear wheels. If the steering wheels now become the rear wheels, the control is closer to the rider and their center of gravity, providing more comfort. In this case, the rider's position and the rear wheels become the larger radius R, allowing the front wheels to take a sharper turn. The difference being, that the rear wheels would track left to make a right hand turn, while the front wheel rotates in a smaller "pivoting" circle towards the right.

Another common recumbent design utilizes a single wheel behind the rider with two wheels up front, beside the rider's hips. In this design, the front two wheels are used to steer, because they are below the rider's center of gravity. However, these wheels turn by pitching the wheels, rather than keeping them straight up and down during the turn.

## 2.7 Functional Requirements

Before the design process can begin, we have to limit our project to a set of functional requirements. These requirements describe what our Human Powered Recreation Vehicle should do. From this list, we will then be able to comprehensibly design the vehicle to meet the requirements. This is a bottom up approach, in which we set goals and engineer them.

Many of our requirements are based on the logic of vehicle mechanics. Others pair mechanics with rider comfort, some analyze the environment that the vehicle is intended to be used in and from that, which materials will withstand that environment. There are also functional requirements on this list that make it so that this vehicle is friendly to the intended rider with hemiparesis, so that they can safely use this vehicle given their medical condition. A list of our functional requirements can be found below:

*The vehicle must be:*

- Stable at slow speeds
- Easy to mount/dismount
  - Can be mounted from both sides
  - Must be able to remain stable on its own
- Easy to fix
  - Simple design
  - Standard hardware -- no odd tools required
  - Easy to access fasteners
  - Open/ visible design
- Able to fit...
  - Through a standard door frame (32 inches wide)



- Into bed of a pick up truck (6 feet long)
- No larger than 36 inches tall
- Able to be used with predominantly right side of the body
- Corrosion resistant according to ASTM B117 corrosion tests
- Supportive of hemiparesis on the left side of body
- Adaptable for riders of different heights
- Able to steer, power, and stop with relative ease
- Able to stop without internal or external damage to user
- Able to stop within 12 feet from under 25 mph
- Able to climb a 1-3% grade
- Able to maintain traction

*The vehicle must have:*

- A turning radius of at most 35.5 feet

*The vehicle is intended to be used:*

- On flat terrain (e.g. open roads or bike trails)
- At slow speeds under 25 mph
- On dry surfaces

*The user of the vehicle:*

- Must not weigh more than 250 lbs
- Intended for average sized adults
- Will feel comfortable and safe during use

*The vehicle must not:*

- Be used in water
- Be used to fly
- Weigh more than 55 pounds

### 3.0 Preliminary Design Concepts

The functional requirements for the project, outlined in 2.7, focus on size limitations, ease of use, comfort for the user, and specific metrics to measure turning, stopping, and steering. After finalizing the functional requirements for the project, the MQP team developed designs for the Human Powered Vehicle. The concepts explore different methods of steering, braking, seating, and powering a vehicle. From these concepts, the team was able to understand the elements of each design that worked in order to piece together the final design.

Prior to designing concepts in SolidWorks, the team made sketches and small-scale physical models to understand the structure of some vehicles. These models were made using K'nex, which are plastic building parts that click together, as seen in Figures 11 and 12. Once the physical models were complete and the team had an understanding of the direction they wanted to pursue, each team member modelled concepts in SolidWorks. These designs were scored in a Decision Matrix, and elements of each were analyzed to choose the best parts from each design. Refer to Tables 1 and 2 in 3.6 for the scoring information.



*Figure 14: Tricycle model using K'nex.*



*Figure 15: Four wheeler model using K'nex.*

### **3.1 Dual Pedal Vehicle**

The Dual Pedal recumbent tricycle is a 3-wheeled vehicle with both foot and hand pedals for powering the vehicle. Like a standard bicycle, the vehicle is steered by pushing, pulling, and turning the handlebars. The vehicle utilizes coaster brakes, which are engaged by pedaling backwards with the foot pedal. With attention to the rider's comfort, the vehicle has a supportive, adjustable seat for riders of various heights. The seat swivels 90 degrees at its base to allow for easy mounting and dismounting. The vehicle would likely be stable when still, but could also use a kickstand to improve stability when mounting and dismounting.

The disadvantages are mostly related to the coaster brakes. The user must be prepared to stop and in the right foot position in order to brake by pedaling backwards, so if the rider is caught off guard, he or she might fail to stop. Over time, the coaster brakes will wear down and will require more and more backwards pedaling to engage, so the longevity and lifespan of the vehicle would be diminished with this style of braking. Steering this model of the vehicle could be complicated for the user if he or she is also powering the vehicle with arm power. While cranking the hand pedal, it could be challenging to also turn the handlebar.

The advantages of this design are easy mounting, easy braking to design and build, and power coming from the right arm and right leg. The Dual Pedal model is beneficial because it can be powered with lower and upper body strength to compensate for the lack of power coming from the entire left side. The Dual Pedal model presented a creative method of powering the vehicle and exposed challenges with regards to steering and braking.



*Figure 16: Dual Pedal design concept, isometric view.*



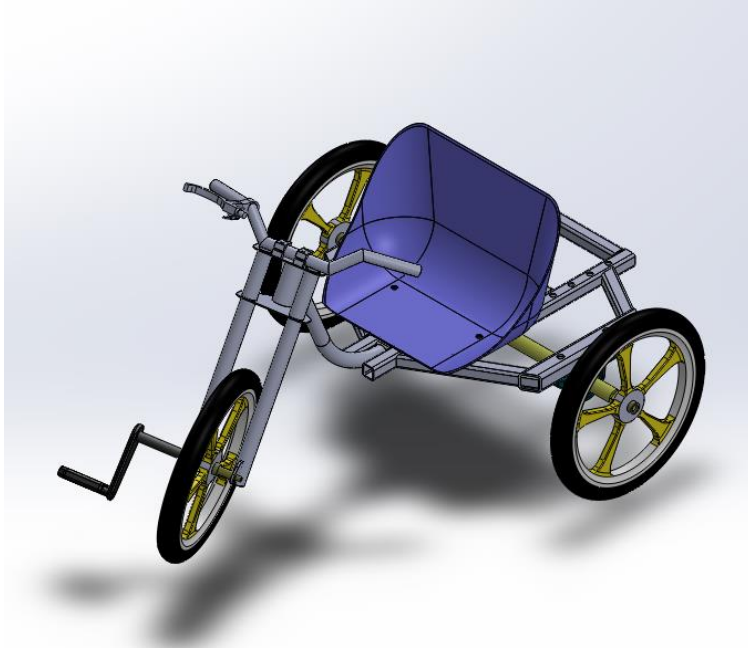
*Figure 17: Dual Pedal design concept, side view.*

## 3.2 Right Side Tricycle

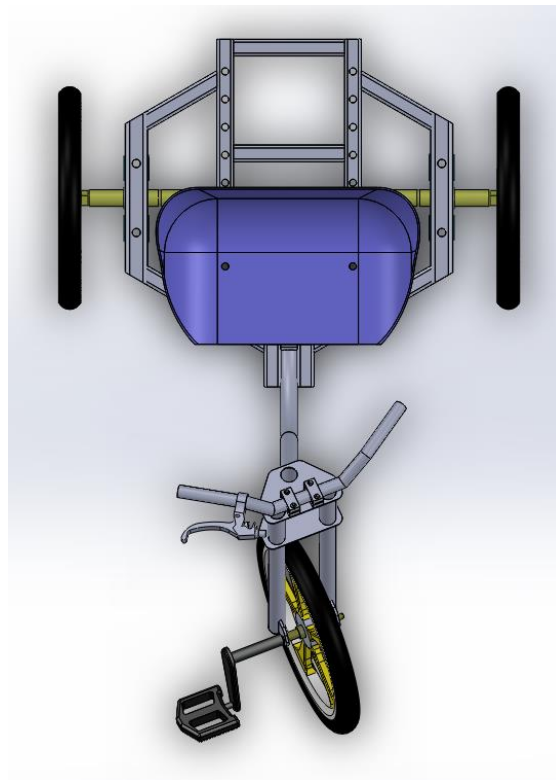
The Right Side Tricycle design is a 3-wheeled vehicle that is low to the ground. It is powered by a single foot pedal on the right side. The steering is the same as a standard bicycle, which is steered by turning the handlebars. The tricycle has a hand brake on the right handlebar which would engage a rim brake on the front wheel. For this model, the seat clips into holes on the frame at various distances, much like a shaft on a scooter, in order to be ridden by people of varying heights. The vehicle is low to the ground to provide stability.

The height of the vehicle relative to the ground, although providing stability, poses as a challenge for mounting and dismounting. Another disadvantage is that the seat does not rotate to allow for mounting from the side of the vehicle. The design is not supportive of the left side of the body and it would be difficult to mount a sling on this model to support the left leg. Additionally, all the power is coming from pedaling with the right foot, which on some terrain or inclines could be very challenging.

Although there is only a front brake, most of the braking power on human powered vehicles comes from the front, so using a front brake exclusively should not pose a problem. The front handlebars for steering will allow for a small turn radius, assuming the user has enough strength on the right side. Overall, this model does not present many advantages and is not necessarily the most comfortable vehicle.



*Figure 18: Right Side Tricycle design concept, isometric view.*

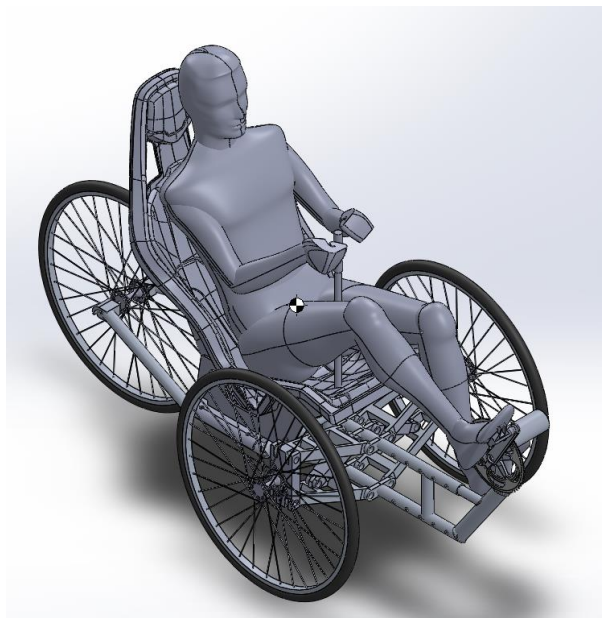


*Figure 19: Right Side Tricycle design concept, top view.*



### 3.3 Lean Steer

The lean steer is a tadpole-style recumbent tricycle, with two front wheels and one in the rear. Propulsion comes from a right sided pedal and attached shoe. This pedal will operate a chain drive which will turn the rear wheel. This design offers a simple gear mechanism, as there is no shifting. The lean steer feature utilizes two “wishbones” that are connected to the bike frame in order to turn the bike, as well as a suspension arm on either side of the bike, to add resistance to the rider’s weight. Instead of the wheels turning to steer, the wheels tilt. This design also features a single bar in between the rider’s legs. This will aid the rider in turning, as well as returning to the upright position. On this handlebar will be the brake levers. The design incorporates both a rear and front brake lever, side by side. When pulled, the brakes would be applied to either both front wheels, the rear wheel, or all three via disk brakes.

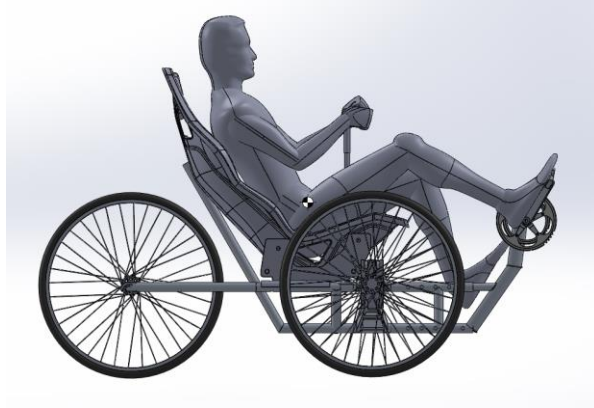


*Figure 20: Isometric view of the Lean Steer.*

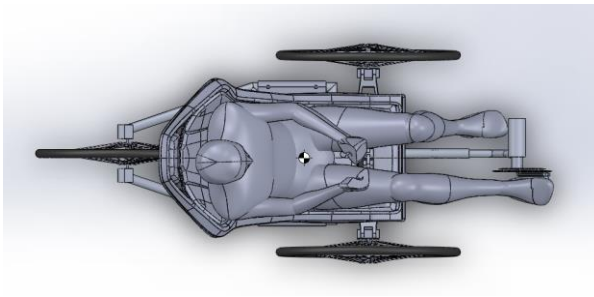
Since this bike offers lean steering, it is most stable at lower speeds. The design also meets numerous functional requirements for the final design, as previously listed. One is the ability to be

operated by just the right side of the body, supporting the left. While the right leg is propelling the vehicle, the left leg will rest comfortably in a harness. The right side of the body can experience as much ease or difficulty that the rider would like. This is because, instead of gears, the pedal will be able to be loosened, translated along the crankshaft, and then resecured. The single handlebar will also aid in this, because all essentials are compiled to one side. This will allow the left arm to rest wherever the rider deems comfortable. This bar will have two positions: riding and mounting. While in the riding position, this bar will be upright and stable. While mounting the bike, the bar can be collapsed down, like the handlebar on a scooter, so the rider can get their legs to either side of the bike. At the same time, if the rider is taller or shorter than the vehicle's set length upon getting on the vehicle, the frame is adjustable. Finally, the seat offers a 3-point locking mechanism that allows the rider to lock in, release the lever, turn 90 degrees to the riding position, and lock back into place. This operation can be reversed, in either direction, to dismount the vehicle. Because of these features, this vehicle will fulfill many of our functional requirements. Its size also meets intended requirements for storage and transport.

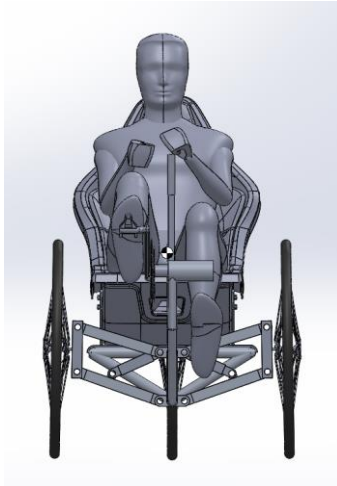
Disadvantages of this bike come from the steering design. The functional requirements state that the vehicle is only intended to be utilized at low speeds. However, if ignored, and speeds became too high, the bike would become unstable. Another disadvantage is the instability of the steering design during mounting. Under current conditions, the bike would tip back and forth during mounting, unless the arms could be locked in some way so that the bike cannot lean to either side.



*Figure 21: Right side view of the Lean Steer.*



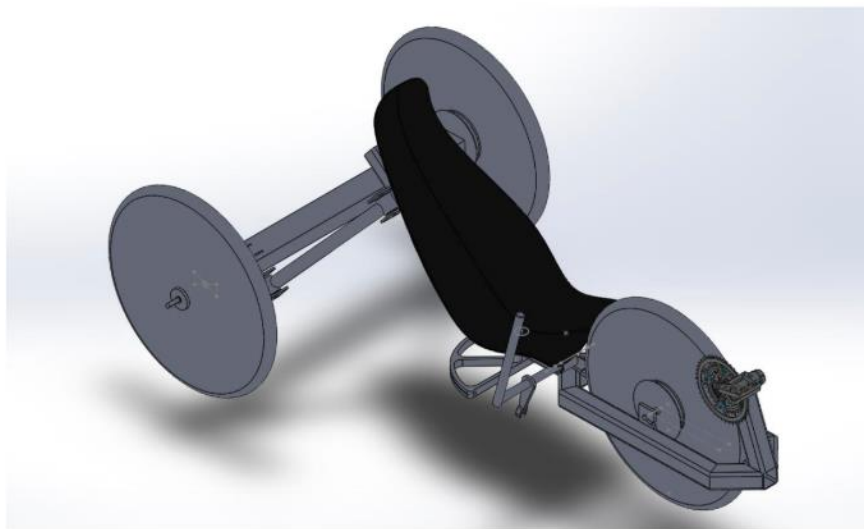
*Figure 22: Top view of the Lean Steer.*



*Figure 23: Front view of the Lean Steer.*

### 3.4 Red Machine

The Red Machine is a recumbent 3-wheeled vehicle with 2 drift-style wheels in the back and a typical bicycle wheel in the front. It is powered by a clip-in shoe/pedal system so pushing the pedal forward and pulling it back will generate power for forward motion. For steering, this design implements a cable/rod steering mechanism. The system is driven by a crank on the right side of the vehicle. When pushed or pulled the crank's forward or backward motion will be translated to rotational motion around an axis perpendicular to the bottom of the frame. The motion will rotate the semi-circle under the seat which will have two connecting rods attaching the semi-circle to the back axle. This rotation will turn the back axle resulting in the drifting of the back tires. For braking, there is a simple cable and rim pad braking system as seen on average bicycles. The hand brake will be accessible through the handle positioned on the right of the vehicle.



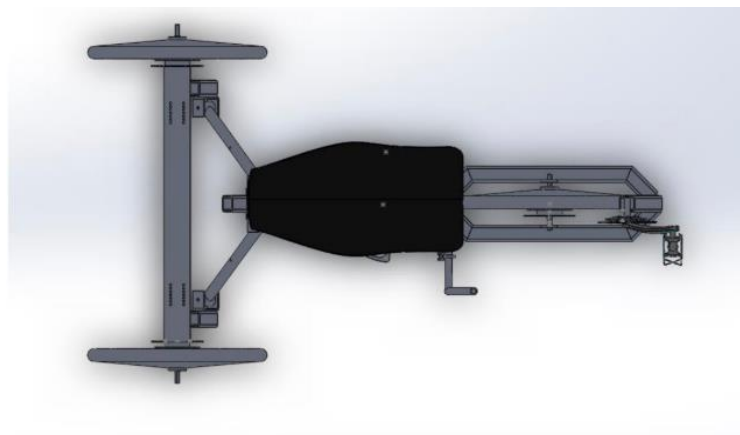
*Figure 24: Isometric view of the Red Machine.*

This design will be equipped with a sling with velcro straps along the left side of the frame to support the affected leg. There will also be a harness attached to the seat to provide stability for the user as well as support the affected arm. For adjustments, the seat will be able to move forward

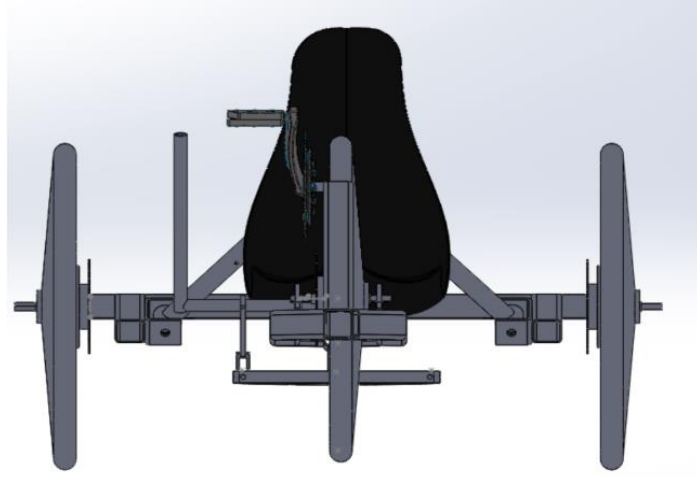
and backwards with a simple bolt and holes in the frame. This vehicle is low to the ground providing stability while riding and turning at moderate speeds.

Advantages of this design begin with a simple steering system. This system will be easy to fabricate and maintain due to having all fasteners and linkages visible. The pedal is also an advantage of this design. The user will only be expected to power this vehicle with one leg so generating as much power as possible is a necessity. The pedal will allow the user to clip in their shoe to the pedal and power the bike both by pushing forward and pulling back.

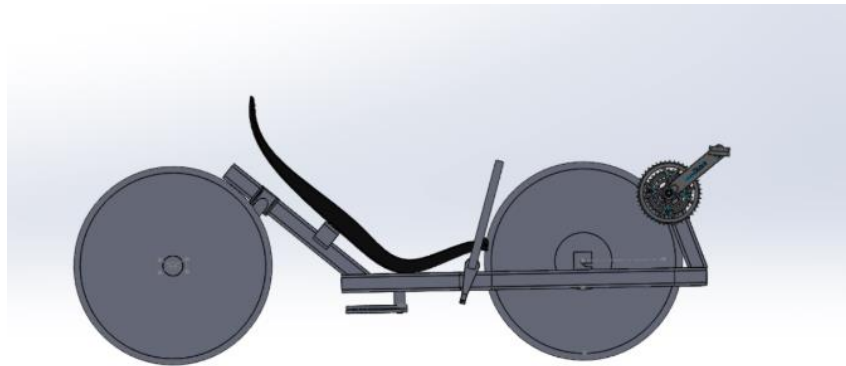
Disadvantages of the Red Machine include the lack of accommodations for the user's left side. There could be many more devices added to this design to improve the user experience, for example, a rotating seat or park brakes for mounting stability. The Red Machine's greatest disadvantage is the efficacy of steering. In theory, this design is an effective way to steer, but in practice, the force required to actually turn the back axle may be too much for the user. This system will require the user to generate enough force on a crank to drag two wheels while they are being weighed down by the frame and the user themselves.



*Figure 25: Top view of the Red Machine.*



*Figure 26: Front view of the Red Machine.*



*Figure 27: Side view of the Red Machine.*

### **3.5 HPRowV**

The HPRowV is a tadpole recumbent tricycle combined with a propulsion system from a crew machine. Contrary to a typical recumbent tricycle, the main focus of this design was to utilize arm strength on the user's right side to power the vehicle rather than a pedal system. To build this prototype, our group would have to select key parts from both a recumbent tricycle and a crew machine. A typical crew machine involves seat movement as the user pulls on the bar. The HPRowV design incorporates the rowing motion to spin the front axle, and the bar recoils like a typical crew machine to allow the user to continually pump as needed. The vehicle would ideally

have a seat that would be able to swivel and be mounted from both sides and lock into place at the ideal riding position. The user's feet would be able to slide into position as shown in the figures below.

As the design progressed, some flaws were identified including the steering system, braking, and adaptive features for the user. The users' dominant arm powers the vehicle, but the dominant leg is mostly acting for stability. The HPRowV design would need to incorporate lean steering, as a typical recumbent tricycle steering would not function with the crew machine attachment. Because the propulsion system requires arm motion, extra stability is required to incorporate lean steering safely into the vehicle. The design also would need a more efficient braking system to be feasible and safe for the user. There is currently a handle attached to a clamp brake on the user's right side. The brake would need to be incorporated into the handle of the rowing machine for the user to power the vehicle without sacrificing the integrity of the brake. With the lean steering incorporated into the crew machine, the design may become too difficult for the user to ride comfortably.



Figure 28: HPRowV, Isometric View.



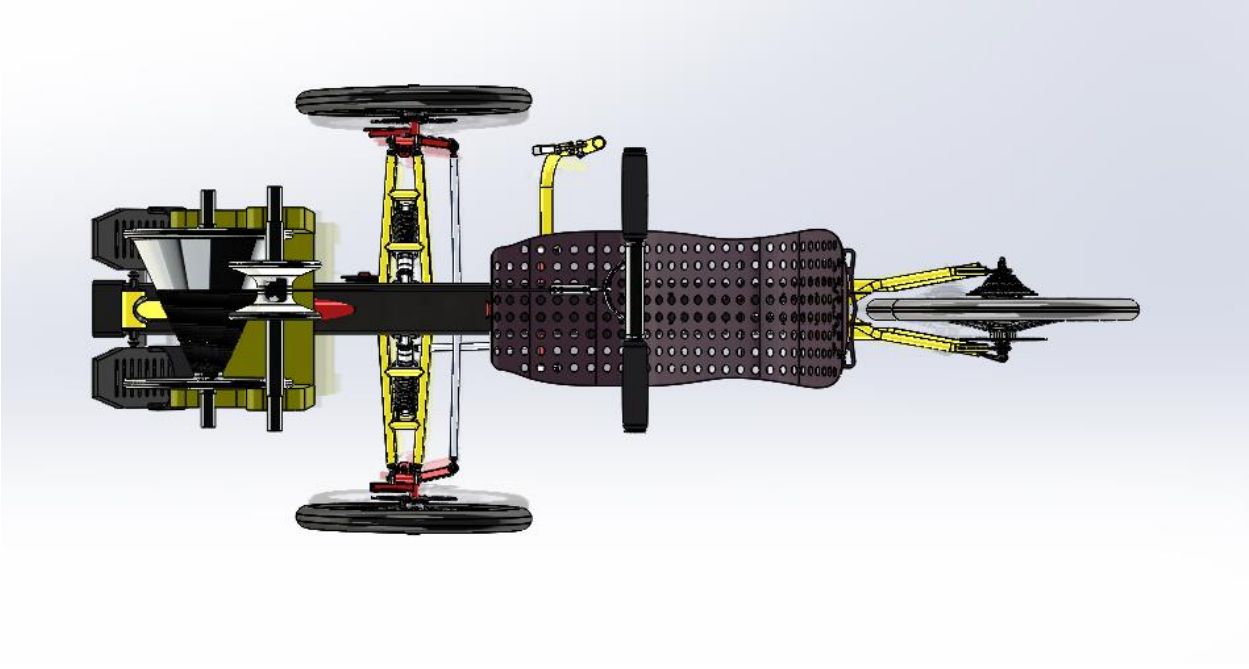


Figure 29: HPRowV, Top View.

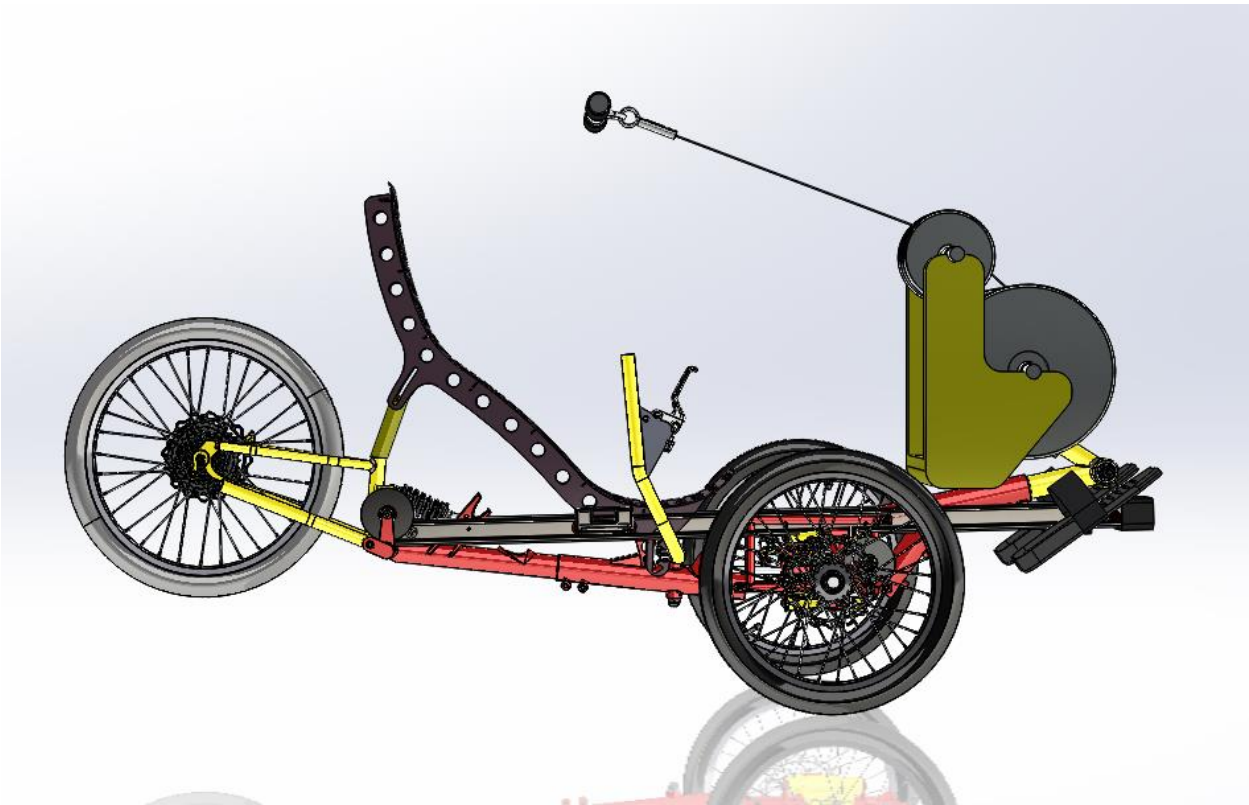


Figure 30: HPRowV, Side View.

### 3.6 Design Matrices

The team used two different matrices to produce the aspects of the final design. The first was a Decision Matrix (Table 1), which compared the five designs. These designs were all scored on a scale of 1 to 5, 5 being excellent. From looking at the chart, the Lean Steer vehicle had the highest score primarily because of its ability to steer, power, and stop the vehicle with ease. Each design had some strong aspects and some weaker aspects, which led the team to using a Morph Chart (Table 2) to select specific elements of each design that worked. These elements were then combined to produce the final design of the Human Powered Vehicle for Recreation.

Table 1: Decision Matrix for all five design concepts.

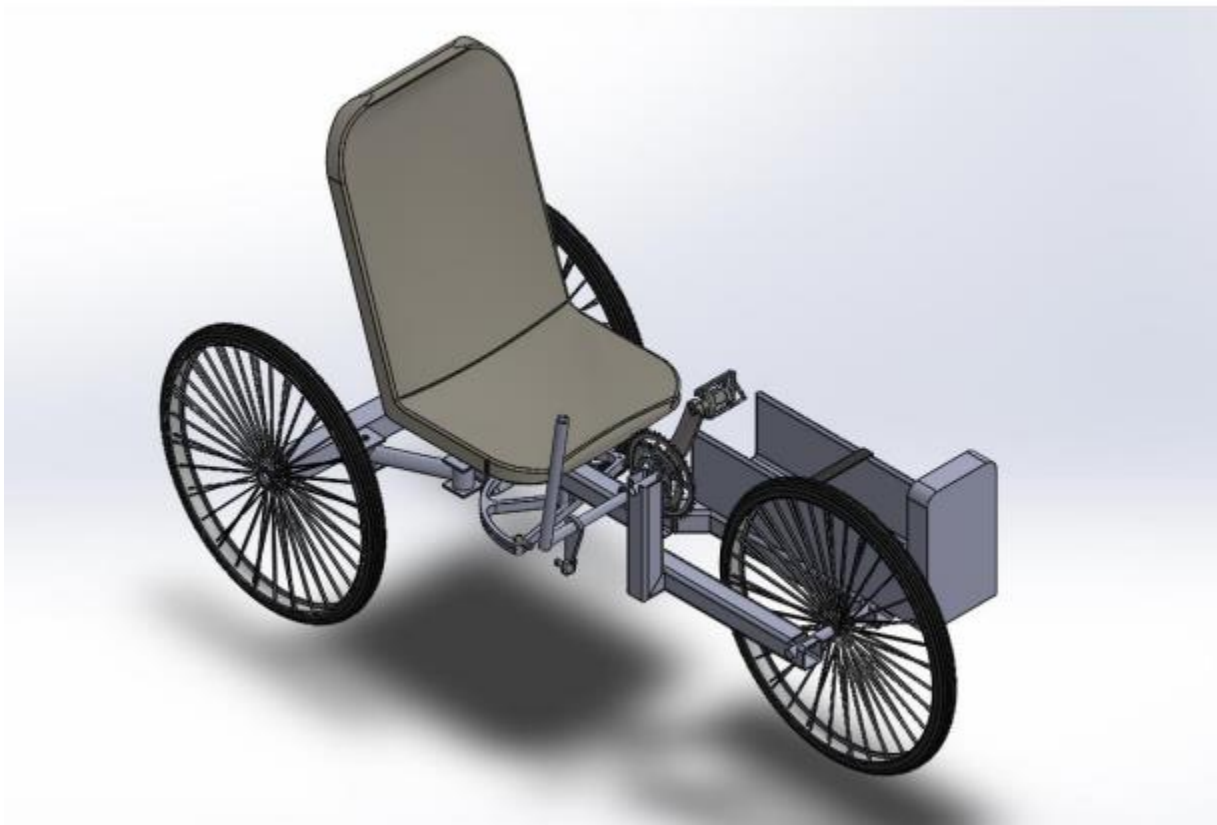
Functional Requirements	Design Concepts				
	I - Lean Steer	II - Dual Pedal	III - Tricycle	IV - HPRowV	V - Red Machine
Stable at low speeds	5	5	5	5	5
Able to be mounted from both sides	3	4	2	1	1
Stable on its own	2	5	5	5	5
Easy to fix	4	4	4	3	4
Fits through a standard door frame (32 in wide)	5	5	5	5	5
Fits into bed of pickup truck	5	5	5	5	5
No larger than 36 in tall	5	5	5	5	5
Used with right side of body	5	5	3	2	5
Corrosion resistant	3	3	3	3	3
Supportive of left side of body	5	2	1	1	4
Adaptable for different heights	4	4	2	5	3
Steer, power, and stop with ease	5	2	4	1	3
Stop without user damage	5	2	3	1	2
Stop within 12 ft from under 25 mph	3	1	2	1	1
Climb a 1-3% grade	4	3	1	5	4
Turning radius less than 35 ft	4	4	4	1	5
<b>SUM OF SCORES</b>	<b>67</b>	<b>59</b>	<b>54</b>	<b>49</b>	<b>60</b>

Table 2: Morph chart for all design concepts to produce final design.

	Concepts						Final Design
	Lean Steer	Red Machine	HPRowV	Dual Pedal	Tricycle		
Design	Steering	Lean	Rod / Drift-style	N/A	Standard	Standard	Needs testing
	Power	Single Pedal	Single Pedal	Crew Machine	Hand and foot pedals	Single Pedal	Single pedal
	Wheel powered	Rear	Front	Front 2	Front	Front	Front wheel
	Braking	Disk	Rim braking	N/A	Coaster brakes	Hand lever rim brake	Rim braking
		3 wheel	1 wheel	N/A	1 wheel	1 wheel	3 wheel
	Handlebar	Single in center	Single on right	Crew Handle	Hand pedal	Chopper	Single on right
	Pedal	Clip in	Clip in	Velcro Footstrap	Standard	Clip in	Clip in
	Wheel Config.	2 Front 1 Rear	1 Front 2 Rear	2 Front 1 Rear	1 front 2 rear	1 front 2 rear	1 front 2 rear
		20"	20"	20"	20"	20"	20"
	Left Leg	Support sling	Support Sling	Clip In	Support foot rest	N/A	Support sling
	Mounting	Swivel Lock 90 deg.	Swivel 90 degree	Swivel chair 90 deg	Swivel chair 90 deg	N/A	Swivel and lock
	Adjustments	Push Button Telescoping	Push Button Telescoping	Seat Distance on Crew Machine	Telescoping frame	Adjustable seat	Telescoping frame with quick release
	Stability	Kick stand	3 Wheels	3 Wheels	3 Wheels	3 wheels	3 wheels
Parking Brake		Parking Brake	Parking Brake	Kickstand	Kickstand	Parking brake	

## 4.0 Design Selection

The final design concept was a combination of various elements from each of the preliminary design concepts outlined in Chapter 3. From the morph chart in Chapter 3 (Table 2), the team identified the elements worth carrying into the final design. Each of these elements were used to develop the final design concept, the Human Powered Recreation Vehicle (HPRV). This chapter discusses the design choices made for the final design.



*Figure 31: Final model for HPRV.*

The steering mechanism is a four bar linkage which makes it easy to maneuver the vehicle with only one side of the body. For powering the tricycle, there is a single pedal on the right side and a sling on the left side for support. Braking power comes from a rim brake on the front wheel

and provides enough braking power to meet the functional requirements of the project. The frame of the vehicle is length-adjustable so riders of various heights can operate it. A swivel and lever are added to the seat assembly to aid in mounting and dismounting of the vehicle. The seat swivels 90 degrees and locks in place for mounting and then swivels back to riding position. Using a lever, the seat is raised and lowered for the rider's comfort.

The team made sure to emphasize ease of use for the rider while making design decisions. Mounting, dismounting, powering, and braking are meant to be intuitive and not induce struggle. A parking brake is combined with the rim brake lever on the right side; this keeps the tricycle stable during mounting and dismounting. To ensure the user can power the vehicle with ease, the pedal on the right side is clipped into with a cycling cleat. This allows the right leg to push and pull the pedal in order to get full rotation.

The final design meets all functional requirements of the project, and the team moved forward with manufacturing.

## 5.0 Detailed Design Description

The Final Design was agreed upon through the use of a “Frankenstein” method that the team created. Using a spreadsheet (Table 2, Chapter 3.6), design features were given for each row and the team member’s put their individual design concept in the columns with the corresponding design feature that the concept utilized. The design features seen in the first column are based on inputs that are needed to fulfill the functional requirements of this vehicle. The team discussed the viability and usefulness of each of the inputs for all of the concepts and selected the most useful and practical ones to be implemented into the final design. The features have been compiled into Table 3.

*Table 3: Final design components and justifications.*

<b>Major Component</b>	<b>Inspired From</b>	<b>Justification</b>
Steering	Red Machine	Stable at low speeds Single handlebar on the right
Power	Lean Steer	Single pedal on the right
Braking	Lean Steer	Rim brakes
Mounting	Red Machine	Swiveling seat for easy mounting Parking brake
Support	Dual Pedal	Sling for left side Seat belt
Adjustability	Dual Pedal	Telescoping frame for various riders

## **5.1 Steering**

Steering of the vehicle comes from a linkage system developed in the Red Machine concept. There is a single handlebar on the right side. The user can push and pull on the handlebar to turn the vehicle with ease.

## **5.2 Power**

The purpose of the single pedal was an easy way to power the bike and also it creates a simple manufacturing process as opposed to other options. The team decided for simplicity reasons to attach the pedal directly to the front wheel to power. If the back wheels were to be powered, the team would have to attach chains from the front pedals all the way to the back axle. The pedal selection will be a strap-in pedal to allow for the maximum power output to the crank. An attached shoe will allow for both the push and pull of the cycle to contribute to the powering of the vehicle.

## **5.3 Braking**

The means of braking was decided to be rim braking due to the pricing, which is relatively cheap compared to other options. Rim braking also offers an easy setup and use for the user, all while keeping the overall design simple. The purpose of having a single brake lever on the right handlebar would allow for braking with the right side. Three-wheeled braking from the single brake lever was also selected for stability reasons and to assure that the bike will not flip or have troubles braking.

## **5.4 Mounting**

When mounting the vehicle, it is necessary for it to be stable and still. The parking brake will allow for the brakes to be fully engaged and keep the vehicle steady. Having a chair on the bike that could swivel 90 degrees would make mounting much easier and allowing for the user to mount without assistance from another person. Without a handlebar on the left, the user can rotate the seat to the left and not have to move around a handlebar.

## **5.5 Support**

To support the left leg, a sling was selected due to the simplicity of the design and ease of use for the intended user. For more support, a seat belt was designed into the seat to help hold the user in place throughout the ride.

## **5.6 Adjustability**

Fitting this vehicle in the bed of a standard bed of a truck was stated in the functional requirements and a telescoping frame will allow for this and for easy storage. The telescoping frame also allows users of various heights to use the vehicle.



## 6.0 Manufacturing

This chapter will detail the manufacturing processes used to complete the build of the Human Powered Recreation Vehicle. To begin building the vehicle, we assembled a Mobo Adult Triton Pro 20" Three Wheeled Cruiser that we purchased. In order to have the tricycle meet our functional requirements, numerous modifications needed to be made and parts needed to be produced. Once manufacturing was complete, final assembly could begin.



*Figure 32: The Mobo Triton Pro pre-assembly.*



*Figure 33: The Mobo Triton Pro post-assembly.*

## 6.1 OEM Modifications

The first goal of the project was to disassemble parts of the OEM tricycle that did not meet functional requirements, such as powered only with the right side. To do this, we removed the left handlebar and the left pedal. The pedal was press fitted onto a square member, making it nearly impossible to remove. So that we could fully remove the pedal, we used a saw to remove the square member. This also removed a hazard. If the square member was left attached, it could have been caught in the riders clothing as it rotated under operating conditions.

The next functional requirement that we worked to complete was “easy to mount/dismount: must be able to remain stable on its own”. We removed the stock brake lever and replaced it with a brake lever that featured a parking brake.



*Figure 34: Updated brake levers, featuring a parking brake.*

This new lever was attached to the existing brake lines on the bike. Now, when the rider engages the button, it keeps the brakes in the locked position, until the rider deactivates the brake.

By making modifications to the OEM frame, we were able to meet a few of our functional requirements. However, it was essential to make different subassemblies to fully encompass all of the requirements we outlined before starting the design process. To do so we designed and manufactured parts for three major components: a seat swiveling mechanism, a leg

harness, and a safety harness. All of these parts were manufactured using readily available parts. They were also manufactured by solely utilizing tools and machines already available on WPI campus.

## 6.2 Seat Swiveling Mechanism

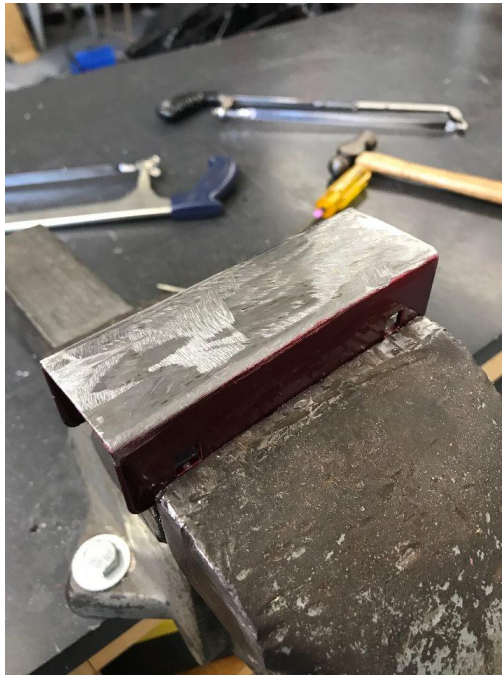


*Figure 35: Rear view of seat frame with swivel mechanism.*

An additional modification to provide “Easy to mount/dismount” is the ability to be “mounted from both sides”. To do this, we wanted to design and manufacture a mechanism that would allow the rider to swivel and lock the seat into different positions, allowing them to get on and off the bike without the main frame in between their strong leg and their weak leg. This led to a large change to the stock seat that came with the tricycle. The OEM design featured a seat frame with a bracket welded to the bottom that allowed it to be bolted to the main frame of the tricycle in two places. Cutting these welds with a grinder was nearly impossible because of the tight spacing and limited clearance. This led to cutting the bracket off using hand saws.



*Figure 36: Bottom of the seat frame.*



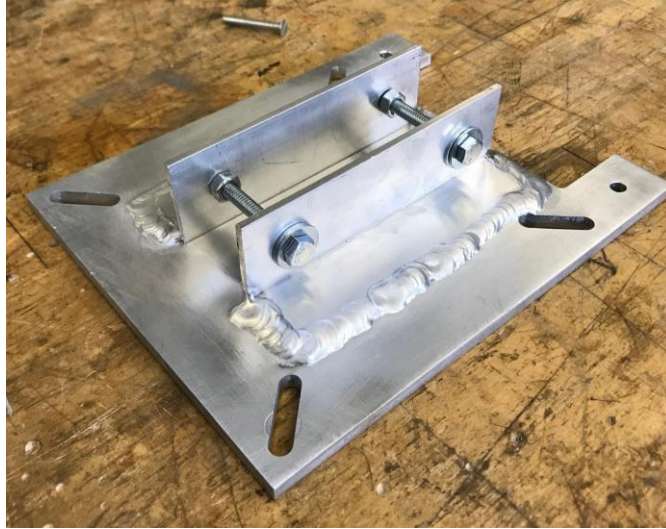
*Figure 37: Bottom of the mounting bracket.*

Once the bracket was off, the grinder was utilized to smooth out both surfaces, removing imperfections and preparing the surfaces for future welding.

With the OEM frame disassembled, we were able to move onto the production of our locking swivel mechanism. The swivel mechanism had to be attached to the seat frame components in Figure 32. To do this, we needed metal plates to sandwich the swivel between the frame components. We machined a top and bottom plate in the Mills of Washburn Shops that would bolt to the swivel. The original intent was to weld the seat frame to the top plate and the bracket to the bottom plate. However, we machined the plates out of 6061 Aluminum, instead of steel, in order to limit added weight. This posed a huge issue because aluminum and steel cannot be welded together. Instead, we decided to take a different approach to both the seat mounting and the bracket mounting.

The seat was a custom shape, produced using tube steel. This made it out of our range of manufacturing ability to reproduce in aluminum. Instead, we utilized nuts and bolts to attach the plate to the frame. The bottom side of the plate was countersunk to allow clearance for the swivel below. The tops of the bolts were then cut to size, to fit the cushion back onto the frame.

The mounting bracket required a tight fit to the main frame, so that ruled out the use of nuts and bolts in the bottom plate. Instead, we decided to remake the 'U' shaped mounting bracket out of aluminum, so we could utilize welding. To do this, we made the negative of the mounting bracket out of aluminum angle brackets. We drilled the holes that were in the OEM bracket into the aluminum angles, so the new bracket could mount to the main frame. While maintaining alignment, we were able to weld the angles to the bottom plate.



*Figure 38: Bottom plate with new mounting bracket after welding.*

With the top and bottom plates both complete, the seat was ready for final assembly. Both plates were secured to the swivel with appropriate hardware. The seat sub assembly was then attached to the main frame of the bike in four places, an additional change compared to the OEM two attachment points.

### **6.3 Left Side Support**

The major intent of the improved tricycle design in the Human Powered Recreational Vehicle is for it to be a vehicle utilized by people with hemiparesis. This led to a functional requirement where “the vehicle must be: supportive of hemiparesis on the left side of the body”. With the left side pedal removed, we needed something to hold the left leg, while the right leg powered the vehicle. For this, we designed and manufactured a sling. The frame of the sling was made out of PVC and solidified using PVC glue. The sling itself was made using traditional sewing techniques on a Sunbrella fabric. This fabric was chosen because of its durable design, so

it could hold the weight of the rider's leg. This sub assembly was then attached to the front fork of the OEM frame using hardware.



*Figure 39: The sling sub assembly attached to the OEM frame.*

The hardware was placed in such a way to keep the sling sturdy and level, preventing it from rotating and hitting the ground.

## **6.4 User Safety**

The final modification made to the overall design was for safety. Another one of the functional requirements that we had was “the user of the vehicle: will feel comfortable and safe during use”. In order to have the rider feel even more secure on this vehicle, we decided to add a seatbelt/harness mechanism. The purchased design featured three mounting points. We cut a piece of steel to size and drilled holes for attaching it to the frame and attaching the upper contact point of the harness to it. We then attached it to the back of the OEM seat frame utilizing generic hardware such that the seat belt would comfortably fit over the user's right shoulder.



*Figure 40: The seat belt mounted to the OEM frame.*

The bottom two contact points were attached to the upper plate that we produced for the swivel mechanism. By utilizing the bolts that held the upper plate to the swivel, the rider can connect or disconnect the seat belt in any of the locking positions, because it rotates with the seat.

To further enhance the safety of the vehicle, the team performed a sharp edge test which consisted of checking the edges of the vehicle and bolts protruding from the frame, making sure the user does not cut themselves. There were several sharp edges found from the pieces that the team manufactured and those were filed down to avoid injury. Some bolts are protruding from the frame towards the wheel to attach the frame but those prove to be of no risk to the user.





*Figure 41: Final prototype of the human powered recreation vehicle.*

## 7.0 Testing

This prototype was tested by members of the team on a series of road tests to satisfy the functional requirements. The first road test was proving that this prototype was stable at slow speeds. The team rode the prototype at varying speeds from 3 to 10 miles per hour while maneuvering around the WPI campus. The user was not concerned about maintaining stability nor had any issues with falling off the prototype. The three wheels on this vehicle proved to provide stability and distribute the weight of the user properly. This also led into the success of being able to mount and dismount the vehicle with relative ease. The prototype is stable while motionless and with the addition of a parking brake, remains motionless while mounting and dismounting. The team manufactured and assembled a swivel mechanism that allows the seat to rotate and lock in twelve positions allowing the user to mount the prototype from each side.

The size of the prototype satisfies the functional requirements by fitting through a standard door frame, into the bed of a standard pickup truck, and not exceeding 36 inches tall. The prototype has a width of 28 inches stretching from the two rear wheels, has a length of 65 inches fully extended and 48 inches collapsed, then a height of 31 inches. The prototype has a final weight of 54 pounds and was tested using a household scale.

While one member of the team was riding the prototype, the others tested it for turning radius, stopping distance and climbing select percent grade hills. The turning radius was tested by one member turning and riding the prototype while the other members marked the locations of the circle it made. A measuring tape was then used to figure out the distance between points which was 8.5 feet. Next was the stopping distance, where a member reached approximately 5 miles per hour on the prototype and then braked and the other members measured the distance using a tape measure. The stopping distance required for traveling 5 miles per hour is 3.25 feet

which is well within range for the functional requirements. Finally, was the prototypes ability to climb a 1-3 percent grade hill. A hill of both 1 and 3 percent grade were selected and one member rode the vehicle up both the hills. The prototype was able to climb both the hills with relative ease.

## 8.0 Conclusions & Recommendations

The human powered recreation vehicle we built met all of the previously defined functional requirements. The primary factors of our design resulted from these functional requirements, and the vehicle was modified accordingly. Specifically, the human powered recreation vehicle focused on the adaptive features such as the swivel seat mechanism, powering and steering the vehicle with one leg, and ease of mounting.

### 8.1 Future Recommendations

Due to the time limitations and scope of this project, there were some aspects of the prototype that could be improved given additional time and resources. The following are the recommendations for design improvements in the future.

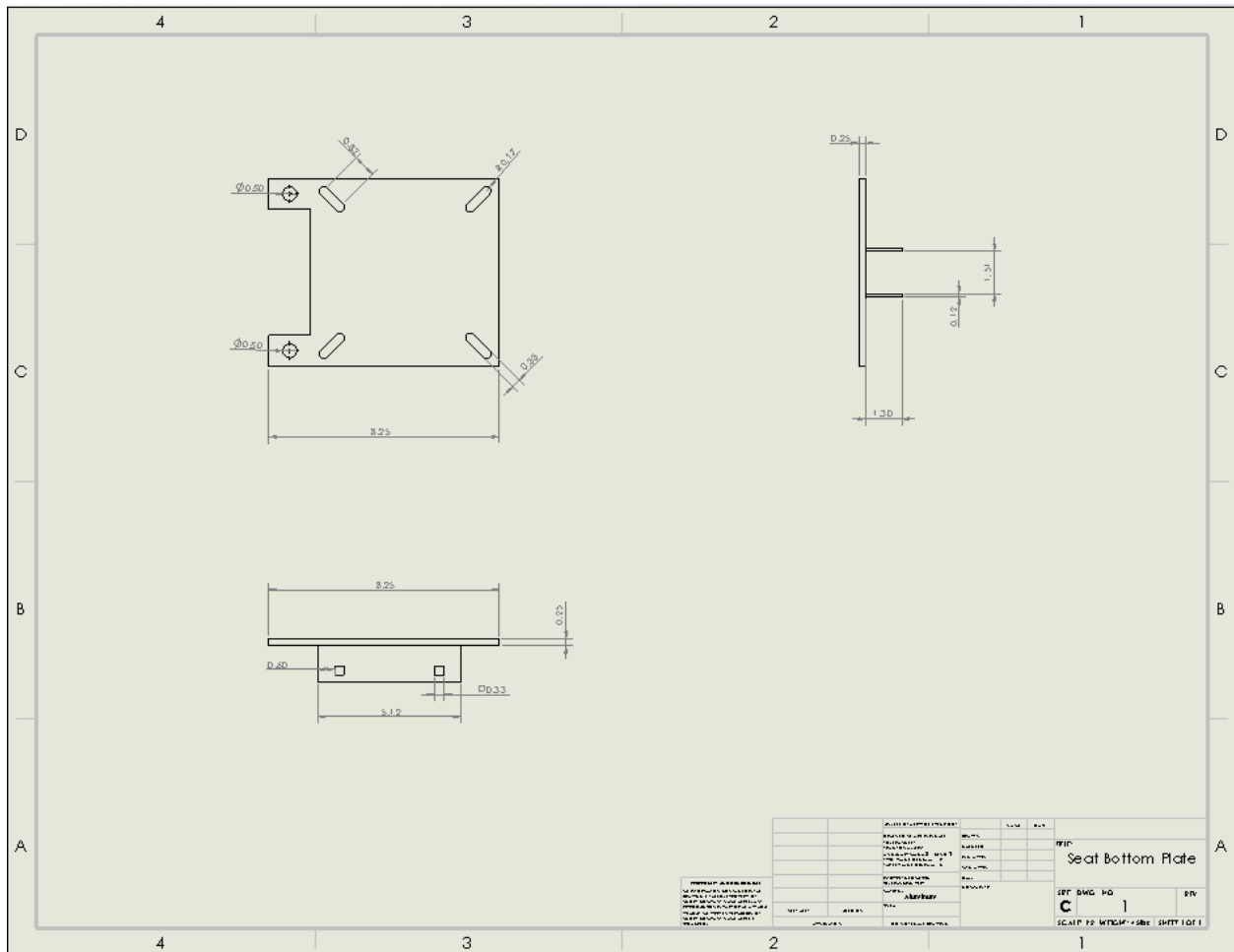
- **Add a handle on the back of the seat to aid in mounting and dismounting:** When we tested our prototype, there was some difficulty mounting the vehicle because there isn't a handle to hold onto while lowering yourself onto the seat. We recommend that a handle be added behind the seat to provide extra stability during this process.
- **Add accessories:** Because our primary audience for the vehicle are adults with mobility difficulties, it is likely that the users of the vehicle would use a cane. We recommend accessories be added to the vehicle to hold a cane and a cup holder for a water bottle.
- **Redesign right pedal:** We suggest that the right pedal be redesigned so that it is easier to strap into with one hand. Replacing the current pedal with a specialized clip in pedal might be the easiest solution.

- **Make arm move with the swivel mechanism:** On the swivel for the seat, the lever that invokes the swivel stays stationary. As the seat moves away from the lever arm, the lever arm can become hard to reach. We recommend that the lever moves along with the swivel so that the user can always reach it.
- **Add a pouch for tools:** One of our functional requirements was that the vehicle is that it is easy to fix. We recommend that a pouch or case be attached to the vehicle to hold the few tools required to fix anything. This pouch could be attached behind the seat to be out of the way.
- **Reinforce the sling on the left side:** The PVC sling on the left side of the vehicle should be further reinforced. The sling experiences vibration when the vehicle is moving. Over time these stresses could make the sling weak, and it could fail. We recommend either changing the material or reinforcing it on the far left side to better secure it to the vehicle frame.
- **Make the seat height adjustable:** To further aid in mounting and dismounting the vehicle, we recommend that the seat height be adjustable. Similar to a desk chair, the seat should be able to be raised and lowered with a lever.
- **Increase the length of the seat belt:** Currently, the seat belt is not as long as we expected it to be. The seat belt should be replaced with a longer one in order to fit a larger range of users.
- **Fix the female end of the seat belt to the seat:** When mounting the vehicle, the female end of the seat belt either rests on the seat or hangs down. Either of these options is not ideal because the user either sits on it or may have difficulty reaching it. We recommend

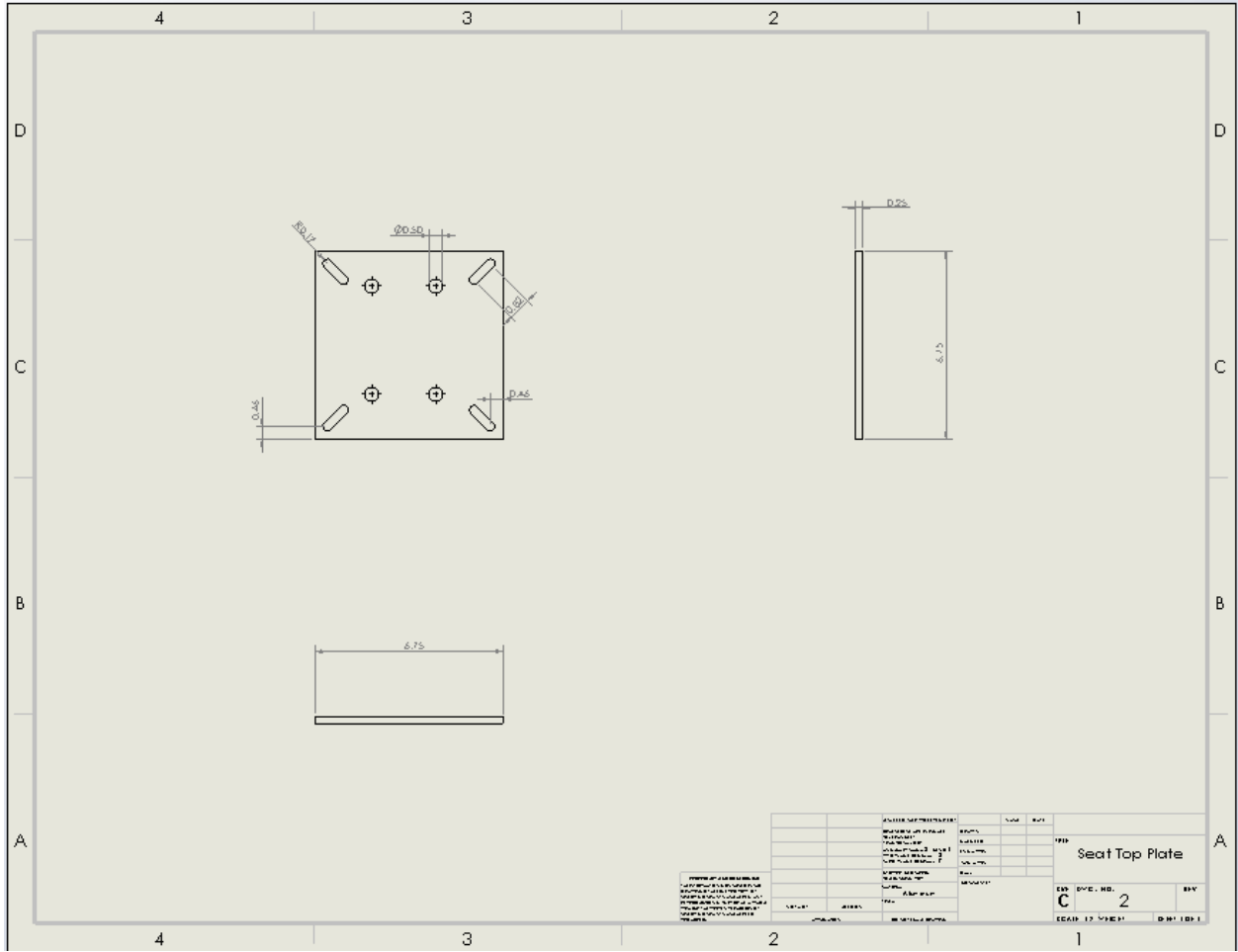
that the female end of the seat belt be fixed to the side of the seat so that it is not on top of the seat when the user sits down.

- **Make the vehicle reversible:** Although the intention of our prototype was for it to be used predominantly with the right side, we recommend that the vehicle be modified so the pedal can be switched to the left side. This way, the vehicle could be used regardless of which side is affected by hemiparesis. The steering and braking can easily be reversed as it is now, so only the pedal would need to be modified.

# Appendix A: Part Drawings

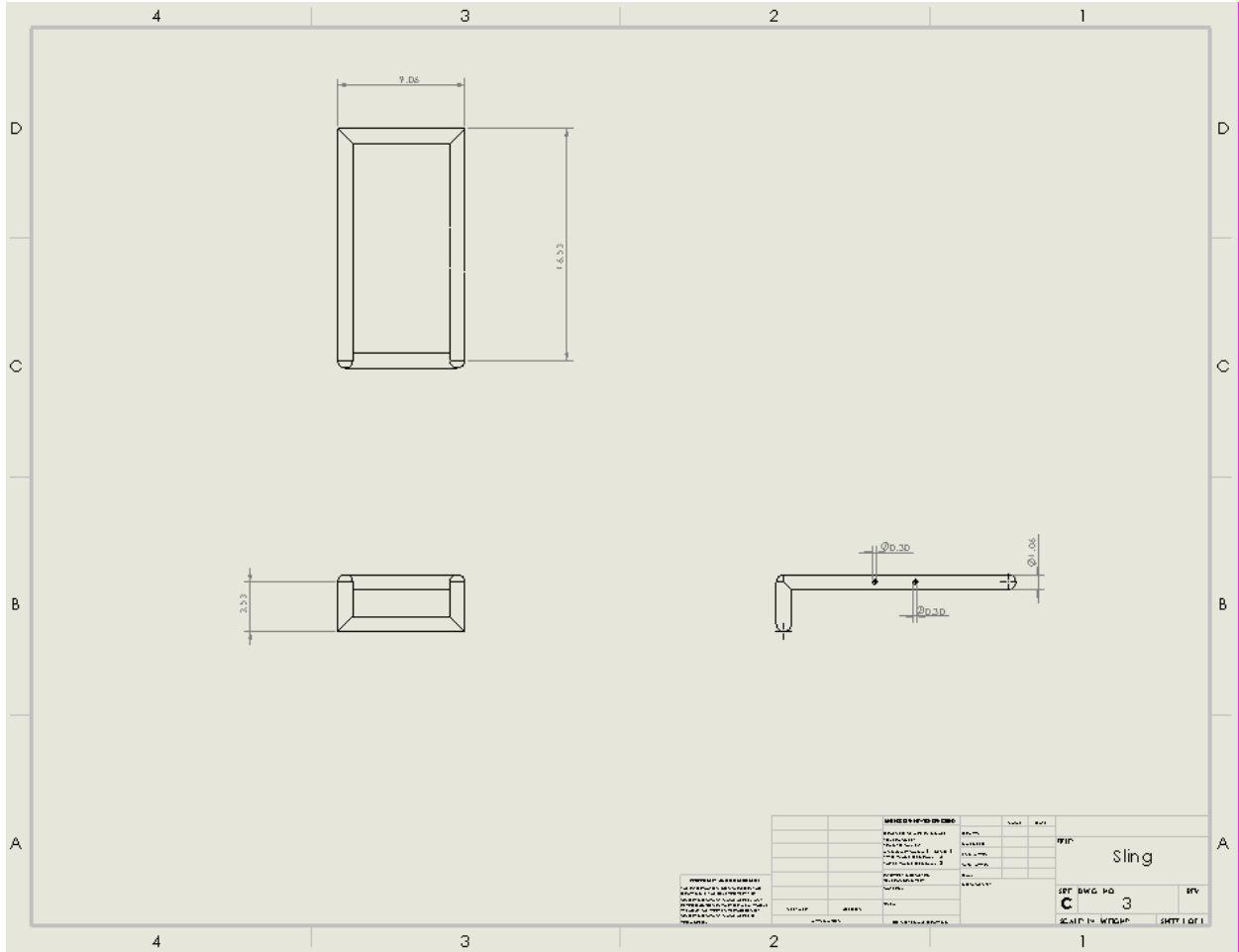


Seat swivel mechanism bottom plate.



*Seat swivel mechanism top plate.*





Left side support sling.

## Appendix B: Bibliography

1. NHLBI. (n.d.). About Stroke. Retrieved from <https://www.nhlbi.nih.gov/health-topics/stroke>
2. CDC. (2018, October 10). About Stroke. Retrieved from <https://www.cdc.gov/stroke/about.htm>
3. Heart.org. (n.d.). Heart and stroke association statistics. Retrieved from <https://www.heart.org/en/about-us/heart-and-stroke-association-statistics>
4. Medical definition of hemiparesis. (n.d.). Retrieved from <https://www.merriam-webster.com/medical/hemiparesis>
5. Hemiparesis – national stroke association. (n.d.). Retrieved , from <https://www.stroke.org/we-can-help/survivors/stroke-recovery/post-stroke-conditions/physical/hemiparesis/>
6. Watanabe, T., Honda, Y., Fujii, Y., Koyama, M., Matsuzawa, H., & Tanaka, R. (2001). Three-dimensional anisotropy contrast magnetic resonance axonography to predict the prognosis for motor function in patients suffering from stroke. *Journal of Neurosurgery*, 94(6), 955–960. <https://doi.org/10.3171/jns.2001.94.6.0955>
7. Fenichel, G. M. (2009). Chapter 11 - Hemiplegia. In G. M. Fenichel (Ed.), *Clinical Pediatric Neurology (Sixth Edition)* (pp. 249–265). <https://doi.org/10.1016/B978-1-4160-6185-4.00011-3>
8. Rak, A. (2014). SPORT AND RECREATION AS A QUALITY OF LIFE FACTOR ON EXAMPLE OF POLAND. *Human Capital Without Borders*.

9. Aksoy, Y., Çankaya, S., & Taşmektepligil, M. Y. (2017). The Effects of Participating in Recreational Activities on Quality of Life and Job Satisfaction. *Universal Journal of Educational Research* , 1051–1058. <https://doi.org/10.13189/ujer.2017.050619>
10. Georgian, Bădicu & Balint, Lorand. (2017). THE IMPACT OF LEISURE SPORTS ACTIVITIES ON THE INDEX OF QUALITY OF LIFE IN ADULTS. *JOURNAL PLUS EDUCATION*. 2068-1151.
11. Schwarzenegger, A., Chrisman, M., & Coleman, R. (2005). The Health and Social Benefits of Recreation.
12. Benefits of sport and recreation. (n.d.). Retrieved from <http://www.dsr.wa.gov.au/support-and-advice/research-and-policies/policies/benefits-of-sport-and-recreation>
13. Survey finds Disabled Sports USA participants twice as likely to be employed as adults with disabilities. (2009, May 19). Retrieved from: <https://www.disabledsportsusa.org/survey-finds-disabled-sports-usa-participants-twice-as-likely-to-be-employed-as-adults-with-disabilities/>
14. Disability Grants (n.d.). Grants for sports. Retrieved from: <https://www.disability-grants.org/grants-for-sports.html>
15. Recreation important for adults with disabilities. (2015, August 26). Retrieved from: <https://www.paraquad.org/blog/recreation-important-adults-disabilities/>
16. Miller, A. M. (2015, April 6). Exercising With a Disability. *U.S. News*.
17. Breakstone, White & Gluck. (n.d.). Facts about massachusetts bicycle laws. Retrieved from website: <https://www.bwglaw.com/facts-about-massachusetts-bicycle-laws.html>

18. Massachusetts bicycle coalition. (n.d.). Retrieved , from Massachusetts Bicycle Coalition website: <https://www.massbike.org/laws>
19. Important ma traffic laws related to bicyclists, pedestrians and motorists | masco. (n.d.). Retrieved from [https://www.masco.org/directions/MA\\_laws](https://www.masco.org/directions/MA_laws)
20. Elert, G. (n.d.). Motion. Retrieved from The Physics Hypertextbook website: <https://physics.info/motion/>
21. Kovacevic, Ahmed. (n.d.). Mechanical Analysis Belt and chain drives. Retrieved from <http://www.staff.city.ac.uk/~ra600/ME2105/Analysis/ME2104-A-3.pdf>
22. How bikes work - brakes | madegood. Bikes. (n.d.). Retrieved from: <http://www.madegood.org/bikes/complete-guide/brakes/>
23. Bike Gears and Shifting Basics. (2018). Retrieved from <https://www.rei.com/learn/expert-advice/bike-gears-and-shifting.html>

# Appendix C: Authorship

Introduction: Katherine Schweikert

## Background

Stroke: Katherine Schweikert

Recreation & Quality of Life: Katherine Schweikert

Assistive Devices: Alex Gallant

Human Powered Vehicles: Alex Gallant

Road Safety: Nolan Bell

Mechanics of Vehicular Motion: Michael Munroe

Functional Requirements: Nolan Bell

## Design Concepts

Dual Pedal Vehicle: Katherine Schweikert

Right Side Tricycle: Katherine Schweikert

Lean Steer: Michael Munroe

Red Machine: Alex Gallant

HPRowV: Nolan Bell

Design Matrices: Michael Munroe

Design Selection: Nolan Bell

Detailed Design Description: Katherine Schweikert

Manufacturing: Michael Munroe

Testing: Alex Gallant

Conclusions and Recommendations: Katherine Schweikert