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Investigating the Efficiency of Energy Transfer in Vehicular Motion

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by
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I would like to dedicate this project to my father and mother who have made great sacrifices to enable me to pursue my studies in the U.S.

Acknowledgements

I would like to thank God, as well as my family and friends who have all provided support when needed. I would like to thank Dr. Paul Cadden-Zimansky for his advice and availability throughout the course of the project and the driver, Bruno Becher, for his stellar contributions.

Preface

One of my principal interests in life is transportation which involves building and working with vehicles, and that is why I chose to pursue this project. This write-up, in addition to being a small-scale study of the various properties of automobiles, is to serve as a guide for others who wish to pursue such an endeavor in the years to come. To do this, I first take a look at three of the many key structures which enable vehicular movement: The engine, the wheels and the steering system. After this, I give a detailed recount of how I built the vehicle used in this project with efficiency tips littered throughout the section. Then, I briefly explain the turn radius test and maximum velocity and acceleration tests carried out while presenting and analyzing the data. In all, this project investigates the dynamic motion of vehicles both in a straight line and in curves and attempts to use the data gathered to establish a basic understanding of the efficiency of energy transfer in vehicular motion.

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1 Overview

1.1 Choice of Framing Material

In building any sort of vehicle, the framing material most often used is some kind of steel/aluminum alloy which makes it reasonably sturdy while remaining light and nimble. Go-karts are no different as you'll find that most designs incorporate these materials for framing as well. However, while metal frames are ideal (especially for more complex designs), using steel requires a strong background in metalworking, which most do not have. Furthermore, the cost of building a go-kart frame out of metal is higher than if done with other materials, and, for this reason, I opted to build the kart out of wood.

1.2 Basic Design

The dimensions used in this project are tailored to the specifications of my driver, Bruno Becher, who acts as a representative of the average person. The chosen design is fairly simple with all pieces requiring only straight cuts. The kart is powered by a $6.5\ HP$ engine utilizing a single rear wheel drive configuration as well as a foot steering system. The decision to use foot steering instead one more similar to the traditional rack and pinion system was made in order to speed up the assembly period. The frame was constructed using a $4'$ x $8'$ plywood board which served as the base and for structural support, I used 3 long 2” x 4” wooden planks and cut down pieces which were placed on the left and right side of the board with one in the center (which acted as the steering plank mount) across the length of the vehicle. Across the width, I used three more planks and placed them at the front, middle and rear end of the board. The length of the steering plank roughly matched the width of the plywood base and the braking and acceleration are controlled by bicycle style handlebars attached to the extension of the central support plank.

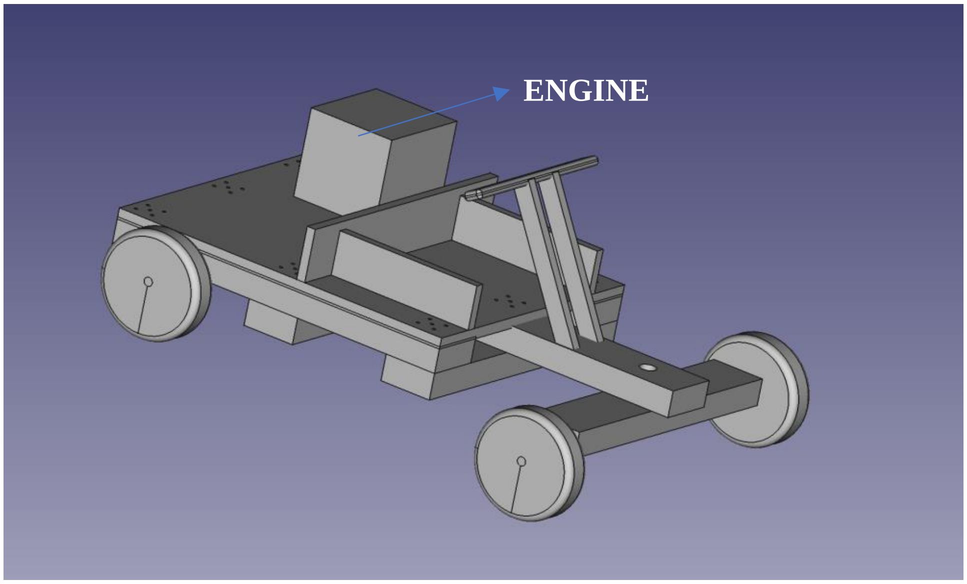

Figure 1.2.1 Kart Model

1.3 Making Cuts

The tool I used most when making cuts was a hand-held circular saw because of the increased controllability and precision it has over the common hacksaw. However, if one isn't too worried about aesthetics or the added physical labor involved, all the cutting in this project can be done with a hacksaw. The process of making cuts with the circular saw involved the use of a guide which, due to the extension of the plate, was offset to ensure the cut was being made at the right location. Any straightedge can be used for this as long as its length is sufficient to guide the cut in its entirety, as it would need to be clamped down; for most cuts, I found that a meter rule was sufficient. However, for another part of the project - which involved cutting galvanized steel into smaller chunks - I used a band saw but a hacksaw could also be used here.

1.4 Drilling and Assembly

For the assembly of all pieces, I used a power drill. Power drills are useful because they offer a quick and efficient way to create lead holes as well as tighten screws into the wood with a hex shank screwdriver bit. The drill is especially useful when attaching the planks to the board using the 3 ½" deck screws and drilling holes in the wood to attach the wheels, engine and steering plank.

1.5 Other Considerations

For this model, the use of foot steering leads to an interesting issue that has to be considered carefully to ensure the safety of the operator. First and foremost, turning doesn't occur in the traditional way, where both wheels are locked into position and turned relative to some fixed axis with the turn angle of the inside tire being greater than that of the outside tire. Instead, the axis itself is rotated with both tires being turned at the same rate and angle. The main issue that arises from this is the need for driver's legs to travel through large arcs to make turns which could lead to oversteering. The risk of oversteering is further accentuated by the fact that the front wheels do not individually have a pivot point but, rather, there is a bolt in the center of the steering plank which acts as the pivot for both wheels. Due to this, the wheels have to remain fixed to the plank to provide a steady and sensible steering system, but that means there won't be restoring (self-aligning) torque applied to them while turning.

Furthermore, this affixation of the wheels to the plank in conjunction with the fact that it is steered by foot, increases the mechanism's overall sensitivity to surface variations on either wheel. Sometimes, drivers may find that the steering plank wobbles forward and backward during acceleration on textured/uneven surfaces due to imbalances as the wheels attempt to create enough traction to launch the car forward. However, these issues are only truly serious at very high speeds and with a 6.5 HP engine, I'm confident that by exercising caution and ensuring the driver adheres to safe driving practices, the issues wouldn't be a hassle. Nonetheless – to lessen any risk – the kart would only be driven in straight lines at its higher speeds, while the maximum velocity and acceleration tests are being conducted.

1.6 Safety Guidelines and Good Work Habits

The fundamental rule of workshops applies here which states that you should, when cutting, wear safety glasses. In addition to this, it is common practice to use over the head ear muffs/ear plugs if the sound is loud enough to require an increase in vocal amplitude above normal speaking levels when talking. Furthermore, when working on the project, it is very important to remember the following things;

- While using a circular saw, ensure off hand remains on the knob through the entirety of the cut to offer stability.
- Ensure all power tools are turned off (remove battery) or centralize the forward/reverse switch when not in use.
- Ensure clamp fastener is pointed away from the path of the saw
- Set drill to Level 1 with less torque while fastening the deck screws (use Level 1 or 2 and drill torque when creating lead holes)
- Ensure lead holes are pre-drilled before inserting deck screws. Failure to do so may result in the wood splitting.
- Use washers on all wood to metal contact points
- Later on, the use of a milling machine - while not necessary - might be helpful if one is readily available. Thoroughly read the manual before operation; the same goes for all machining tools.
- Proper protective gear should be used by the driver while operating the kart at all times.

2 Background

This section gives a brief explanation of some of the processes which permit vehicular motion. Specifically, it highlights the physics behind steering, the rotational dynamics of the wheel to provide motion and a brief description of how the engine converts chemical to kinetic energy. In essentially all key areas, the systems utilized on the go-kart differ from those used in traditional automobiles. So, it is only appropriate to provide a description of the way these key components work.

2.1 Engine Operation

As stated earlier, the engine used is a $6.5\ HP\ (212cc)$ OHV (Overhead valve) horizontal shaft gasoline engine. It is an internal combustion engine which, like all other gasoline or diesel-powered engines, ignites the fuel which exerts pressure on and drives a piston that elicits the change from chemical to kinetic energy. This engine in particular is a recoil-start, 4-stroke engine and at a basic level, it operates like any other engine fitted in commercial vehicles with the exception of its method of starting. In short, pulling on the rope causes the tensioning of a spring which is connected to the crankshaft and is simply a means of getting it to revolve. However, in key/button starter vehicles, this same effect is achieved through the activation of a motor.

The process of converting fuel into energy for continual rotation/motion in a process known as the engine cycle, is more interesting and is likely the most important design feature of the IC engine. A 4-stroke engine, like the one I use, consists of a piston that completes 4 distinct strokes. The first is known as the intake stroke where an air and fuel mixture is let into the combustion chamber. The second is the compression stroke where the piston pushes up against and compresses the newly introduced mixture. Succeeding this, there is an ignition event where an electrical current is sent through the spark plug and it ignites the mixture which causes a release of heat and the subsequent pressure – a result of this heat – forces the piston down in what is known as the power stroke. Then via a connecting rod, the piston exerts a torque on the shaft and causes it to rotate (the clutch is attached to the shaft on this engine). The fourth and final stroke is the exhaust stroke in which the toxic waste gases produced are released from the chamber via a valve or pipe.

2.2 Wheel Velocities

Each wheel of a vehicle in motion exhibits two types of velocities namely; angular and translational with the relation being that the rotation of the wheels causes the forward or backward motion of the vehicle. The equation that relates these two quantities is;

$$\vec{V}_T = \vec{\omega} r \qquad [2.1]$$

Where, $\vec{V}_T$, is the translational velocity in $\frac{m}{s}$ and, $\vec{\omega}$, is the formal notation for the angular velocity of a moving body in $\frac{rad}{s}$. Equation 2.1 simply states that the translational velocity of the wheel is equal to the product of the wheel's angular velocity and radius. Another thing worth noting here is how these velocities add or subtract based on the point of observation on the wheel. At the very top of the wheel, the vectors, $\overrightarrow{V_T}$ and $\vec{\omega}$, are pointing in the same direction and from our knowledge of vectors, this means the quantities add up directly. Furthermore, recall from $equation$ 2.1 above, that $\overrightarrow{V_T} = \vec{\omega} r$ and so,

$$\vec{V}_{top} = \vec{\omega} r + \vec{\omega} r = 2\vec{\omega} r \qquad [2.2]$$

$$\Rightarrow \vec{V}_{top} = 2\overrightarrow{V_T} \qquad [2.3]$$

And at the very bottom (point of contact between the wheel and the ground), $\overrightarrow{V_T}$ and $\vec{\omega}$ are equal and opposite so they cancel out and the net velocity is zero. Figure 2.2.1 below gives a visual representation of this.

$$\Rightarrow \vec{V}_T = \vec{\omega} \qquad [2.4]$$

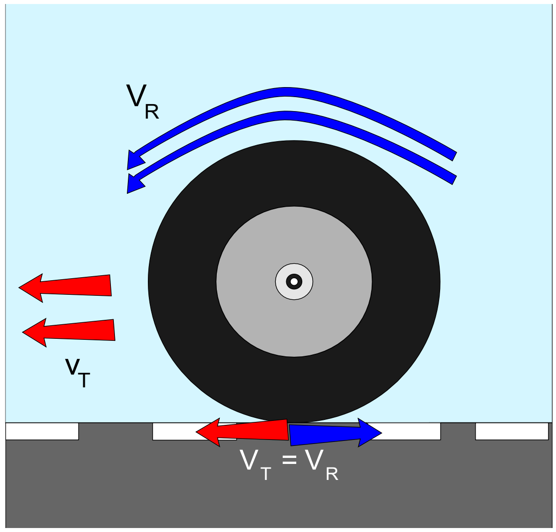

Figure 2.2.1 Velocity components of wheel

2.3 Steering

As mentioned earlier, this go-kart will use a foot steering system with the front wheels connected and turned via a steering plank. However, production vehicles are typically fitted with a system that utilizes a rack and pinion design or a recirculating ball steering system, as well as a differential – among other parts – to control the vehicle's orientation. While turning, the inside wheels of a vehicle always cover a smaller distance than the outer wheels and so it is necessary for its steering to account for this and it is achieved through the use of a differential. This is essentially a device – conventionally connected to the rear wheels – that is used to increase the speed of the outer wheel while turning so as to compensate for the greater distance covered. Furthermore, as I will demonstrate in this section, it is necessary for adjustments to be made to the front wheels as well to provide greater control of the vehicle while turning. But why is this the case? The diagram below depicts the circles formed when the front wheels of typical production vehicles are turned at the same angle;

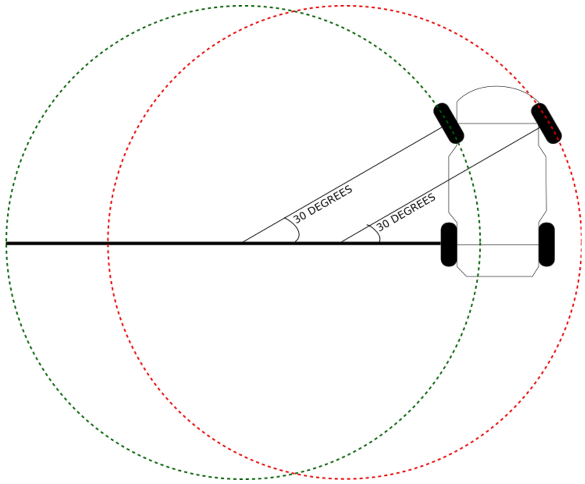

Figure 2.3.1 Vehicle steered with 1:1 ratio

As we see from the diagram, wheels turned at the same angle i.e. 1:1 ratio, would result in differing centers of rotation and because of this, the circles formed by the inner and outer wheel would intersect. This is a sign that sideslip would occur (especially at high speeds) as the inner or outer wheel, given its fixed position in relation to the car and to the other wheel, would try to correct for the intersection of the paths and force the car to traverse a more circular route thus, it would slip or skid into its ideal position which could lead to fatal accidents. So, this means the tires have to be turned at different angles to ensure the vehicle completes the turn smoothly and this is achieved in most production vehicles via the use of Ackermann steering geometry. Which is comprised of an inelastic bar called a tie-rod and a set of linkages to the steering arm that offset the angle of the outer and inner wheel while turning so the inner wheel turns at a greater angle than the outer wheel.

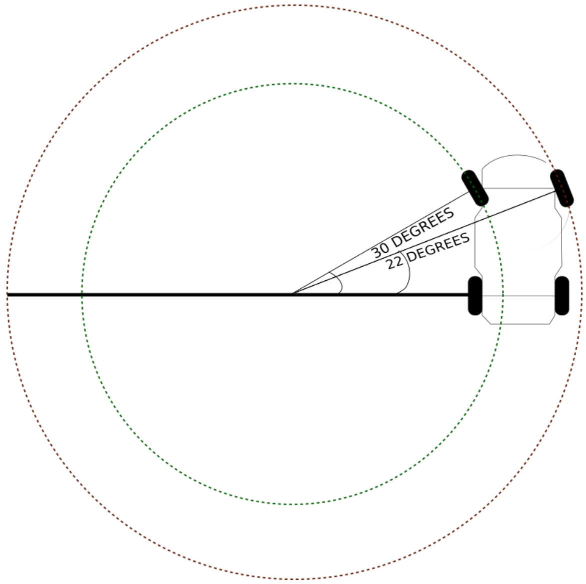

Figure 2.3.2 Ackermann Geometry Applied to Vehicle

From Figure 2.3.2 above, we see that when Ackermann geometry is applied and as an example, say the external angle is turned by 22°, the center of rotation is the same for all wheels and the car is able to complete the turn without slipping.

Interestingly, the go-kart's steering system is able to somewhat mimic the effects noticed through the application of Ackermann's principle and turn without much slippage. This happens because the wheels aren't individually turned/steered on a fixed axis/ball joint but the axis itself is shifted by some angle; like a turntable. As a result, while one tire moves x degrees below zero, the other moves x degrees above zero and the vehicle is able to steer with relative ease because neither circle intersects.

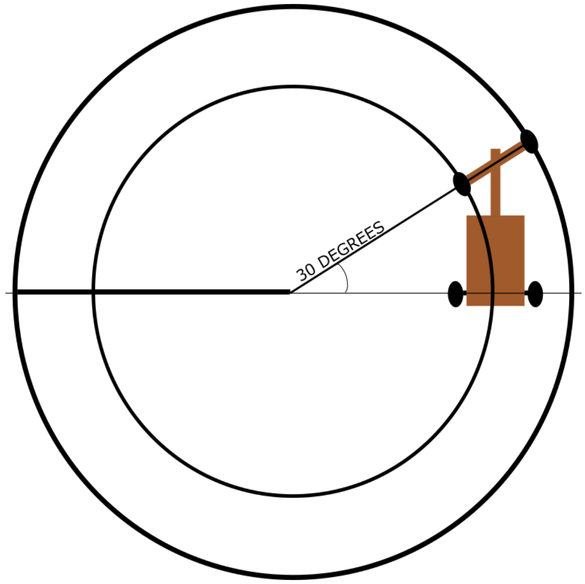

Figure 2.3.3 Go-kart steering at a 30° angle

3 Assembly

3.1 The Frame

The process of constructing the frame of the kart started with cutting a 4′ x 8′ (L) plywood board into two equal 4′ x 4′ pieces. However, the board was later trimmed to a narrower 2’8”’ x 4′ base per the request of the driver. The next step involved cutting two, 2” x 4” wooden planks to use as the supports for the plywood board in order to minimize flexing. As stated earlier, they were placed both across the width and along the length of the plywood board. Furthermore, the central plank along the length of the kart is to be used as the steering mount; as a result, it should extend past the kart’s length. The length of this extension is based on the driver’s preference which was obtained by simply asking them to sit on the plywood board with each leg on either side of the central plank and simulate steering the kart (this should be done with a mock steering plank placed on the mount with the bottom of their feet lightly resting on the edge of the plank directly facing them). For Bruno, we found that his back, when in a seated position on the board was around 10” − 12” from the front end and for the steering plank, placement anywhere between 16” − 20” in front of the board was comfortable for him. The configuration is shown below;

Figure 3.1.1 Depiction of how steering plank connects the kart[1]

[1] A bolt should run through the middle of both the central beam and steering plank to provide a pivot for steering. Washers should be placed between the wooden pieces to reduce friction.

3.2 The Wheels

Mounting the wheels was done through the use of thin-walled square tubing, with holes pre-machined or drilled after purchase, in order to securely fasten the wheels onto the wood. In this case, I used galvanized steel rails and cut them into 8 sections – each with three holes – using a bandsaw. The intent was to use two cutouts for each tire and instead of using one long axle to connect the wheels on either side, I used partially threaded bolts to individually fasten each wheel to the kart. This was done to eliminate the need for welding because threading allows for the use of lock nuts to secure each wheel in place. Furthermore, partial threading was preferred over full threading because there would be less friction and wear on the wheel bearings during motion as the tires rotate on a smoother axis.

Figure 3.2.1 Wheel mounted onto the steering plank using galvanized steel rail.

The diameter of the holes in the galvanized steel rail was slightly bigger than 3/8" so it was convenient to use this size bolt to fasten them to the board. Furthermore, the bolt that acts as the axle for the wheel needs to be sturdy, so I used 5/8" diameter bolts. However, given that the holes in the steel rail are smaller than this diameter, it is necessary to – either with a milling machine or a drill – enlarge the central hole to this diameter. This must be done through both holes of each rail cutout. For the tires at the back of the kart, longer bolts might be needed to provide enough room for spacing and adjustment of the drive wheel while aligning the sprocket with the engine's clutch.

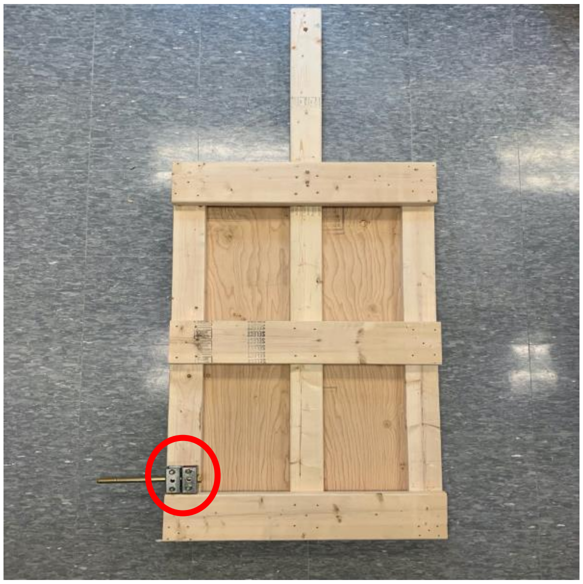

Figure 3.2.2 Underside of the kart which reveals the basic design and support structure.

From Figure 1.2.1, we see the left wheel mount is already attached to the frame and in general, these should be placed as far back as possible to create adequate room for the engine.

3.3 The Engine and Drive Wheel Alignment

Once the rails are attached to the board with the wheel bolts passed through them, the logical next step is to mount the engine. This was done by first of all placing the engine in the desired orientation, with the shaft pointing out towards the drive wheel while ensuring that it extends a reasonable distance past the edge of the kart. Then, the clutch should be fitted onto the shaft using the lock and pins[2] provided.

Afterwards, use a straightedge to make sure the teeth of the clutch and sprocket are aligned[3]; with a pen or pencil, outline the engine's frame on the kart and mark the fastening points. Then using a power drill and a 5/16" bit, drill holes all the way through each point as shown in Figure 3.3.1;

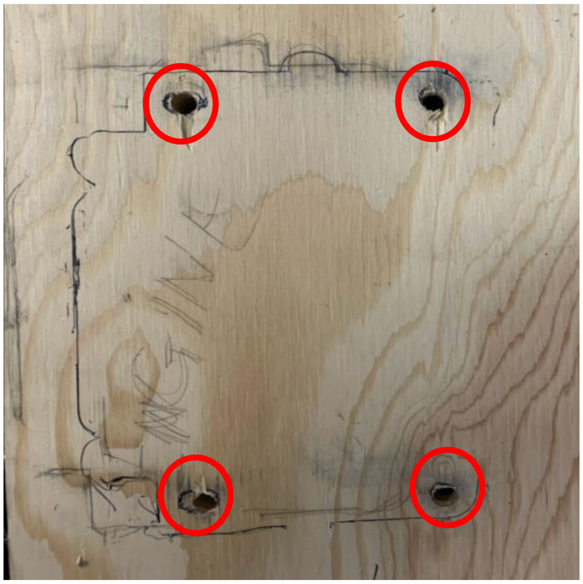

Figure 3.3.1 Engine's outline with fastening holes marked and drilled.

[2] An Allen wrench is needed to fasten the pins.
[3] It is advisable to determine and carry out wheel spacing before this to improve accuracy. Another technique which proved handy for alignment was – without the clutch pinned to the shaft – connecting the sprocket and clutch via the chain and spinning the free drive wheel by hand until the clutch eventually settles in its aligned position.

After this, drill holes slightly above each of the initial holes then connect them by slowly boring through the wood. That can be achieved via moving the drill up and down in the direction perpendicular to the plywood board's plane while slowly pulling the drill towards the initial fastening hole. This is done so the engine can be shifted forward to tauten the chain during installation. The result is shown in Figure 3.3.2[4];

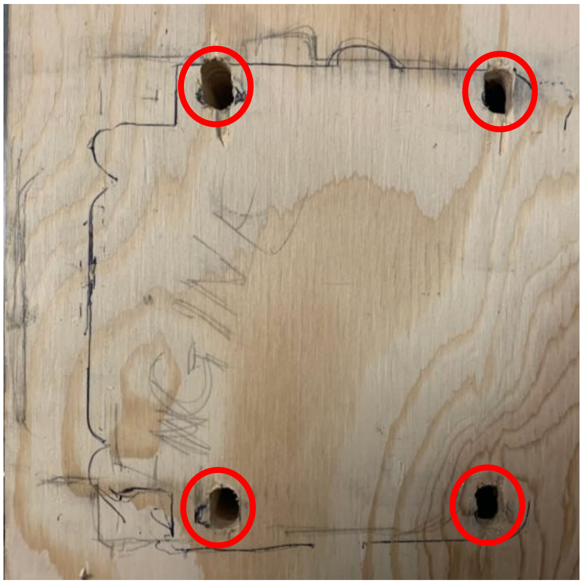

Figure 3.3.2 Holes extended. Might need to be repeated depending on chain length.

Once this is done, depending on how far the clutch extends past the board, it might be necessary to insert wheel spacers to ensure the drive wheel doesn't slide out of its aligned position. The spacing of the drive wheel should be replicated as accurately as possible on the other rear tire to increase the ease of maintaining a straight path while driving. For spacing, I used a standard PVC pipe with a diameter of 0.957" which is slightly bigger than the bolts. Once the distance from the drive wheel hub to the galvanized steel rails is found, any saw can be used to cut out the required length for spacing on both sides. Figure 3.3.3 shows what this should look like;

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[4] This process might need to be repeated again over time as the chain naturally slackens.

Figure 3.3.3 PVC used for spacing on Right rear wheel

Note: washers could be an alternate means of providing spacing if one is able to stack a sufficient number of them[5].

Unlike the rest of the tires, the drive wheel is a special configuration which includes a sprocket hub, sprocket and brake drum. This can be purchased pre-assembled, but due to the unpredictability of its availability, it might be necessary to purchase the individual parts and assemble by oneself. All parts can be purchased on the website stated in Appendix B – or from other sources. Naturally, the drive wheel must be the same size as the other tires on the kart and should ideally be purchased with the sprocket hub already attached to it. The assembly is relatively straightforward as long as the sprocket used has a smaller[6] diameter than the wheel itself. The first step is to pass the bolts through the fastening points on the sprocket hub, then align them with the holes on the sprocket itself and pass the bolts through (this is best achieved

[5] Even if the distances don't match the initial measurement, the position of the clutch can be adjusted easily to restore alignment with the sprocket.
[6] Approximately the same as the rims or the wheels inner diameter

with the wheel in its upright position to prevent the bolts from falling out). After this, pass the bolts through the brake drum as well and partially secure the entire configuration using locknuts[7]. Then lay the wheel on its side with the face of the sprocket pointing upwards and screw in the nuts completely.

[7] This is done to enable us to lay the wheel on its side and tighten each bolt individually without worry of the others falling out.

3.4 The Backrest

The backrest was built using a 28” (L) , 1 ½” x 12” plywood board and three 12” (L), 2” x 4” planks as the supports. Assembling the seats is a relatively simple task; it was done by attaching the three planks to the left edge, center and right edge of the board using deck screws, then connecting it to the kart using corner brackets. In total, three braces were used to fasten the backrest to the plywood base which has proven a sturdy setup thus far. As an added safety feature, side rails/protectors were installed. This consisted of two 3 ½” x 18 ½” planks on either edge of the plywood base.

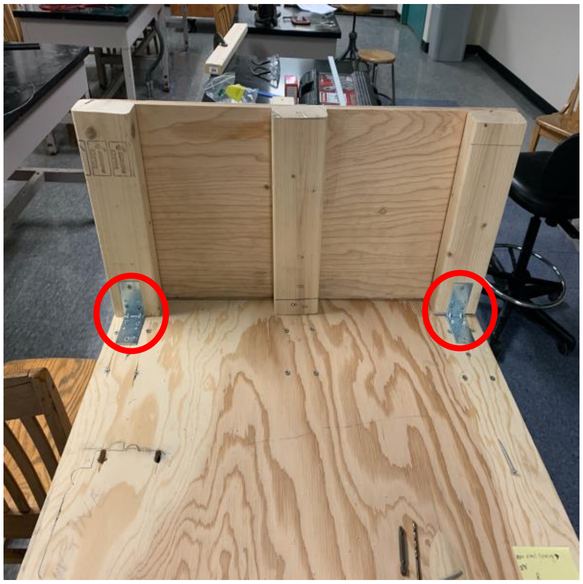


Figure 3.4.1 Backrest fastened to the kart with 6-hole corner brackets

3.5 The Handlebars

The handlebars were purchased as a set at the website shown in Appendix C – Parts List and contained the brake lever and throttle twist grip as well as the throttle and brake cables; the set ships unassembled[8]. Simply loosen the strap mount, position the component as desired and relink/tighten (not all the way initially so as to allow for final adjustments). Then, to find out the most comfortable handlebar position for the driver, I attached it to a 2” x 4” wooden plank (using U-bolts with a mounting plate) and asked the driver to place it on the central support plank (where it will be mounted) and hold it up in a comfortable position.

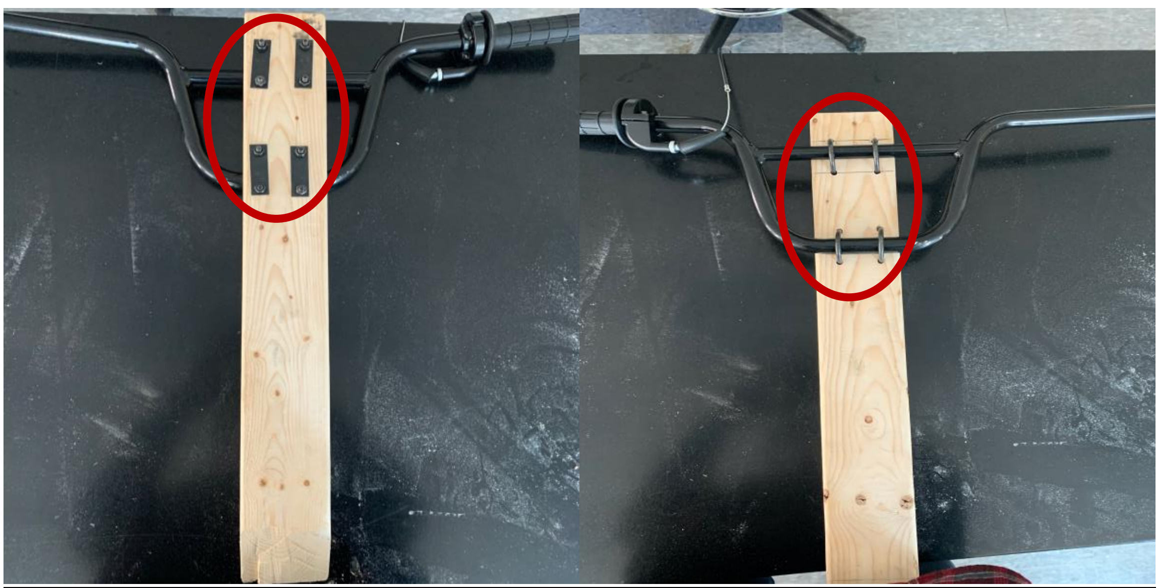


Figure 3.5.1 Handlebar attached to plank using U-bolts

Next, measure the angle created between the central plank and the bottom face of the plank and mark it on the plank.

[8] Fitting the brake lever and twist grip onto the handlebars requires the use of an Allen wrench.

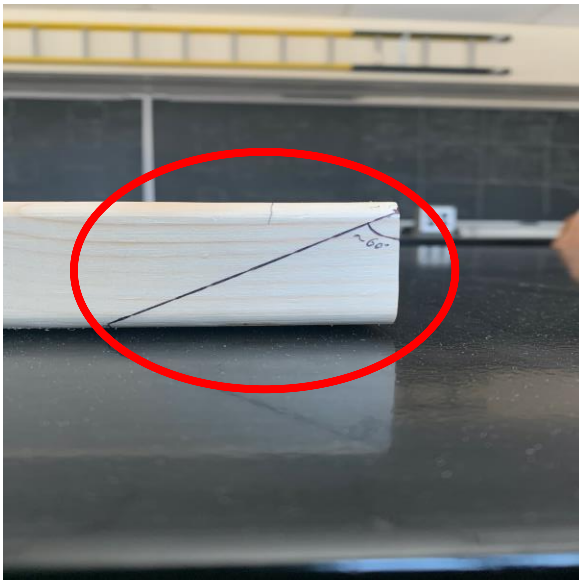


Figure 3.5.2 Marked angle for Handlebar mount

Then, I cut this angle out using a circular saw; the handlebar mount can be attached to the kart using 3 ½” deck screws. As added support, I cut the bottom of a smaller wooden plank at the same angle and secured it to the kart as well as to the back of the handlebar mount.

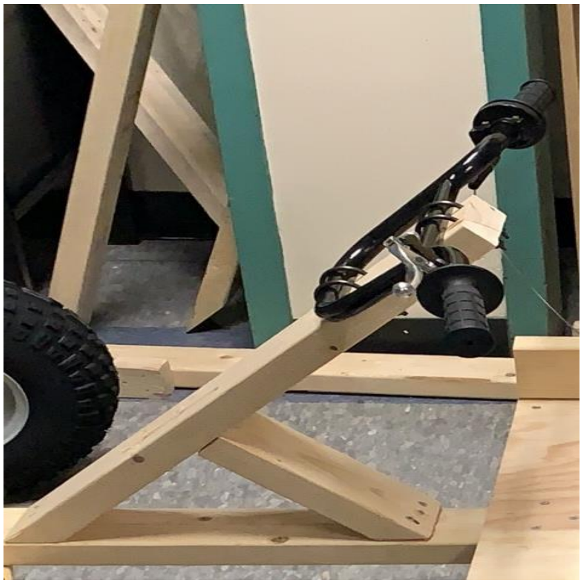


Figure 3.5.3 Handlebar mount attached to Go-kart with added support

As mentioned earlier this kart utilizes foot steering, so the handlebars can remain affixed to the frame. Its main purpose is to provide a convenient means of throttling and braking.

3.6 The Brake

On this kart, the most convenient means of braking is through the use of a brake band mounted around the drum on the drive wheel. Installation is fairly tricky as the band has to be set up in a way so that, once the brake is engaged, it would cover enough of the drum and grip it tightly enough to create adequate stopping/friction force to overcome the wheels rotation. Although, the predator engine conveniently begins to automatically slow the kart down once the throttle is disengaged, as the RPM of the shaft is contingent on how far the throttle lever is pulled away from zero. Thus, once the throttle is returned to its idle position during motion, the kart slows down. However, it is still important to have strong brakes to increase the overall controllability of the kart and as an extra safety precaution for the driver. To do this I used, a 5/8" bolt which was to be passed through a wooden block or something similar to act as an anchor point for the band. I also used a few lock nuts (or at least one lock nut and a few regular ones) to keep the band steady and fairly stationary. I started off by cutting out a wooden block and drilling a hole straight[9] through it at a height which ensured the top of the band was as close to the drum as possible without actually touching it. I found that drilling the hole near the bottom of the block worked best as shown in item K on Appendix A – Wood Cutouts.

The next step was to pass the bolt through one set of clips and mark out the spot on the bolt that fell between each clip. A small[10] hole was then drilled through the bolt at this point to allow the brake cable to pass through. Once this was completed, I used lock nuts to secure the brake band in place, passed the bolt through the wood and fastened it to the kart. Figure 3.6.1 shows what this should look like.

[9] It is very important to drill straight through the wood
[10] About 7/64"

Figure 3.6.1 Brake band attached to kart

To complete the brake assembly, insert the brake band pin into the second (in this case the lower) set of clips and loosen the Allen head screw to the side of it. Pass the brake band through the bolt and the pin and squeeze the band clips toward each other without allowing the inner padding/friction material of the band to rub against the drum. The wheel should be spun a few times to ensure there is no unwanted contact. Then retighten the Allen screw and test the brakes. This process might need to be repeated a few times until the band fits and functions as desired.

3.7 Mounting the Engine

Mounting the engine to the frame of the kart requires 4 bolts and locknuts. Depending on where the engine is placed relative to the edge of the kart, it might be necessary to get two sets of bolts with different lengths as one side of the engine might go through a support beam as well as the plywood board and the other goes through just the plywood. Thus, longer bolts would be needed on one side. I used two 4" and $2"$ (L) fully threaded $5/16"$ screws to bolt the engine onto the kart. However, I ended up having to cut the 4" bolt by about a ½" so the lock nuts could be fastened.

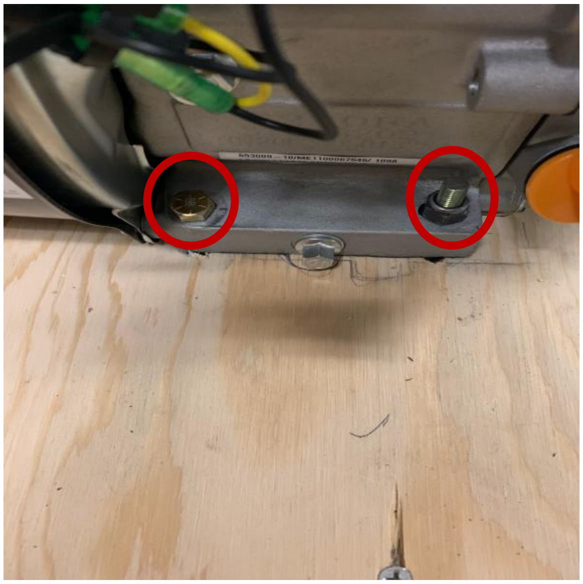


Figure 3.7.1 Shown from the front. The bolt on the right is the longer ~3 1/2" bolt which goes through both the support plank and plywood board so it should be passed through the wood from the bottom.

It is important to use oversized washers (with the outer diameter $>> \ 5/16"$) when tightening these bolts to spread out the contact force and prevent the locknuts/screw heads from driving into the wood[11].

[11] This happens because of the expanded holes drilled into the wood for engine adjustments. These weakened areas make it easier for the nuts and screw heads to drive into the wood.

3.8 Connecting the Throttle Cable

The throttle cable is connected to the engine via a lever located in the top center of the engine. As shown in Figure 3.8.1, the cable is connected to the engine by partially unfastening the screws on both the housing clamp and pinhole. Then, the cable should be passed through the housing clamp to prevent unnecessary movement and the wire itself should be pulled through the pinhole.

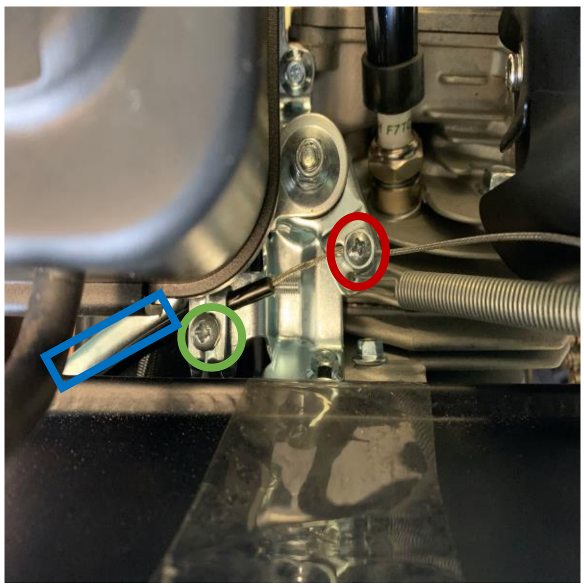


Figure 3.8.1 The blue rectangle is the lever; the green circle is the housing clamp and the red circle is where the hole is located.

Both screws should then be tightened. To ensure that the throttle always returns to the disengaged position, I decided to add an extra spring which can be found at any local hardware store and attached it to any suitable point that creates spring extension when the throttle is engaged.

3.9 Wiring the Kill Switch

This is an optional additional feature but nonetheless, an important one. The kill switch is mounted on the handlebar and gives drivers the ability to toggle the engine off from their seat in emergency situations. The switch and wires ship with the handlebar as well. The switch is attached to the handlebar in the same way as the brake lever and throttle twist grip; connecting the switch is fairly easy. This is done by disconnecting the switch on the engine from the oil sensor[12] and plugging the kill switch from the handlebar into this (male to female connection) as shown in Figure 3.9.1;

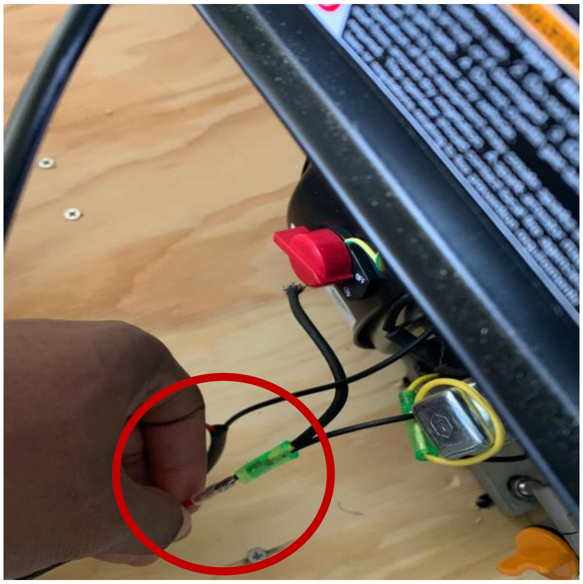


Figure 3.9.1 Driver's Kill switch wired directly to the Engine

After doing this, all that's left is to ground it which can be done by unscrewing one of the nuts directly above the wiring, passing the ground through the screw and securing it to the engine using the nut.

[12] The low oil sensor triggers warning light on a dashboard if one is available but since that isn't necessary here, it's convenient to disconnect this from the Engine's on/off switch and use this connection for the kill switch.

Figure 3.9.2 Grounding the switch

Figure 3.9.3 Kill switch mounted on handlebar

4 Experimental Results and Analysis

4.1 Determining the Turn Radius

From Figure 4.1.1, we see that it is possible to estimate what the outer wheel's turn radius should be, given a certain angle theta. The variable, r, represents this radius while, h, is the distance from the outer rear wheel axle to that of the front wheel i.e. center to center distance between both wheels. Furthermore, x represents the vertical distance travelled by the center if the outer wheel when the steering plank is turned at a certain angle theta and is calculated by multiplying the distance from the pivot to the tire, s, by the sine of the turning angle. So,

$$x = s \cdot \sin(\theta) \qquad [4.1]$$

The triangle below shows this relationship;

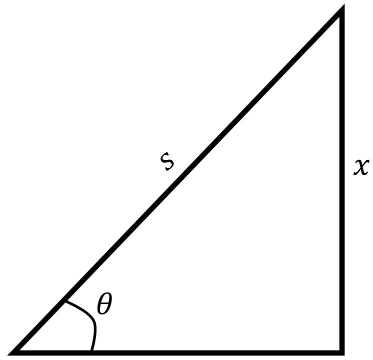


Figure 4.1.1

Finally, the addition of the quantities, x and h effectively gives us the base of the right triangle which can then be divided by the *sine* of the turn angle to yield the turn radius. Hence,

$$r = (h + x)/sin(\theta) \quad [4.2]$$

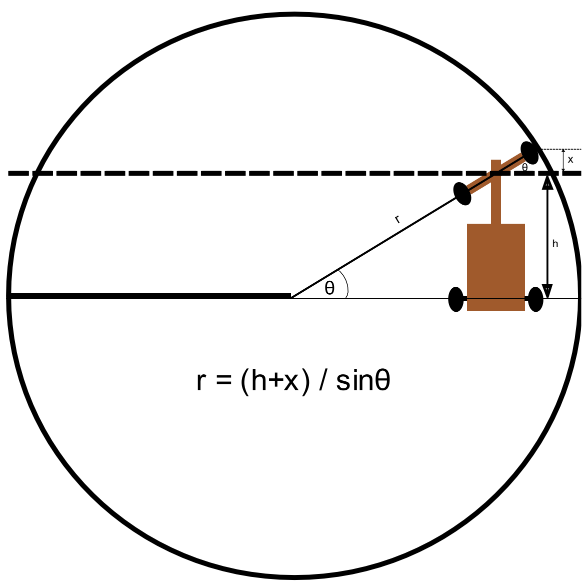


Figure 4.1.2

This formula helps us to determine what the turn radius of the vehicle should be for any turn angle, θ.

To test this, I used the $Angle\ Meter^{TM}$ app on the IOS App Store as a protractor by clamping the phone to a stand, with the rear camera pointed to the ground, and aligning the top edge of the steering plank to its zero axis then, I moved it to the desired angle. Figure 4.1.3 shows this;

Figure 4.1.3

To prevent any accidental movement of the steering plank during testing, I locked it in place by tightening the nut below; this ensured the angle would remain constant throughout the experiment. Finally, the driver was asked to slowly drive around in a circle and rocks were placed at various points on the circle traced out by the outer wheel. The distance from one end of the path to the other, through the center, was measured. This gives us the diameter of the circle and the turn radius could then be found by dividing this diameter by two.

Figure 4.1.4 Measuring the diameter of half circle formed

4.2 Results

The table below shows the radius found $\hat{R}$, as well as the expected radius R and the absolute value of the relative error δ_R;

Table 4.2.A

$\boldsymbol{\theta}$°	$\hat{\boldsymbol{R}}$ (inches)	$\boldsymbol{R}$ (Inches)	$\lvert\boldsymbol{\delta_R}\rvert$ **(%)**
20	191	194.93	2.02
22 – 22.5	174	179.67 – 176.29	3.16 – 1.30
25	155.75	161.47	3.54
27 – 27.5	151.5	151.66 – 149.44	0.11 – 1.38
30	139.75	139.50	0.18

The relative error is calculated using the following formula;

$$|\delta_R| = \left|\frac{\hat{R}-\mathrm{R}}{R}\right| \quad [4.3]$$

4.3 Calculating the Expected Maximum velocity of the Go-Kart

The maximum velocity of the go-kart was computed through a fairly simple algorithm which did not include any additive forces (traction/friction) or resistive forces (inertia and aerodynamic drag) as a more precise estimate would. For this calculation, I only consider the gear ratio, RPM of the engine and the diameter of the wheel. The steps are as follows,

First of all, find the circumference of the drive-wheel by measuring its diameter and multiplying this by Pi so,

$$C_w = \pi d_w \quad [4.4]$$

However, it is possible to increase accuracy as this circumference neither accounts for the static compression of the wheel when a mass is placed on it, nor does it factor in compression due to the dynamic motion of the wheel. For this, we define new variables, d_{ws} and d_{wd}, where $d_{ws}$is the static diameter and d_{wd} is the dynamic wheel diameter.

$$d_{ws} = 0.95 d_w \quad [4.5]$$

$$d_{wd} = 0.98 d_{ws} \quad [4.6]$$

Which means the dynamic circumference can now be calculated;

$$C_{wd} = \pi \times (0.98)(0.95) d_w \quad [4.7]$$

$$C_{wd} = \pi \times (0.931) d_w \quad [4.8]$$

Equation 4.8 states that the circumference[13] of the drive wheel in motion is the product of 0.931 times the free wheel diameter, d_w, and Pi.

[13] The circumference should be expressed in feet (ft).

After this, we can compute the gear ratio by dividing the number of teeth on the sprocket by the number of teeth on the clutch. This ratio allows us to determine the RPM of the drive wheel due to the rotation of the clutch. So,

$$GR = \frac{Sprocket\ teeth\ \#}{Clutch\ teeth\ \#} \quad [4.9]$$

Then using this value, we can find the wheel's RPM by dividing the maximum RPM of the engine by the gear ratio calculated above,

$$wRPM = \frac{eRPM}{GR} \quad [4.10]$$

With this information, we can now compute the maximum translational velocity of the kart by multiplying the circumference of the wheel by the wheel's RPM;

$$\vec{V}_{max}\left({}^{ft}/_{min}\right) = C_w \cdot wRPM \quad [4.11]$$

The result of this is the maximum velocity in $\frac{ft}{min}$, which can be changed to mph by the following conversion;

$$1\left(\frac{ft}{min}\right) = \frac{1}{88}\ (mph) \quad [4.12]$$

The data required to compute this is shown on Table B 2 in

Appendix B – Other Important Data & Calculations.

Using that information, I found that the maximum achievable velocity of the kart is about $24.09\ mph$. The goal for this test is to be able to reach $20\ mph$.

4.4 Results

The velocity of the kart was found through utilizing the video analysis capabilities of a program called *PASCO Capstone*. It is able to compute the velocity of a moving object through an automatic or manual tracking tool built into it. The first step is to select and input the length of the distance covered via the scaling tool to give the program a sense of the scale. I utilized the manual tracking tool as I found that it led to more consistent results. The distance covered was determined by measuring the lengths of the 15 parking spots covered in the video. This was found to be roughly $42.28\ m$.

Then, the frame increment/advancement rate (number of frames advanced after each tracking point has been placed) should be set. I tested the results with a frame increment/advancement rate (FAR), of 5 frames which corresponds to a $0.166\ s$ interval between each point. As each tracking point is placed, the program determines the velocity and acceleration by computing $\vec{V}_T$ as the distance travelled divided by the time taken and $\vec{a}_T$ as the change in velocity over the time interval. However, the acceleration data collected by the program was quite erratic for some unknown reason, so I opted to calculate this myself using the velocity and time data provided.

$$\vec{V}_T = \frac{D}{t} \tag{4.13}$$

$$\vec{a}_T = \frac{\Delta\vec{V}}{t} \tag{4.14}$$

Furthermore, the data (specifically the kart's velocity) can be used to calculate the kinetic energy of the go-kart and subsequently the power consumed. However, it is important to note that this calculation does not take into account other forms of energy as well as energy lost to the surroundings, so the power shown in the table below is not the total output of the engine. That being said, the equations needed to calculate the kart's kinetic energy and power output due to the kinetic energy are as follows;

$$KE\ (J) = \frac{1}{2} m {V_T}^2 \qquad [4.15]$$

$$P\ (Watts) = \frac{W\ (J)}{t\ (s)} = \frac{\Delta KE\ (J)}{t\ (s)} \qquad [4.16]$$

Where m is the total mass of the kart with the driver on it, KE is the translational kinetic energy of the kart found in Equation 4.15 and W is the work done which can also be represented by the change in kinetic energy. The kinetic energy of an object is typically expressed in $Joules\ (J)$ while power has units, $\frac{Joules}{second}$; otherwise known as $Watts\ (W)$. However, when dealing with engines, power is often expressed in $Horsepower\ (HP)$ where $1\ HP = 735.5\ W$.

Here is the data collected from the best maximum velocity run carried out from rest;

Table 4.4.A

Time (s)	Velocity (m/s)	Velocity (mph)	Acceleration (m/s²)	Kinetic Energy (J)	Power (HP)
0	0	0.00	0.00	0.00	0
0.167	0.27	0.59	1.62	4.26	0.03422717
0.333	0.53	1.19	1.57	16.42	0.13247323
0.5	0.8	1.78	1.62	37.42	0.1686005
0.667	1.06	2.37	1.56	65.70	0.2270543
0.835	1.32	2.96	1.55	101.88	0.2888025
1.002	1.33	2.97	0.06	103.43	0.01244197
1.168	1.6	3.57	1.63	149.68	0.37366568
1.335	1.86	4.17	1.56	202.28	0.42236983
1.502	2.13	4.76	1.62	265.27	0.50580149
1.668	2.53	5.65	2.41	374.25	0.88043589
1.835	3.06	6.84	3.17	547.48	1.39101279
2.002	3.72	8.32	3.95	809.12	2.10095658

Time (s)	Velocity (m/s)	Velocity (mph)	Acceleration (m/s^2)	Kinetic Energy (J)	Power (HP)
2.168	4.12	9.22	2.41	992.47	1.48124837
2.335	4.25	9.51	0.78	1056.09	0.51087218
2.502	4.89	10.94	3.83	1398.11	2.74643685
2.67	5.42	12.13	3.15	1717.60	2.55026418
2.837	5.72	12.79	1.80	1913.01	1.56909736
3.003	6.38	14.27	3.98	2379.94	3.7720821
3.17	6.91	15.46	3.17	2791.78	3.30707693
3.337	7.05	15.76	0.84	2906.05	0.91760739
3.503	7.04	15.76	-0.06	2897.81	-0.0665523
3.67	7.31	16.35	1.62	3124.35	1.81911063
3.837	7.31	16.36	0.00	3124.35	0
4.003	7.44	16.65	0.78	3236.46	0.90570591
4.17	7.58	16.95	0.84	3359.41	0.98728245
4.337	7.8	17.45	1.32	3557.25	1.58862892
4.505	8.33	18.63	3.15	4057.09	3.98988955
4.672	8.37	18.73	0.24	4096.15	0.31363167
4.838	8.11	18.13	-1.57	3845.62	-2.0238689
5.005	7.97	17.83	-0.84	3713.99	-1.0569575
5.172	7.97	17.84	0.00	3713.99	0
5.338	8.24	18.44	1.63	3969.90	2.0672767
5.505	8.64	19.33	2.40	4364.68	3.1701213
5.672	8.91	19.92	1.62	4641.73	2.22476597
5.838	9.17	20.52	1.57	4916.58	2.22036107
6.005	9.13	20.41	-0.24	4873.78	-0.3436802
6.173	8.73	19.53	-2.38	4456.08	-3.3342033
6.34	8.64	19.33	-0.54	4364.68	-0.7339826
6.507	7.97	17.84	-3.95	3723.32	-5.1501325
6.673	7.71	17.24	-1.63	3475.63	-2.0009606
6.84	7.97	17.83	1.56	3713.99	1.9140922
7.007	7.71	17.24	-1.56	3475.63	-1.9140922
7.173	7.31	16.34	-2.41	3124.35	-2.8377998
7.34	6.64	14.86	-4.01	2577.87	-4.3882611

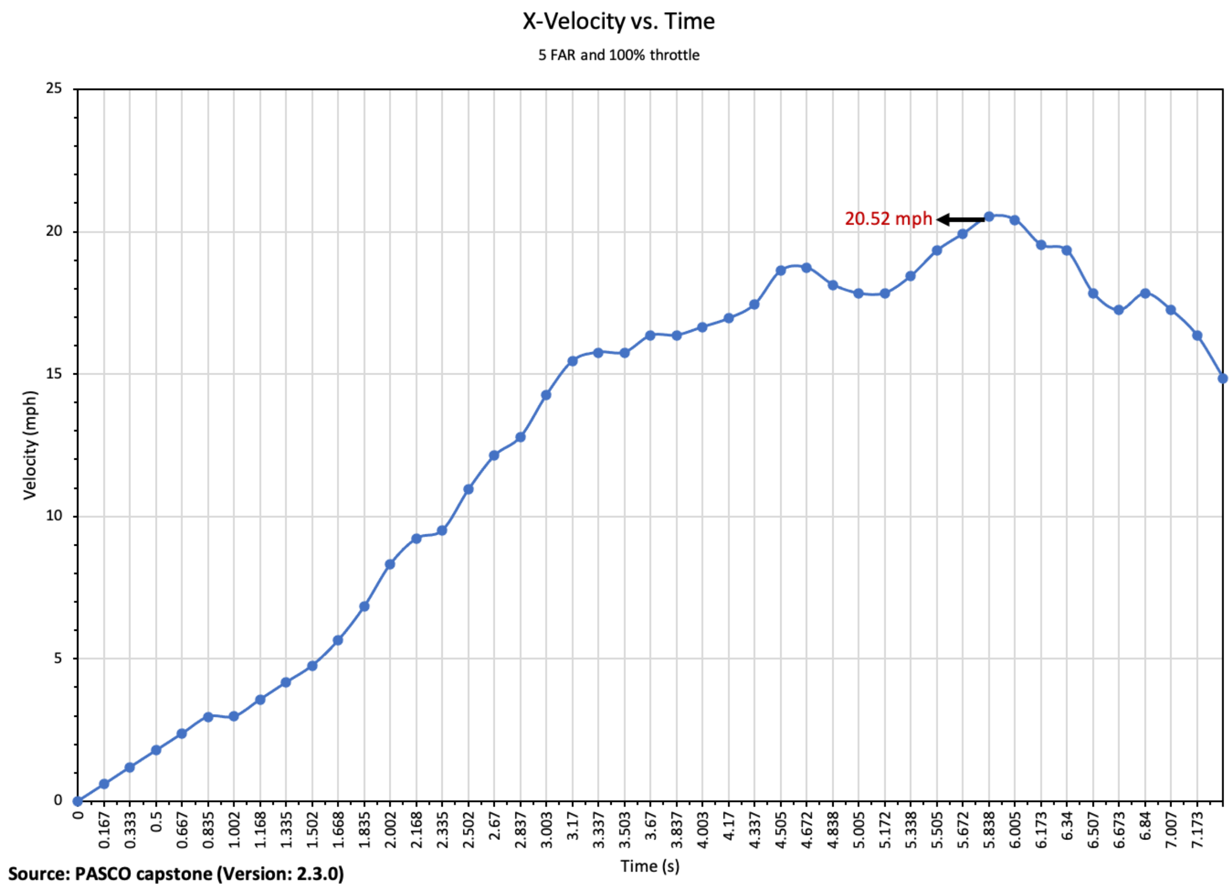


Chart 4.4.I

The chart above shows the kart's velocity in the x direction versus time. From the data presented, we see that the kart is able to reach a maximum velocity of $20.52\ mph$ at the $5.838\ s$ mark which is about 85.2% of the maximum speed attainable. This result means the goal of reaching $20\ mph$ was achieved. For this run, the driver started from rest and accelerated at full throttle with the intention to continue accelerating over the distance of $42.278.m$ specified above[14]. The data shown roughly resembles the expected profile of the velocity versus time graph of a vehicle starting from rest. The acceleration is, on average, highest during the first few seconds until the velocity slowly plateaus once the maximum speed is reached and we can see that on the graph.

[14] The distance covered was merely a function of the number of consecutive free parking spots available that could fit within the frame of the video

However, we also see that the kart actually slows down towards the end of the run and this would have contributed to the result being 14.8% less than the maximum velocity achievable, as the distance covered was probably not sufficient to allow the kart to reach its peak velocity[15].

Nonetheless, we can gain a sense of the feasibility of the data by performing a rough calculation of the velocity through our own frame by frame analysis of the video. iPhone videos are shot at $30\ fps$ so, by using the distance covered, the number of frames taken to cover this distance and the aforementioned $30\ fps$, we can find the velocity at each interval as follows;

$$t\ (s) = \frac{Number\ of\ Frames\ for\ spot\ (F)}{Frames\ per\ second\ (\frac{F}{s})} \qquad [4.17]$$

$$\vec{V}\ (\frac{m}{s}) = \frac{Distance\ per\ spot\ (m)}{t\ (s)} \qquad [4.18]$$

[15] Slowing down was necessary to prevent the driver from running into cars parked at the other side of the lot.

The table of results is shown below,

Table 4.4.B Velocity estimates through frame-by-frame analysis

Lot #	Frames per Lot	Time per Lot (s)	Total Time (s)	Lot Length (m)	Velocity (m/s)	Velocity (mph)
0	0	0.000	0.000	0.0000	0.000	0.000
1	1	1.967	1.967	2.8194	1.434	3.207
2	2	0.700	2.667	2.8956	4.137	9.253
3	3	0.500	3.167	2.8956	5.791	12.955
4	4	0.367	3.533	2.7178	7.412	16.581
5	5	0.333	3.867	2.5908	7.772	17.386
6	6	0.333	4.200	2.6924	8.077	18.068
7	7	0.367	4.567	2.8829	7.862	17.588
8	8	0.367	4.933	2.8829	7.862	17.588
9	9	0.333	5.267	2.8448	8.534	19.091
10	10	0.333	5.600	2.8829	8.649	19.347
11	11	0.300	5.900	2.7432	9.144	20.455
12	12	0.333	6.233	2.7940	8.382	18.750
13	13	0.400	6.633	2.8702	7.176	16.051
14	14	0.400	7.033	2.8956	7.239	16.193
15	15	0.400	7.433	2.8702	7.176	16.051

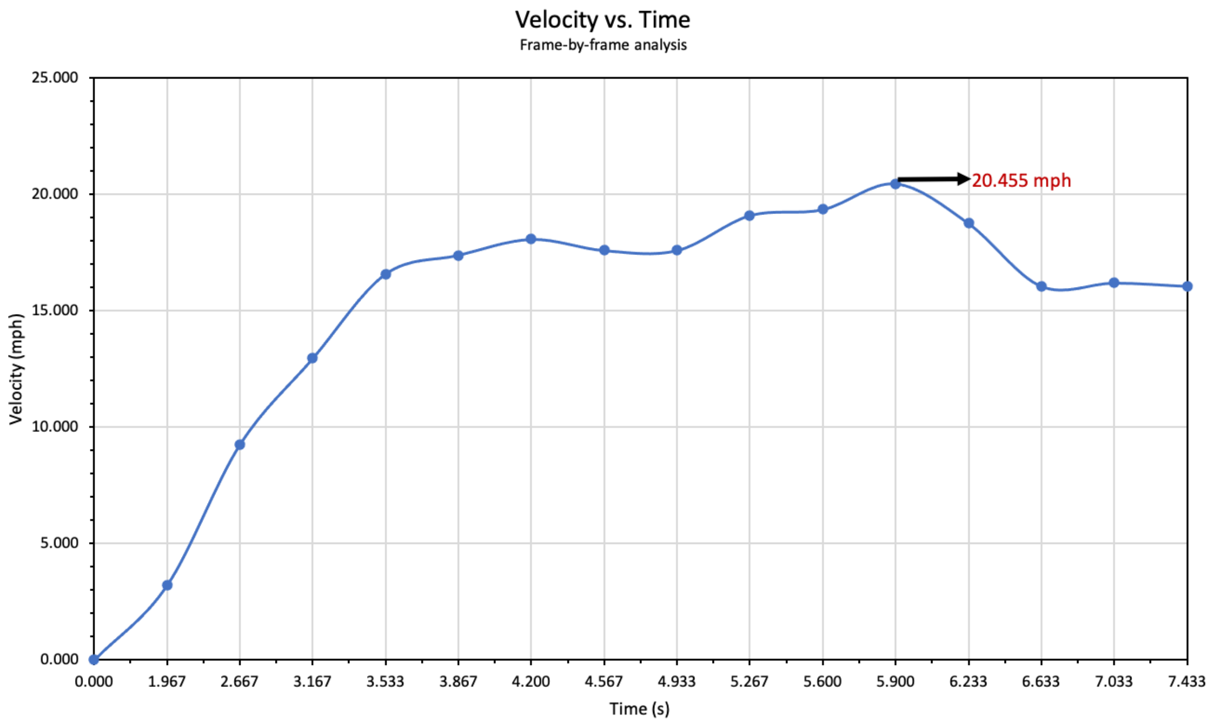


Chart 4.4.II

Overall, the profile of the curve seems to roughly resemble that shown in Chart 4.4.I. At $t = 5.900\ s$, the frame-by-frame analysis shows that the kart is able to reach a velocity of $20.455\ mph$, only $0.0032\ \%$ less than $PASCO's$ derived value in Chart 4.4.I that was taken only $0.062\ s$ prior. This leads me to believe that the data gathered is feasible.

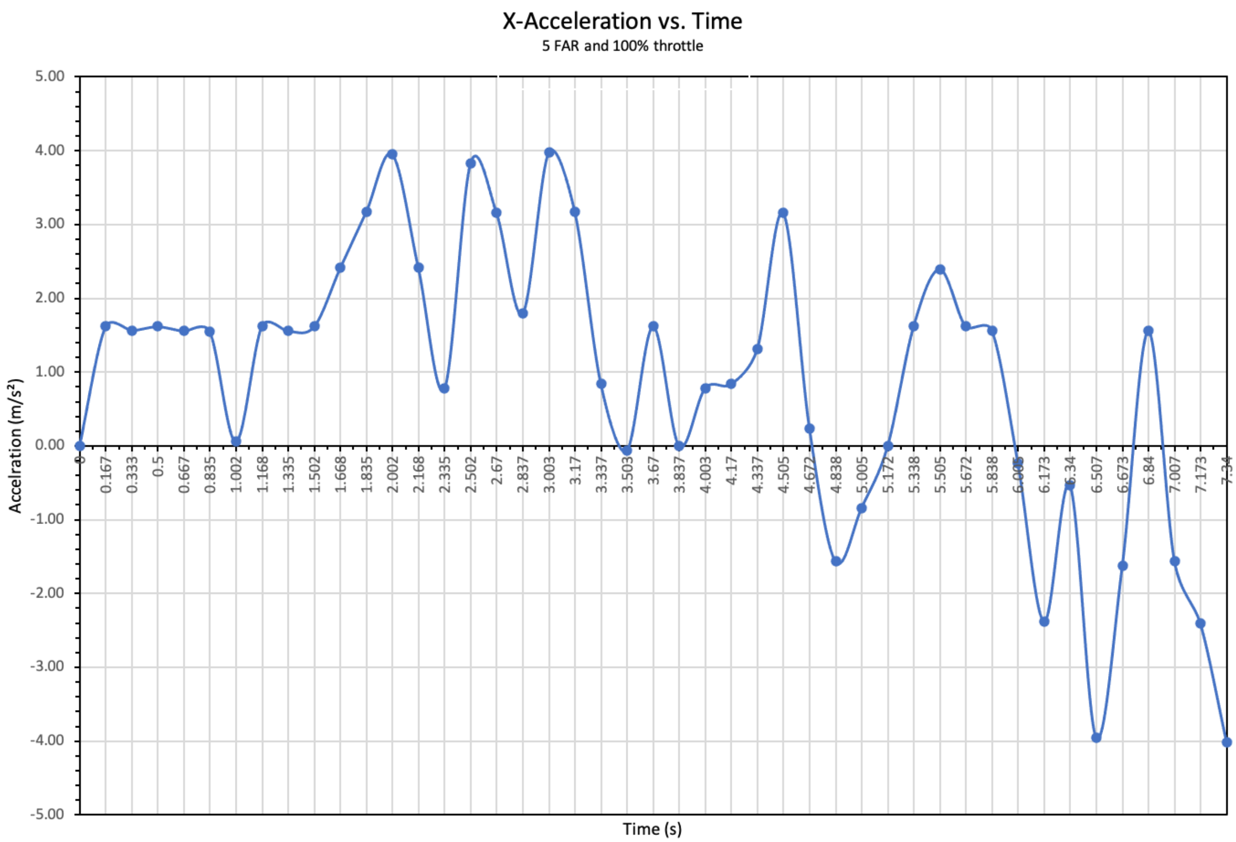


Chart 4.4.III

This chart depicts the acceleration versus time data which tells the story of the change in the kart's velocity over the course of the journey. For this analysis, acceleration means the increase in velocity over time and deceleration means the reduction of velocity over time. The maximum acceleration achieved was 3.98 m/s^2 which occurred between 2.837 and 3.003 s but overall, the data shown clearly indicates that the kart's acceleration is greater during the first 3 seconds of the journey than it is at the latter stages. This is consistent with our expectations for the data as typically, the kart should accelerate more during the initial stages of the run. From the way the data is presented, one might think that the kart is slowing down when the acceleration is zero because the points are connected by a line. However, zero acceleration simply means the kart's speed is constant.

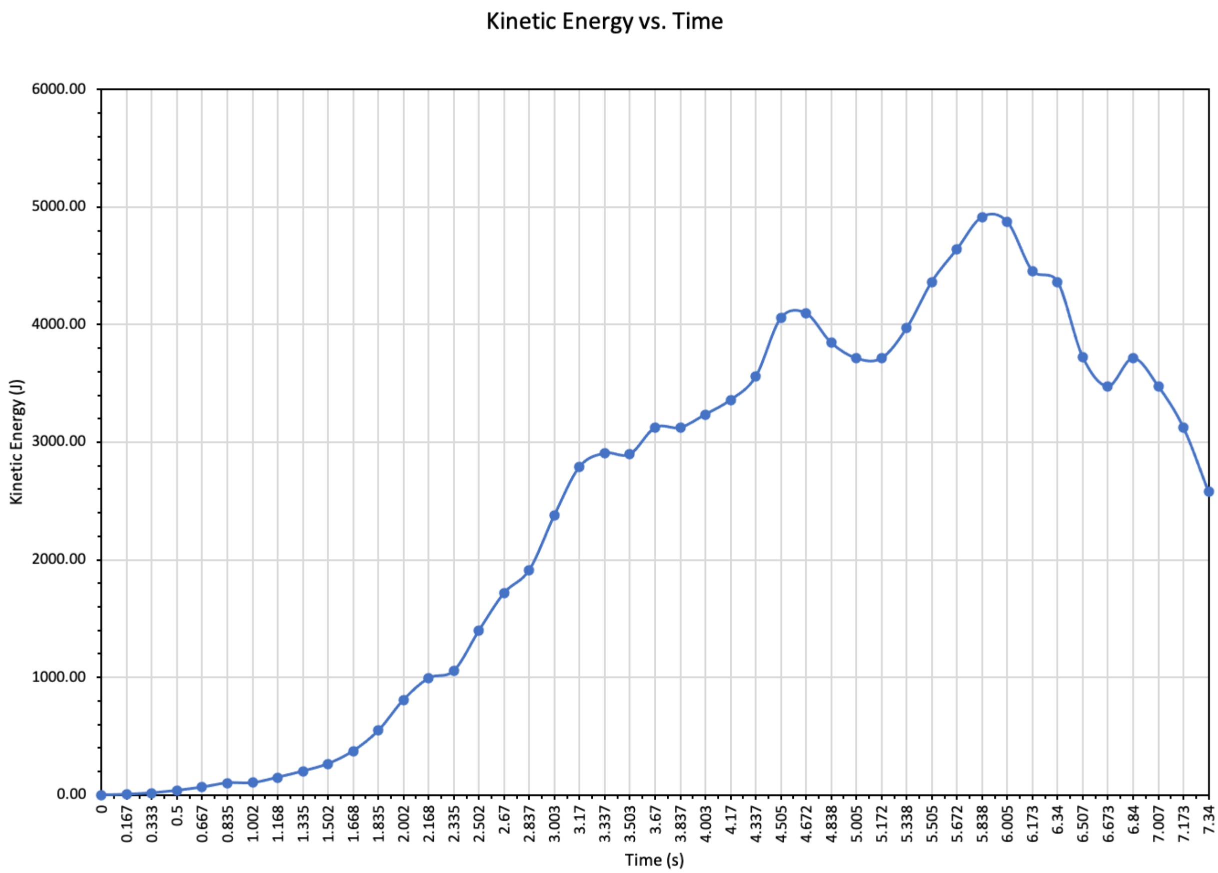


Chart 4.4.IV

This chart shows the kinetic energy versus time and predictably, confirms that greater velocities yield greater kinetic energy.

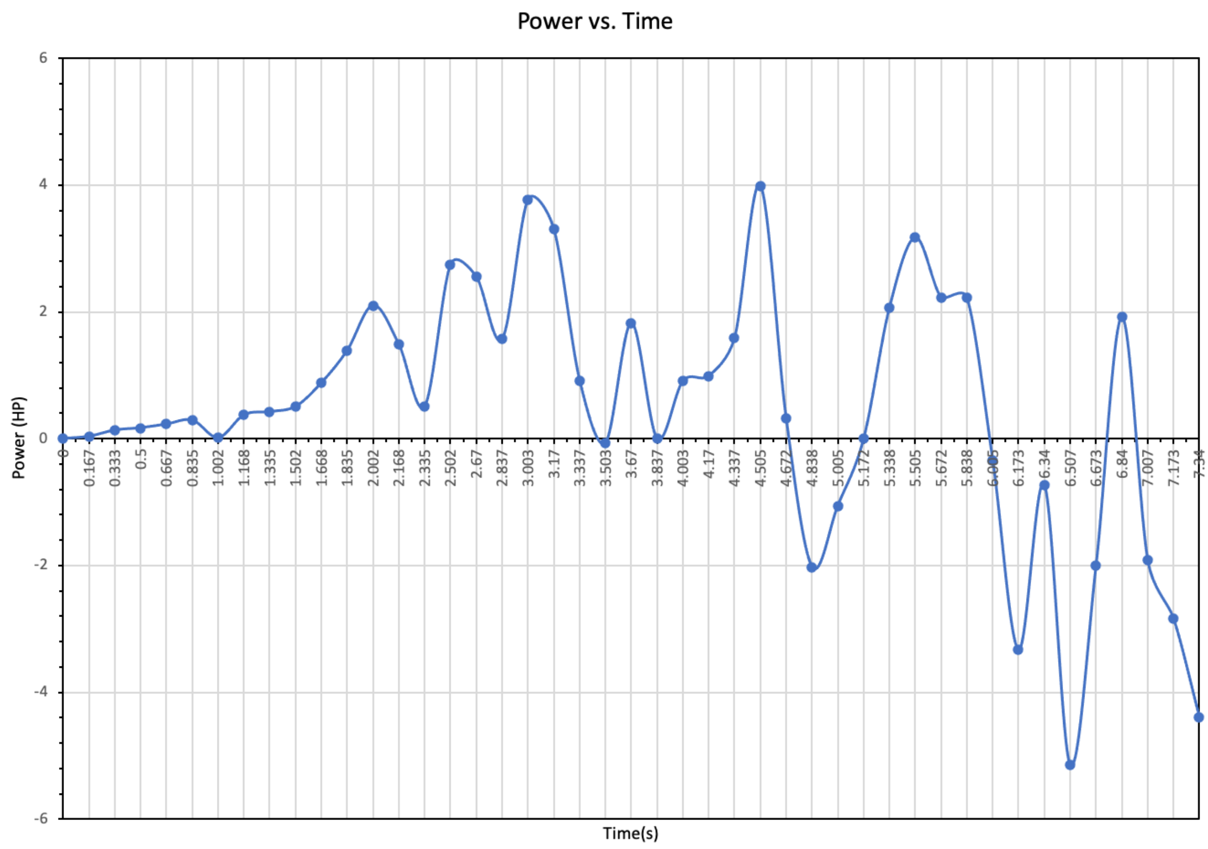


Chart 4.4.V

The chart presented above is the power output of the engine that goes towards its kinetic energy versus time and as stated earlier, this was derived using Equation 4.15. From the chart, we see that the maximum power output was about $3.99\ HP$ at $4.505\ s$. This might seem strange at first because as stated earlier, the maximum acceleration was achieved at 3.003 s. And since power here is calculated as the change in kinetic energy over time, the point with the greatest acceleration should give us the greatest change in velocity and hence, the greatest change in kinetic energy. This means one could reasonably expect the maximum power output to be at this point. However, the key realization here is that the change in kinetic energy is the difference of two squares, i.e.;

$$\Delta K.E = \frac{1}{2}m(\vec{V_f}^2 - \vec{V_i}^2) \qquad [4.19]$$

As opposed to,

$$\Delta K.E = \frac{1}{2}m(\vec{V_f} - \vec{V_i})^2 \qquad [4.20]$$

Where $\vec{V_f}$ and $\vec{V_i}$ are the final and initial velocities respectively. This means that the difference between the velocities isn't the only thing accounted for but the magnitude of the velocities matter as well. Let's take these two points as an example. From the data presented in Table $4.4.$ A, we see that the change in velocity from $4.337\ s$ to $4.505\ s$ is $0.53\ m/s$

Time (s)	Velocity (m/s)	Velocity (mph)	Acceleration (m/s²)	Kinetic Energy (J)	Power (HP)
4.337	7.8	17.45	1.32	3557.25	1.58862892
4.505	8.33	18.63	3.15	4057.09	3.98988955

While, the change in velocity between 2.837 and $3.003\ s$ is $0.66\ m/s$.

Time (s)	Velocity (m/s)	Velocity (mph)	Acceleration (m/s²)	Kinetic Energy (J)	Power (HP)
2.837	5.72	12.79	1.80	1913.01	1.56909736
3.003	6.38	14.27	3.98	2379.94	3.7720821

So, when just the velocities are computed and taken as the squared difference Equation 4.20, we find that;

$$(\vec{V_f} - \vec{V_i})^2 = (6.38 - 5.72)^2 = 0.4356 > (8.33 - 7.8)^2$$
$$= 0.2809$$

However, compute it as the difference of the two squares and we see that,

$$\left(\vec{V_f}^2 - \vec{V_i}^2\right) = (6.38^2 - 5.72^2) = 7.986 < (8.33^2 - 7.8^2)$$
$$= 8.549$$

So, in terms of the change in kinetic energy, this means that it takes more work to increase the velocity of a moving object at higher speeds than it does when it's moving really slowly. This is the reason why the maximum power output is at the $4.505\ s$ mark.

Plausibly, it is hard to numerically compute and plot derivatives especially at very short time intervals as evident with the rather high variance in the acceleration and power versus time charts above. However, it is much easier to make meaningful – albeit slightly less than accurate – observations when the data is averaged out over time so below is a chart of the average power versus time;

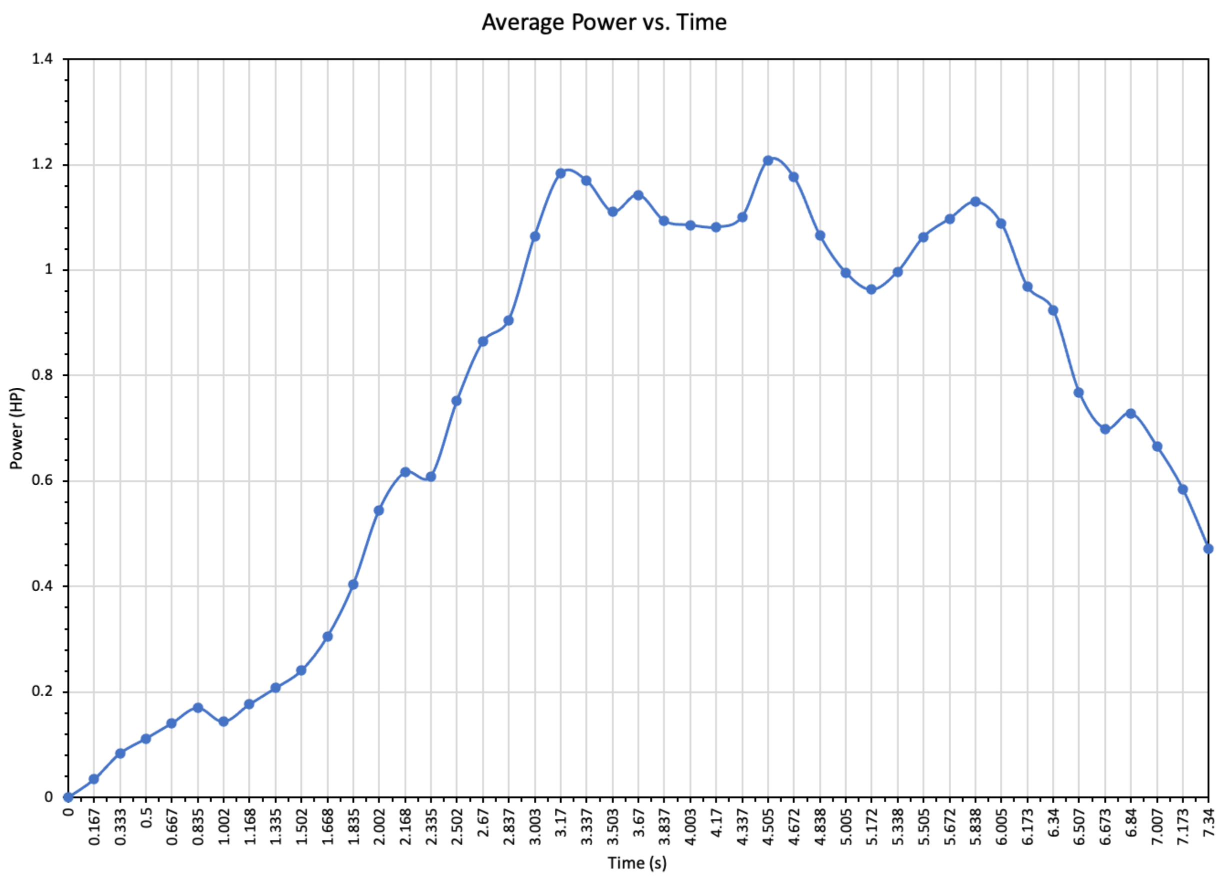


Chart 4.4.VI

This chart shows the average power output of the engine over time was, for the most part, less than 1.2 HP which gives us an idea of the losses experienced given the assumption that at 100%

throttle and max RPM, the engine should output the full $6.5\ HP$. This means at the peak average of $1.206\ HP$ – from the chart above – about $5.3HP$ is being lost to the surroundings and means the engine operates at a meager $18.46\ \%$ efficiency. Now, I understand that the losses experienced at this instance and several others during the run are actually much smaller than $5.3\ HP$. But this chart is simply a means of getting a general sense of the inefficiency of the engine and kart in transferring energy from chemical to kinetic without having to worry about the negative power values found at several instances. The key takeaway here is that a significant amount of energy is being lost to heat, sound, vibration and several other factors which certainly contributed to the fact that the maximum velocity was not reached. Internal combustion engines are typically not very efficient, and the evidence shown here supports that. On average, most IC engines are around $20\ \%$ thermally efficient.

5 Summary

In this project, I have outlined a few features of vehicle operation as well as provided a step-by-step guide on how to carry out the construction of a go-kart from wood. Both experiments carried out were successful as the turn radius tests yielded results within the range of experimental accuracy (5%) and the velocity of the go-kart crossed the $20\ mph$ threshold as desired. Furthermore, the investigation and applications of the velocity data collected by $PASCO\ Capstone$ yielded results that were used to give us a sense of the nature of velocity versus time graphs, as well as the relationship between kinetic energy and the velocity of a vehicle. Likewise, I was also able to point out the key relationship between the work necessary to increase the velocity of a vehicle and its speed; more work is needed to do this at higher speeds than at lower speeds. Finally, I plotted the average power output of the go-kart – that went into its translational velocity – against time and found that a significant amount of the 6.5HP was being lost to heat and other inefficiencies which isn't atypical of internal combustion engines.

6 Possible Modifications

Through the process of building and testing out the kart, I noticed a few shortcomings and so in this section I suggest possible modifications to improve the overall performance of the kart. These are specifically for go-karts made out of wood.

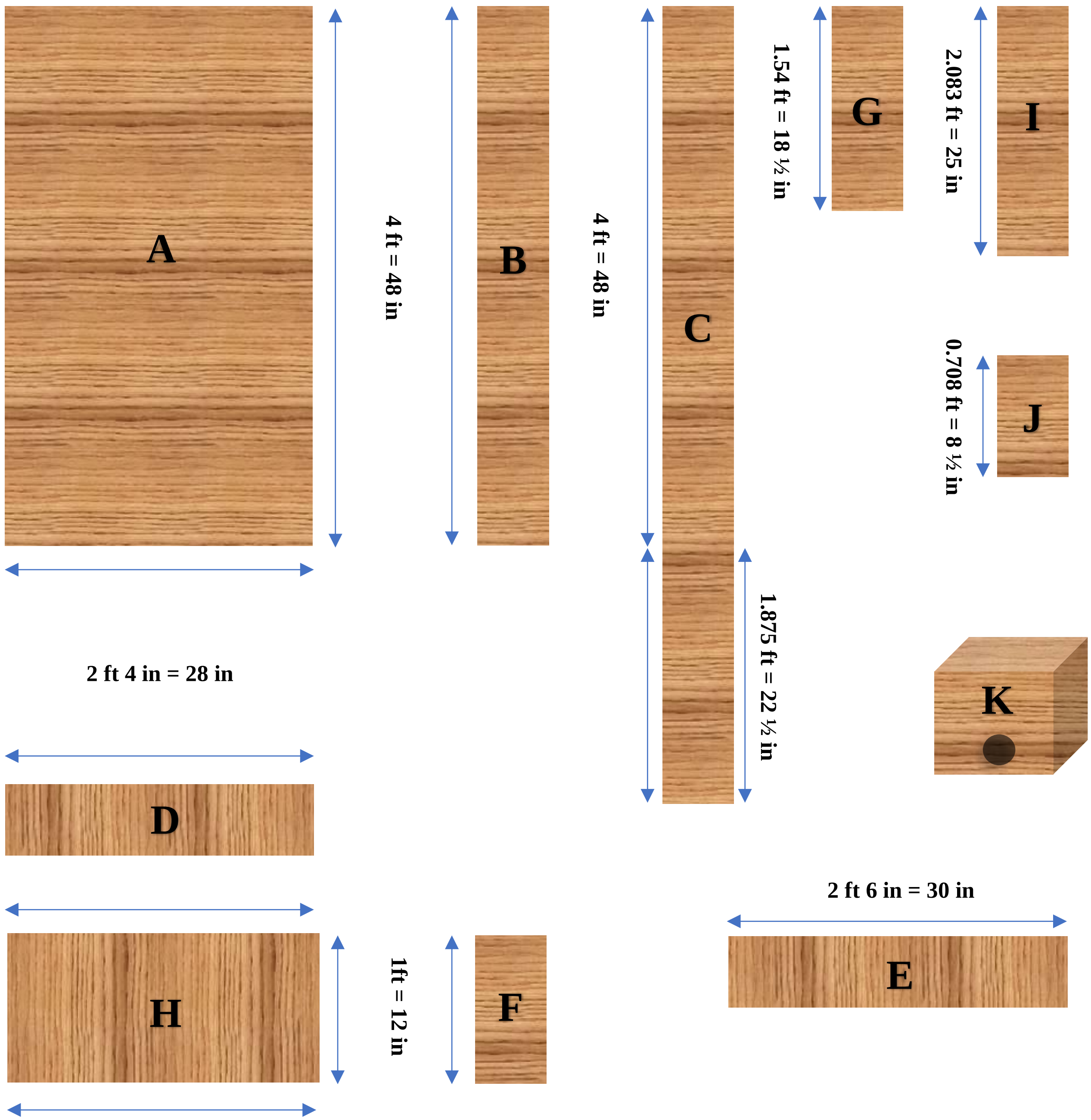
6.1 Steering Modifications

The steering plank could be fitted with footrests and a sturdy spring-like chord – like a bungee cord - that connects the plank to the vehicle's frame and acts as a steering alignment aid. The chord should be calibrated in such a way that after turning, it exerts a force on the plank and resets it to 0 degrees. Furthermore, a bearing could be installed in the steering plank mount to allow for increased agility. Another possible steering improvement would be to use a rear axle that connects both wheels instead of using individual bolts. This ensures both rear wheels are in line with one another and improves stability.

6.2 Minimizing Flexing of the Wooden Frame

During frame assembly, the plywood base is susceptible to flexing if the planks used for support don’t have the same thickness or aren’t completely flat and straight. Flexing/Bending can lead to issues like the misalignment of the drive wheel and sprocket. This can become very problematic over time as the chain, due to the misalignment, would pop out of the sprocket ever so often while driving and it makes for harder maintenance. So, ensuring the supports are flat and have the same thickness should improve the overall stability of the kart, as well as the longevity of the sprocket-clutch alignment.

Appendix A – Wood Cutouts



NOTE:

- **B, C, D, E, F, G, I and J were all cut from 2" x 4" planks**
- **A and H were cut from the 1 ½" thick plywood sheet.**

LABEL	PURPOSE	NO. USED
A	Plywood base	1
B	L & R Vertical Support beams/ planks	2
C	Central Support beam/ plank & Steering beam mount	1
D	Front, Center and Rear horizontal support beams/ planks	3
E	Steering beam/plank	1
F	Seat Back supports	3
G	Side guards for seat	2
H	Seatback	1
I	Handlebar mount	1
J	Handlebar mount support	1
K	Wooden brake mount block	1

Table A 1 – Labelled Cuts

Appendix B – Other Important Data & Calculations

Table B 1 – Total weight calculation.

Label	Element	No. Used	Unit Size (Inches)	Unit Weight (Kg)	Total Size (Inches)	Total Weight (kg)
A	Plywood Board	1	2 x 2	0.017	28 x 48	5.712
B	L &R Vertical Support Plank	2	12	0.297	48	2.376
C	Central Beam (Steering Mount)	1	12	0.297	70.5	1.744875
D	Horizontal Support Plank	3	12	0.297	28	2.079
E	Steering Plank	1	12	0.297	30	0.7425
F	Seat Back Support	3	12	0.297	12	0.891
G	Seat railings/Side guard	2	12	0.297	18.5	0.91575
H	Seatback	1	2 x 2	0.017	12 x 28	1.428
I	Handlebar Mount	1	12	0.297	25	0.61875
J	Handlebar Mount support	1	12	0.297	8.5	0.210375
Note: For B, C, D, E, F, G, I & J Size and Total Size indicated is the length of the plank since they are all 2x4's						
L	Tire	4		3.26587		13.06348
M	Sprocket	1		1.926		1.926
N	Bruno (Driver)	1		61.235		61.235
O	Engine	1		17.055		17.055
P	Brake drum	1		0.324		0.324
Q	Square tubing (Galvanized Steel rails)	8		0.179		1.432
R	PVC pipe	2		0.068		0.136
S	Chain	1		0.848		0.848
T	Wheel bolt	4		0.405		1.62
U	Handlebars	1		1.55		1.55
V	Wood to square tubing bolts	16		0.055		0.88
W	Brake band	1		0.15		0.15
					TOTAL WEIGHT:	**116.93773**

Table B 2 – Maximum velocity calculation

Other Required Data:		Unit	Calculate Top Speed		Unit
Engine HP	6.5	HP	Wheel C (dynamic)	42.40993003	Inches
Engine RPM	3600	RPM	Wheel C (dynamic)	3.534160836	Feet
Sprocket tooth #	60	n/a	Gear Ratio = Sprocket tooth/Clutch	6	n/a
Clutch tooth #	10	n/a	wRPMS = Engine RPM/ Gear ratio	600	RPM
Drive-wheel diameter (free)	14.5	Inches	Max V in ft/min = C *wRPMS	2120.496501	ft/min
Drive-wheel diameter (dynamic)	13.4995	Inches	V in ft/hr.	127229.7901	ft/hr.
			V in mph	**24.09655115**	Mph

Appendix C – Parts List

*Bolt Specification Sample - XYZ Bolt: ½” (Diameter). Bolts:1 − 5” (L) (should be read as: one, five-inch-long bolt)

1. 6.5 HP 212 cc Predator Engine

All parts from 3 to 12 can be found here: https://www.mcmaster.com

2. 4” x 8” Plywood (This can vary depending on preference)
3. Wheel Bolts: 5/8” (D). Bolts: 2 − 8” (L), 2 − 12” (L) and 8 washers
4. Deck screws: 3 ½”
5. Engine/Brake Bolt: 5/16” (D). Bolts: 1-5” (L), 2-2” (L), 1 − 4” (L), 1 − 3 ½” (L) and 10 Washers
6. Steering Bolt: ½” (D) Bolt: 1 − 6” (L) and 6 washers
7. Wood to metal Bolts: 3/8” (D) Bolts: 18 − 4” (L) and 36 washers
8. Lock nuts for all Bolts
9. 2 U bolts for handlebars ¼” × 11/8” × 2”
10. Braces for seats: 4” Heavy duty Corner Braces
11. Wheel spacers: ¾” round tube
12. Galvanized Steel Rail for Bolt-Together Framing. $1\frac{1}{2}$" High x $1\frac{1}{2}$" Wide, 0.105" Wall Thickness

All parts from 13 to 26 can be found here: https://www.gopowersports.com

13. 4” Manco Brake band with clip
14. Throttle twist grip 7/8” (D) [75” 90 − degree bend]
15. Brake band pin
16. 60” Brake cable with 3/8” Barrel on one end
17. Left- and Right-hand shorty lever assembly
18. Push button
19. 420 Chain
20. 10T, 3/4" bore, Centrifugal Clutch, #41/420
21. Minibike Handlebars, Mega Moto 80/105, Complete Kit-Unassembled
22. 145x70-6 Drive Wheel Assembly Complete with 5/8” Bearings, Sprocket and Brake Drum (60 Tooth Sprocket #41/420) (1)
23. 145x70-6 Floater Wheel Assembly Complete with 5/8” sealed bearings (Knobby) (3)
24. Drive Wheel [5” (D) with 5/8” bearing][16]
25. 4” Brake Drum, 1246 Manco[17]
26. Sprocket [48 Tooth][18]

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[16] Only necessary if drive wheel is purchased unassembled
[17] Only necessary if drive wheel is purchased unassembled
[18] Only necessary if drive wheel is purchased unassembled

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