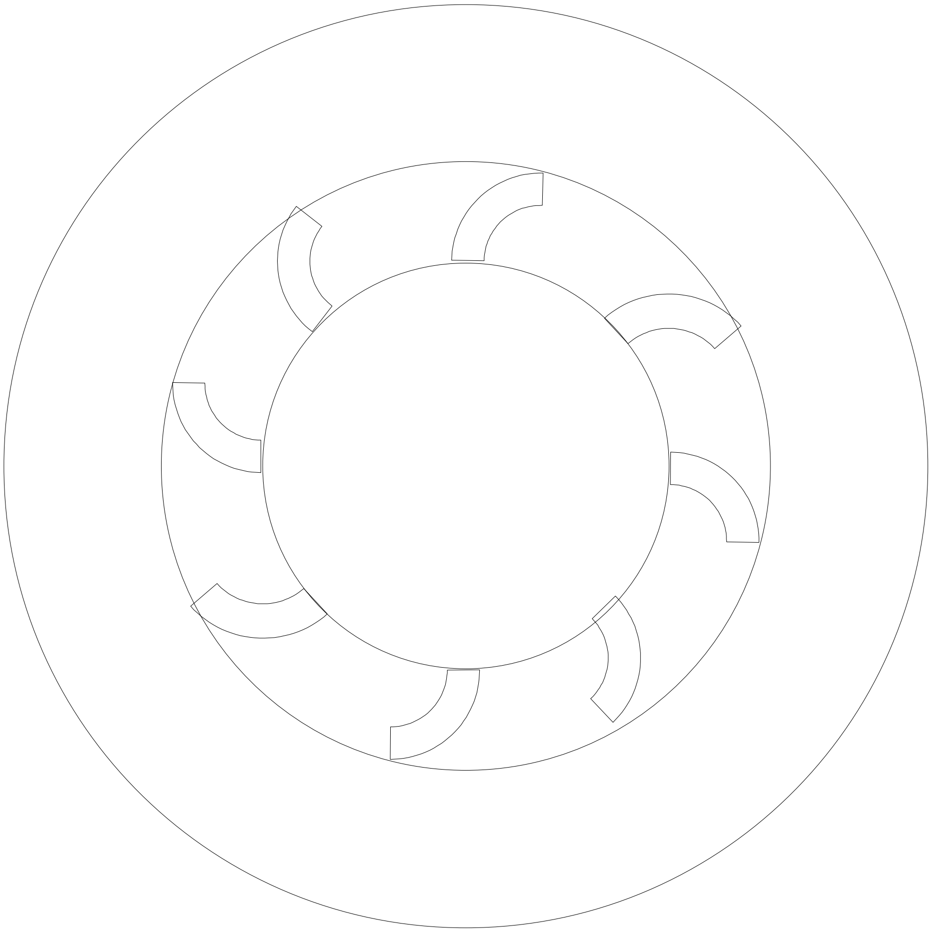
# The Tumbleweed

## Direct Downwind Faster Than The Wind
## (DDFTTW)



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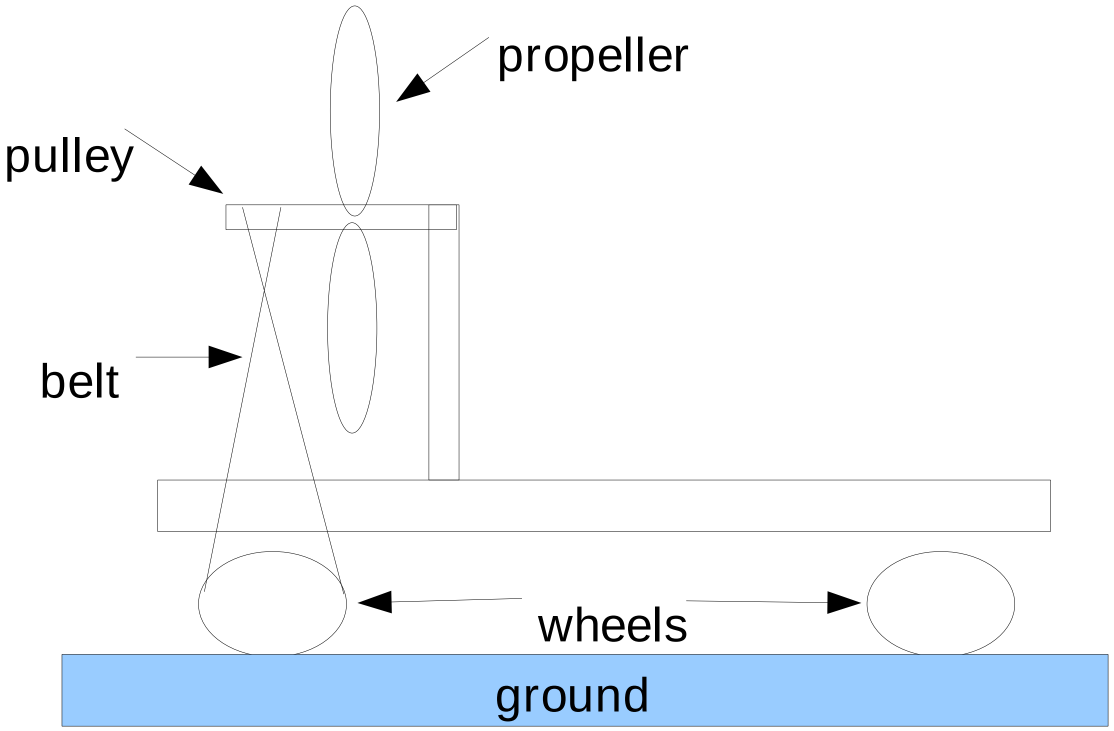
## The Video

There are a couple of videos on youtube showing some gizmo that looks like some manner of Rube Goldberg machine. The folks then claim that this gizmo can go downwind faster than the wind.

For example:



The above profile shows the propeller facing forward (to the right). It is connected by some belt/pulley system to an axle which is connected to a wheel which turns on the ground.

## The Claim

The claim made around these gizmos is that they can travel directly downwind faster than the wind (DDFTTW). If they are on flat ground facing east and there is a 5 mph wind coming from the west directly to the east, the claim is these gizmos can go faster than 5 mph.

The two videos I saw never explained how the gizmos work, they simply demonstrated the gizmo going faster than the wind. The videos go back as far as Jan 2006 that I've seen. There may be earlier versions. As recently as December of 2008, an existing video was posted on a forum I read regularly, and that's how I came to see it.

## The Reaction

The reaction to these videos has been mixed. Some people immediately agree that it is possible to go DDFTTW. Others point out different aspects of the video where they think the claim could be hoaxed. The video doesn't show a wide enough angle to show what's going on ahead of and behind the cart. A cart could be built extremely light, but with an extremely dense flywheel, and the flywheel could keep a cart coasting for a long time, longer than shown on the video. And so on. Others don't know if the claim is true or not.

## The Epistomology

Epistomology is a study of how we come to know things, and how we can know something is true or not.

The thing about the videos is that the videos alone are not sufficient to know that these gizmos do what their owners claim they do. Videos can be faked. Videos are faked. That the person making the video is some expert in the field is also not sufficient. The logical fallacy is called argumentum ad verecundiam (appeal to authority). An example of this would be if Ponds and Fleischmann were to make a video showing a box that generates electricity using cold fusion without explaining how it works, and instead saying, trust us, we're physicists. Nor is it sufficient if a number of people come out and say, yes, this claim is true. The logical fallacy is called argumentum ad populum (Appeal to the people or gallery).

And the thing is, being aware of potential hoaxes is a good thing. Identifying logical fallacies, like appeal to authority and appeal to popularity, is a good thing. Entering into an investigation of whether or not something is true or not with an awareness of various knowledge traps is a good thing.

## The Truth

So, the “truth” is that these things can indeed go directly downwind faster than the wind. But it is “truth”, not truth, because you're the one reading this, and you may not believe the gadget can actually perform as claimed.

I could point to videos and expert opinions and numbers of people who agree that these things work and simply leave it at that. But I haven't proven anything to you at that point. And if you have skepticism about the device at that point, it's a reflection of you having a healthy dose of skepticism about claims made on youtube, not a reflection of whether or not I've explained it to you sufficiently so that you could know it works.

## Getting You to the Truth

So, the idea for me is to figure out a way to prove this claim that a vehicle can go directly downwind faster than the wind in such a way that you know it can be done. You might not be able to design the gear ratios and prop pitches, but you can see the video and nod and get that, yes, it can be done and isn't a hoax.

And I can't resort to mere demonstrations, in the sense of the way The Turk, a chess playing automaton, was demonstrated for decades before it was proven to be a hoax. And I can't resort to appeals to authority. And I can't resort to appeals to popularity. And I can't resort to any other logical fallacy.

The goal is that by the time you finish reading this, you understand how the device works and you don't have to “trust me” to believe it can travel faster than the wind.

## The Underlying Claim

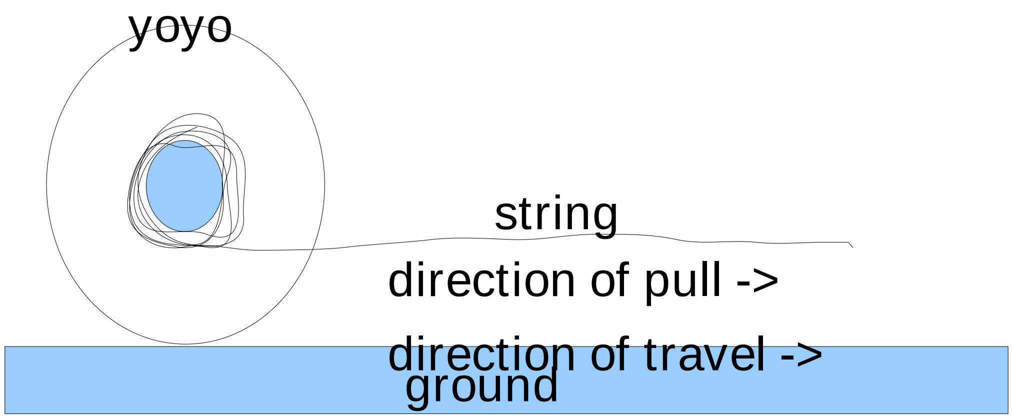
I think that when some people see the video, with the propeller cart and gears or belts and pulleys, they get wrapped up into the idea of that particular device going faster than the wind, they don't understand how it could possibly work, and so they disbelieve it.

But the original claim is simply *any* vehicle going directly downwind faster than the wind. The propeller cart is merely one specific instance or example of that claim. So, instead of starting out by explaining how the propeller cart goes faster than the wind, I'll start by showing a simple vehicle that can go faster than the wind. One simple enough that you can understand it without much difficulty.

From there, I'll extend that simple vehicle until it turns into a propeller cart, and hopefully, you'll see and understand all the steps along the way. By the time you get to propeller cart, hopefully you won't have to trust a video or trust me or trust some expert or trust some popularity contest. That's my goal anyways.

## Yoyo Pulled by a String

One thing that came up during the discussion about these machines was that someone compared the propeller cycle vehicle to a yoyo on the ground, with the string wrapped around the shaft, and a person pulls on the string.



One can easily demonstrate that if you pull the string a fixed distance (1 foot), the yoyo will move more than that distance, perhaps 2 feet, in the direction the string moved.

## Yoyo Mental Exercise

Not everyone can look at the yoyo drawing above and intuit what will happen when you pull the string to the right. Some people imagine the yoyo will go to the left. Others think the yoyo will spin out and then go left. Others think it will spin out and then go right.

The fact is that if you pull the string slowly to the right, the yoyo really will go to the right faster than you pull the string.

If it helps, imagine that the yoyo is made out of some high traction rubber wheel and the ground is something sufficiently frictiony, like 80 grit sandpaper glued to the ground. Yes, if you pull the string fast enough, the yoyo will slip and then skip over the ground. But with some friction, there is a range of speeds at which you can pull the string and the yoyo will NOT slip. We're looking for what happens when the yoyo does NOT slip.

Yoyo Mental Exercise with Example Numbers

So, let's try some numbers.

Say we build a huge yoyo, one that is three feet in diameter. Lets see what happens. We'll make the outer wheel 3.18 feet in diameter (circumference of 10 feet). And we'll make the inner wheel/gear 1.6 feet in diameter (circumference of 5 feet). Say we get a long rope and pull it at a constant 3.4 mph (5 feet per second).

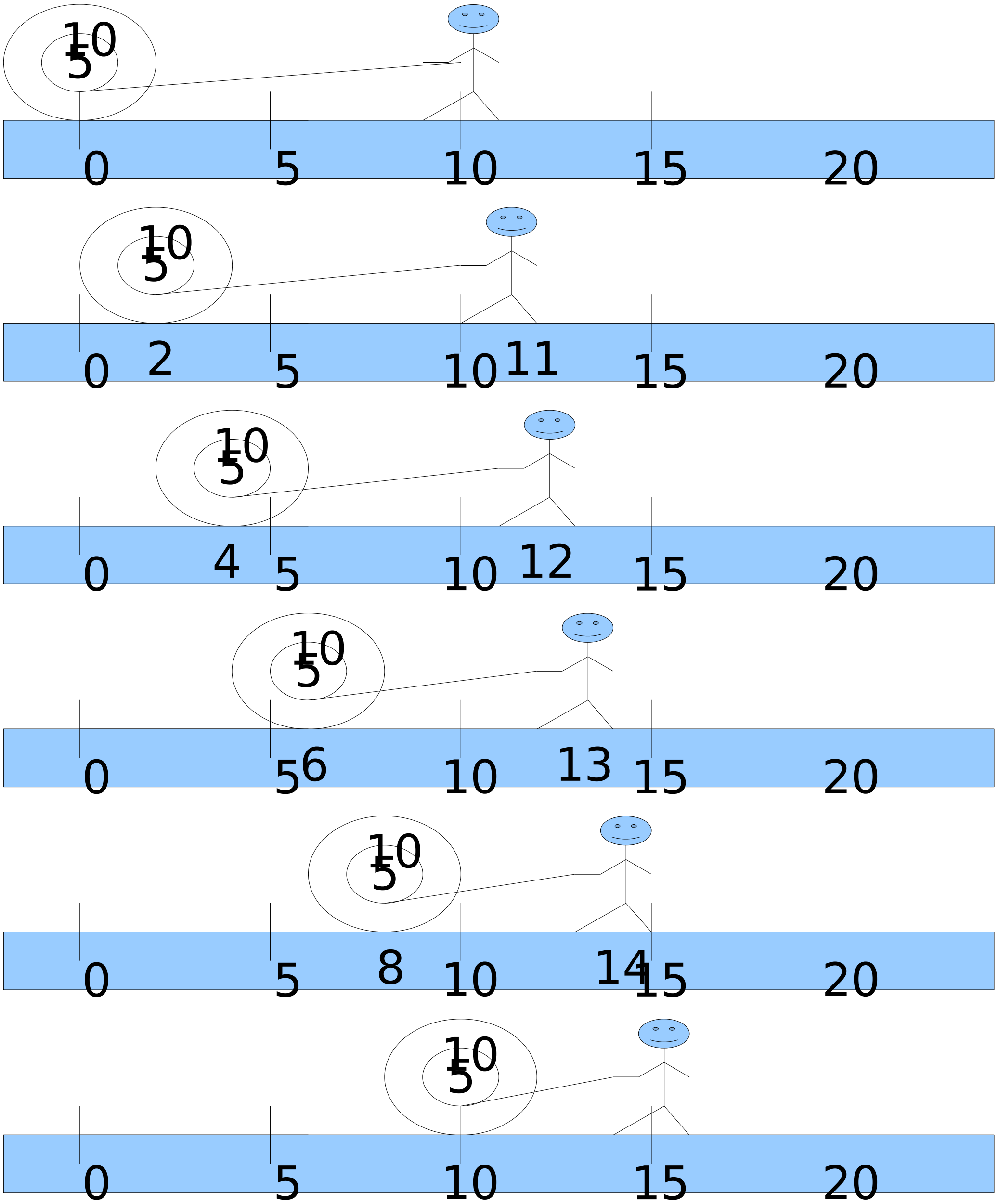
outer circumference: 10 feet
inner circumference: 5 feet
rope speed: 5 feet per second

A rope speed of 5 feet per second pulling the inner wheel with a circumference of 5 feet. We get one revolution per second. But the wheel rotates on the outer rim, which has a circumference of 10 feet, which engages the ground, so our speed over the ground is 10 feet per second.

rope speed: 5 feet per second
ground speed: 10 feet per second

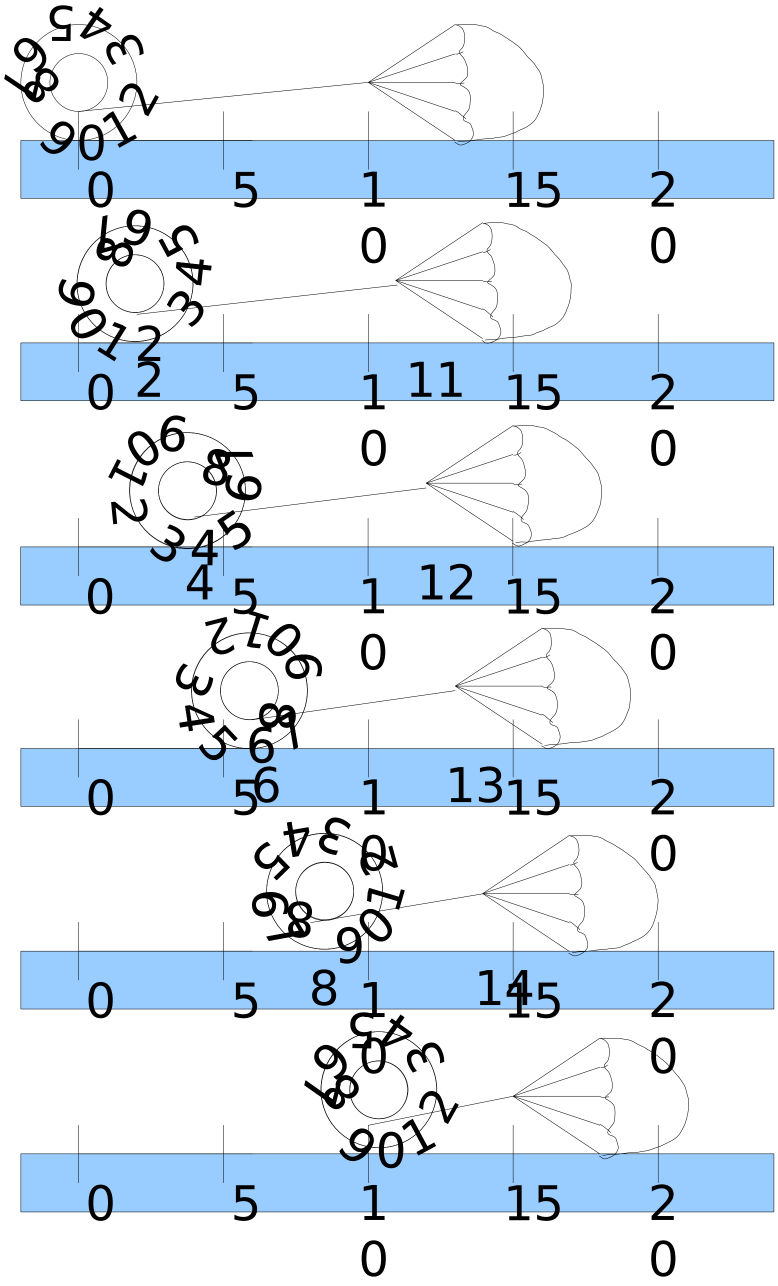
## Yoyo Mental Exercise Timelapse

The diagram below shows a “timelapse” of the above example. The circumference of the outer wheel is 10 feet. The circumference of the inner axle is 5 feet. We stand 10 feet away from the yoyo and start pulling at 5 feet per second. What the image below shows is a timelapse taken every time we move one foot. So, the image below represents 1 second of time, or each snapshot represents 1/5th of a second.



# Yoyo Mental Exercise with Parachute

Now, instead of you pulling the rope at 5 feet per second, you imagine attaching a parachute to the end of the rope and let it go in a 5 mph wind, you can imagine that the 5 mph wind makes the yoyo move at 10 fps. I tried to put numbers around the outer wheel so show that the wheel is 10 feet in circumference, and to show the wheel rolling forward at 10 fps. Since the timelapse is 1/5th of a second per frame, the parachute moves 1 foot per frame and the yoyo moves at 2 feet per frame. But either way, the yoyo moves faster than the wind.



## Different Understandings at this Point

At this point, we've gone through a simple mental exercise that shows a device that moves downwind faster than the wind. You may understand how that device works and can then translate on your own how a propeller-cart might work. If that's where you are at, congratulations, you can stop reading unless you're curious.

Or you may understand the yoyo-parachute can move faster than the wind, but don't yet see how it translates to a propeller-cart. If so, keep reading, we'll get to that.

Or you may not understand that the yoyo-parachute can move faster than the wind just yet. If so, this section is specifically for you. The next step for you is to build a simple yoyo and play around with it for a little while.  You'll be doing the yoyo physical demonstration.

## Yoyo Physical Demonstration

If you're still having trouble visualizing what the yoyo will do, you can easily demonstrate it. All you need is two paper plates, an empty soda can, some string, and some tape. Empty the contents of the soda can. Use the can as the inner axle that the string will be wrapped around. Use the paper plates as the "wheels" that touch the ground. Tape the soda can to the plates so that the can acts like the axle and the plates act like the wheels. Then get some thread or dental floss or fishing line or something, about three feet, and tape one end to the can.

This is a simple enough device to build that it should take only a few minutes, and most people should already have the pieces and parts around the house.

Put the yoyo on the ground facing towards you so it can roll towards you as you pull. Unroll the thread from the soda can axle, then make one wrap around the axle with the thread, and leave the rest off the axle. Have the thread come off the bottom of the axle/can. Then slowly pull the thread towards you.

The plate/can/yoyo will move towards you faster than you pull the string and it will eventually run over your hand.

Even if you think you understand how the yoyo will behave, it might help to build the paper plate-soda can device and play around with it.  You can then play around with different amounts of friction by putting the plate on really smooth surfaces (like linoleum or a smooth counter top) and on really frictiony surfaces (like a rug). On the smooth surfaces, you'll be able to get the wheel to slip and spin more easily than on the rug. If you pull up slightly on the string, and can get the yoyo to slip, you might actually be able to get the yoyo to roll away from the direction your pulling.

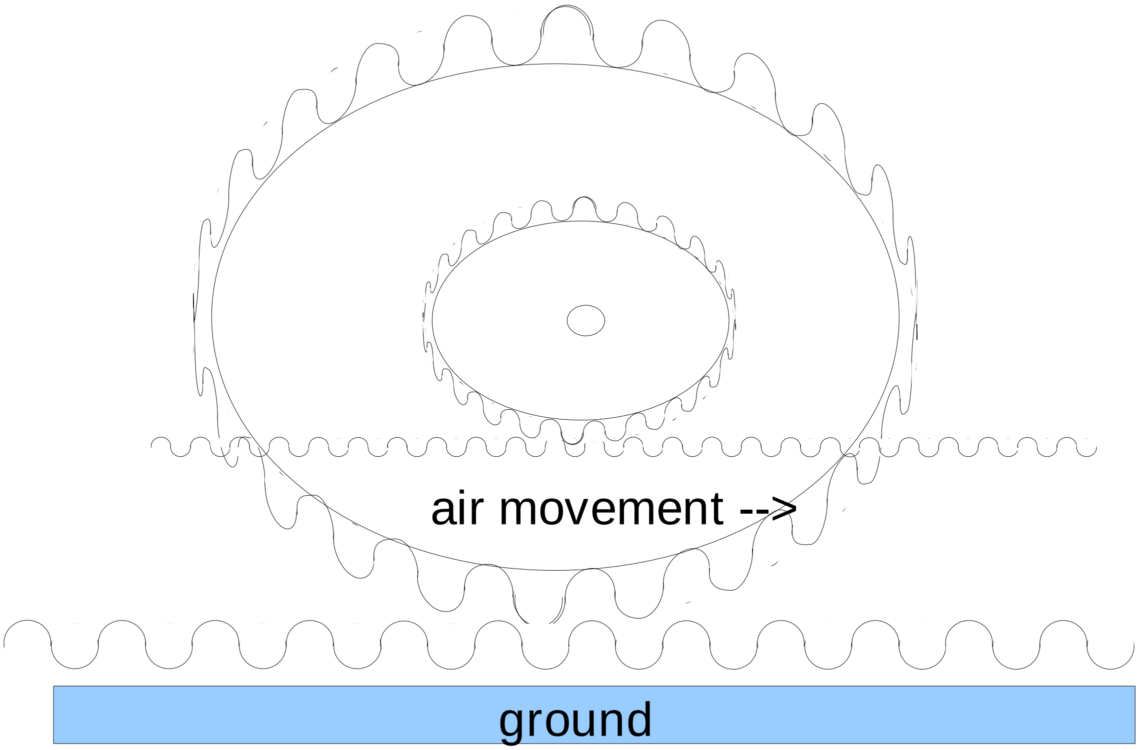
These are all valid demonstrations of how a yoyo pulled by a string will behave. But remember we're interested in the range of behavior where the yoyo doesn't slip on the ground. That's where the propeller cart operates, so that's the part we're interested in.

Really, if you're even the slightest bit curious, go build one and play around with it.

Once you see the yoyo pulled with a string on the ground move faster than the string, you might be able to imagine that it is indeed possible for a vehicle to go directly downwind faster than the wind. If not, play around with the yoyo some more. Then continue reading. We'll try some different exercises and hopefully one of them will make this click for you.

## Yoyo as a Gear

If we translate the yoyo-string idea to gears, we could model the vehicle as a circular gear with two sets of teeth, one that touches "ground" and one that engages the "air". This might allow some people to visualize the yoyo with zero slippage, since the gear teeth won't allow anything to slip at all. So, we might draw the gears like this:

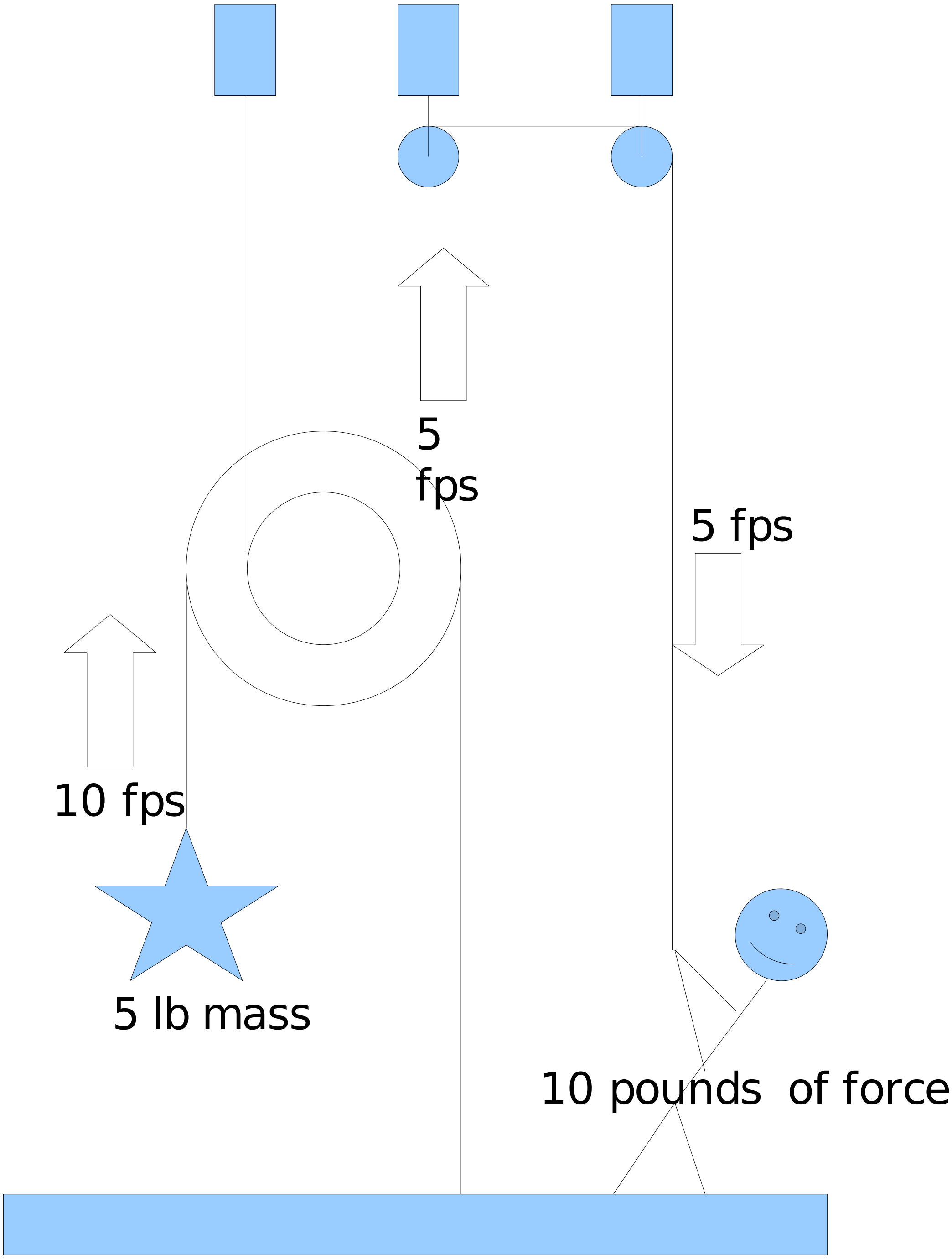


Instead of pulling a string on a yoyo, you have to imagine moving the horizontal gear labeled "air movement". If you imagine moving the "air" gear at one speed, you can see that the circular gear that was our "yoyo" can move twice as fast as the "air".

The main difference between this and the yoyo is to help anyone get over the idea of the yoyo slipping. In the case of the gear drawing, the gears can't slip. And the "yoyo" gear moves twice as fast as the "air" gear moves.

## Rope and Pulley Diagram

Yet another way to look at the vehicle is as an old fashioned rope and pulley system.

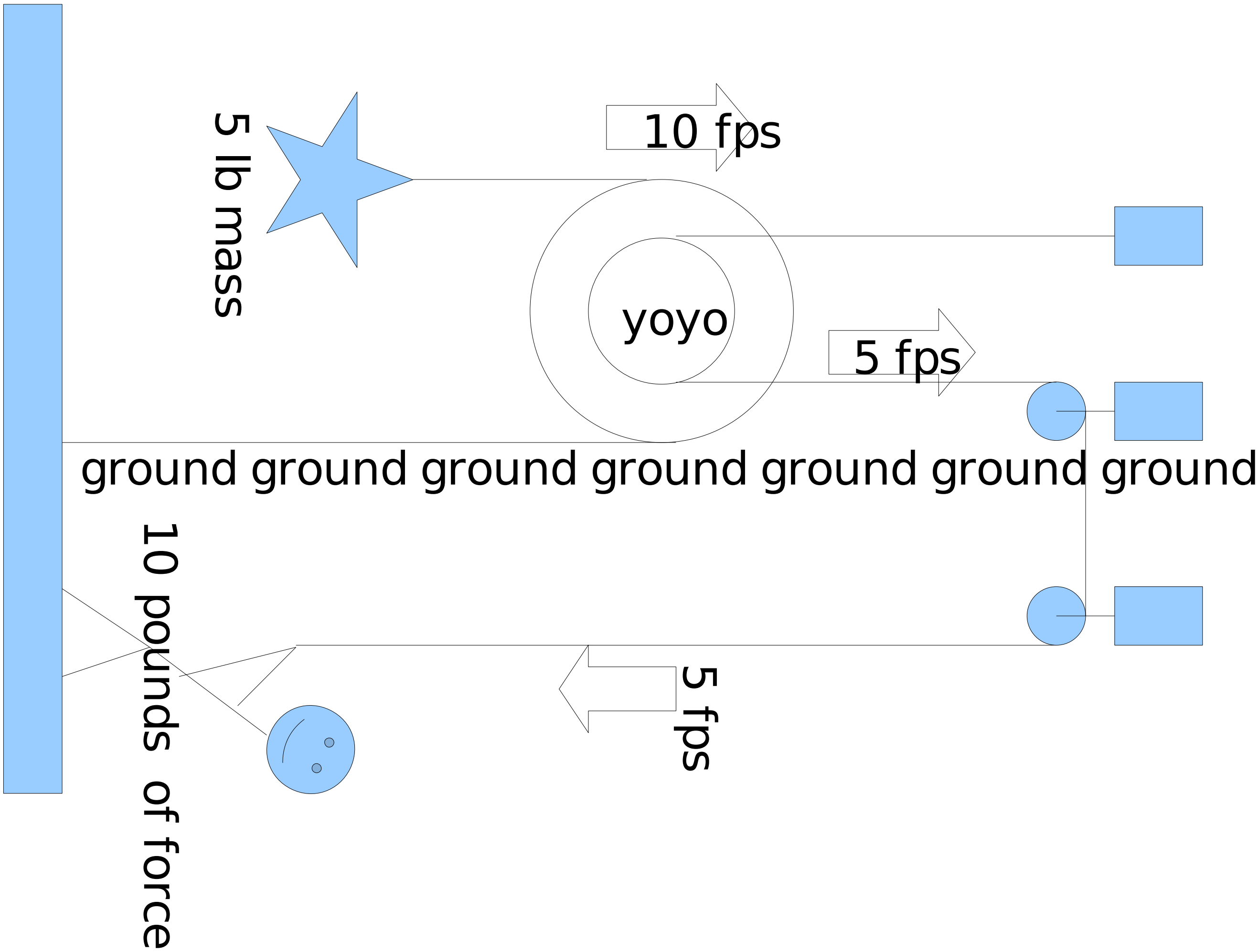


Most block and tackle systems are designed so that you can lift 10 pounds with 5 pounds or less of force, and they accomplish this by requiring that you reel in twice as much rope.

In the rope and pulley system above, we are instead having to use 10 pounds of force to move a 5 pound weight. And we are willing to do this because we would rather reel in only 5 feet of rope to move the weight 10 feet.  If we reel in 5 feet of rope in one second, the weight will move 10 feet in one second. Therefore the weight moves twice as fast as the rope we reel in.

This means we're not getting a free lunch here. This is not a perpetual motion machine. Instead the vehicle acts like a block and tackle, with the block and tackle leveraging between the ground and air, so that it can move faster than the air is reeling in “rope”.

We can take the rope pulley diagram and turn it clockwise and show how the rope/pulley diagram translates into the yoyo-pulled-by-a-string diagram:



We can see the pulley acts the same way as the yoyo. We can also see that a 5 feet per second pull to the right will cause the yoyo to travel to the right at 10 feet per second.

Again, the idea here is to get you to see that a vehicle traveling downwind with the wind can move faster than the wind. In the above example, replace the person reeling in the rope with the wind, and you can see we have the potential for a machine that moves faster than the wind pusing it.

## Possible, Needing Implementation

At this point, you should have the understanding that it is possible for a vehicle to travel downwind faster than the wind. We've shown the basic theory behind how to do this with a yoyo being pulled by a rope, a geared wheel with two gears (air and ground) acting on it, and a rope and pulley diagram showing a block and tackle that lets you reel in 5 feet of rope to move the weight 10 feet.

All of these machines show how we can move downwind faster than the wind.

If you don't understand that it is possible, then stop and review. Construct the actual yoyo and play around with it.

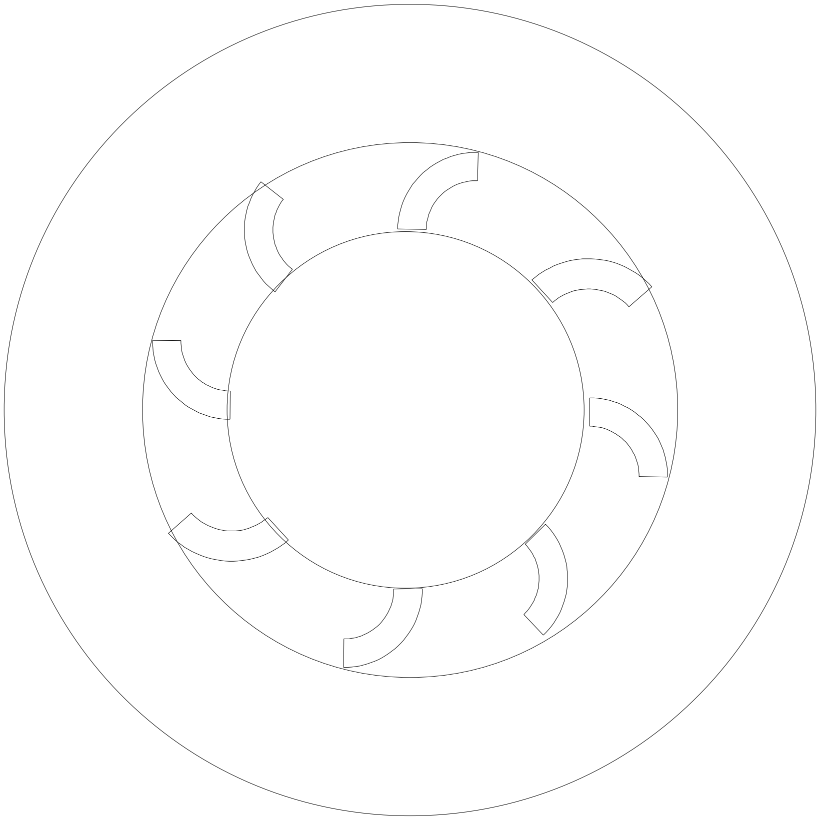
Once you understand that it is possible, then it is a matter of implementing it in some way. Implemenation is the next section of this document.

Implementation, Tumbleweed

We need to get the air to act like the rope and push on the bottom of the inner wheel.

My first idea was to try an anemometer, one of those widgets you see on a weather station that usually has three cups at the end of spokes on a wheel, and the whole thing spins on top of a pole.

Say we draw it as a bunch of vanes and then turn it sideways. And then instead of putting it on top of a pole, we mount it to a wheel that is twice as big as the anemometer is. So now we have something that looks like our two pulleys and looks like we can replace the rope with the wind.

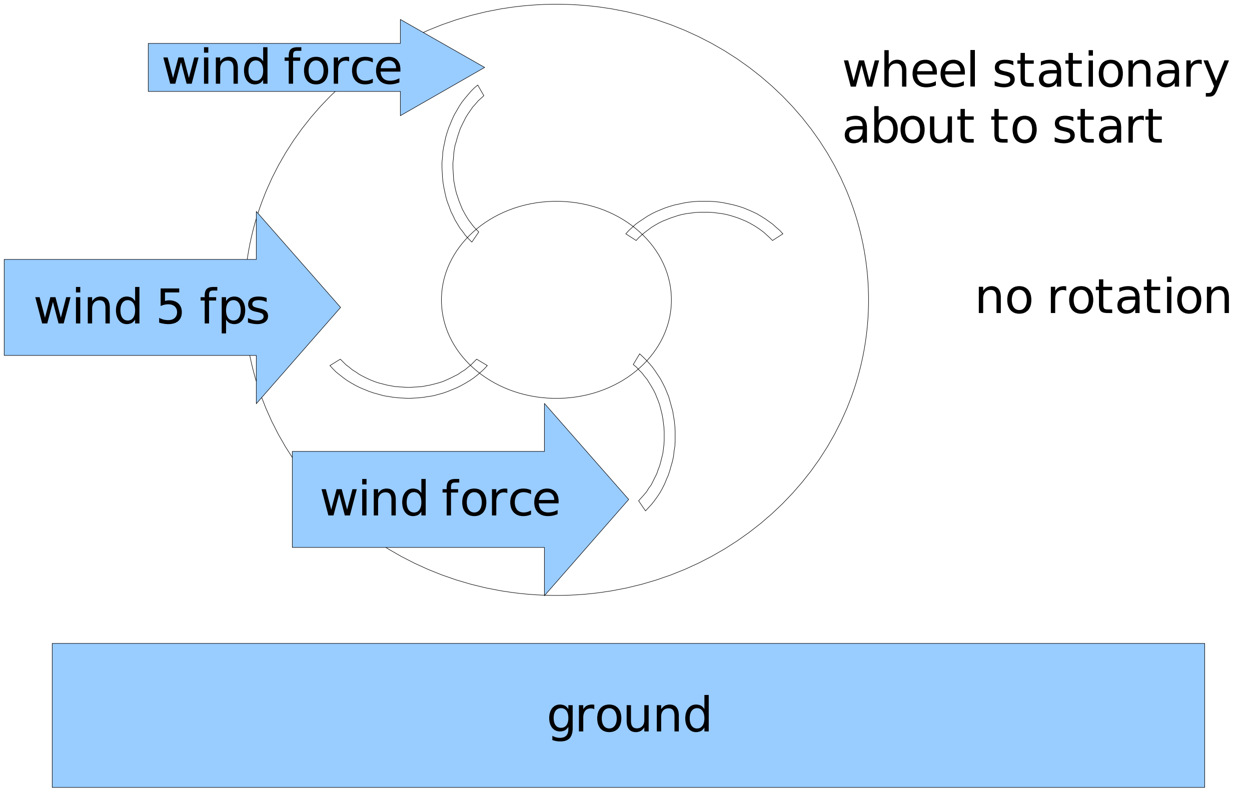


With the wheel sitting at rest, we can imagine the wind coming from the left to the right, blowing over the anemometer vanes. Like any anemometer, the vanes will want to turn because of the wind. In the above drawing, it'll want to turn counter clockwise. And we can imagine the wind blowing with more force on the bottom vane than on the top vane, so we get the leveraging we want.

The problem is that it stops accelerating once we reach the speed of the wind. And that's no good because the goal was to go faster than the wind.

## Tumbleweed At Rest

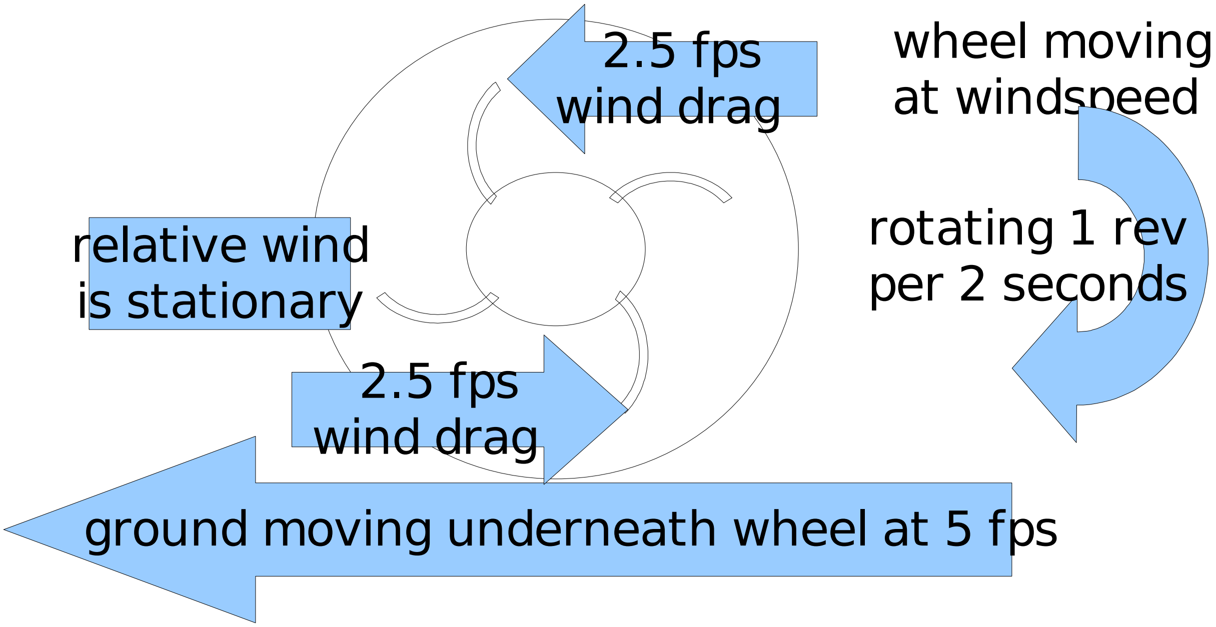
Here's the wheel at rest in a 5 fps wind:



We can see the 5 fps wind on the wheel. And we can imagine it pushing harder on the teeth of the bottom vane and slipping over the top vane with less force, leveraging the wheel forward.

Tumbleweed at Windspeed

Here is the wheel when it is moving at exactly the speed of the wind:



The wheel is moving over the ground at 5 fps, the speed of the wind. The overall relative wind that the wheel sees is zero. However, the wheel is spinning, so the vanes are churning over what is “stationary” (relative to the wheel) wind. This produces an equal amount of drag all around the vanes and slows the wheel down.

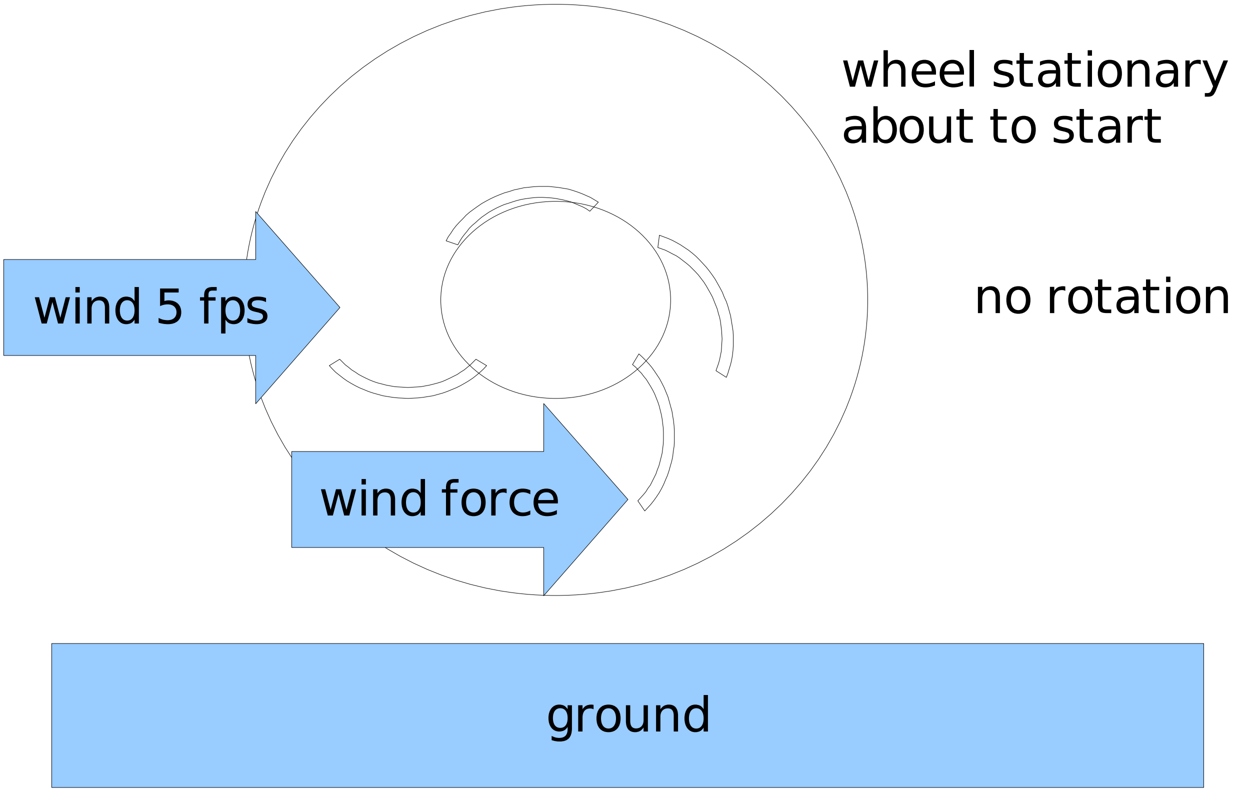
Once it slows down below the speed of the wind, it will speed up again, but once it reaches wind speed, it will slow down again.

So, it turns out that using an anemometer to implement the “pulley” doesn't work.

## Tumbleweed with Flapping Vanes

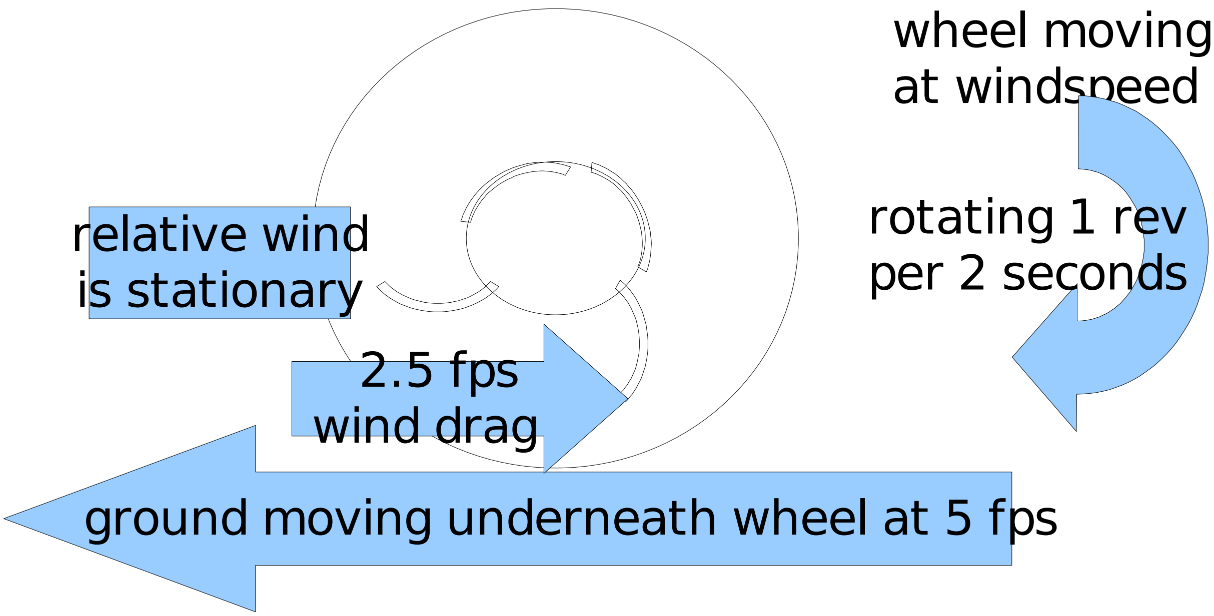
The next idea I had was to modify the anemometer so that the blades retract at the top and then drop down at the bottom. The vanes could be made by cutting a vertical tube into sections. If the axle is the same diameter as the original tube, then you could mount the vertical sections around the tube, and they could all lay flat. Some kind of hinge would allow them to flap out. You'd also need some kind of stop to prevent them from flapping open completely. You could use the weight of the flap to open them at the bottom and then the weight would close them at the top.

It might look something like this at rest:



We can see the vanes flapping down because of their weight, and the wind blowing against only the bottom part of the anemometer.

Here is the device at the speed of the wind.



Here we can see the relative wind is still zero, but now there is no drag on the top vane since it flapped shut. however, there is drag on the bottom vane, so it acts as a force that pushes the wheel forward, faster than the wind.

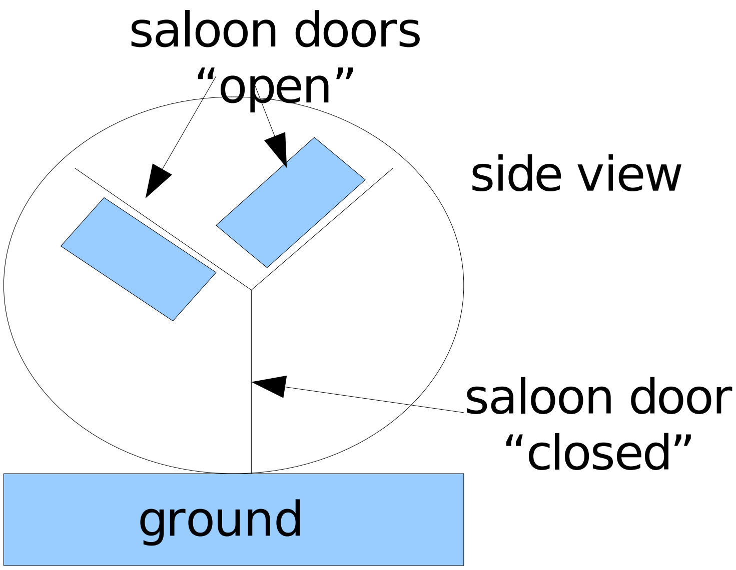
The next immediate problem becomes one of implementing the flapping. At rest, everything behaves fine. In motion, the flaps will have their own inertia and will want to swing out away from the axle simply because the axle is spinning.  The only way this will work without additional mechanical complexities is if we limit the max operational windspeed to below whatever limit would cause the vanes to flap open at the top of the wheel due to rotational velocity. This then means we might have to make the wheel extremely efficient so that it can operate at low speeds. use extremely light flaps so they don't have a lot of inertia, and so on, and so on.

## Tumbleweed with Saloon Doors

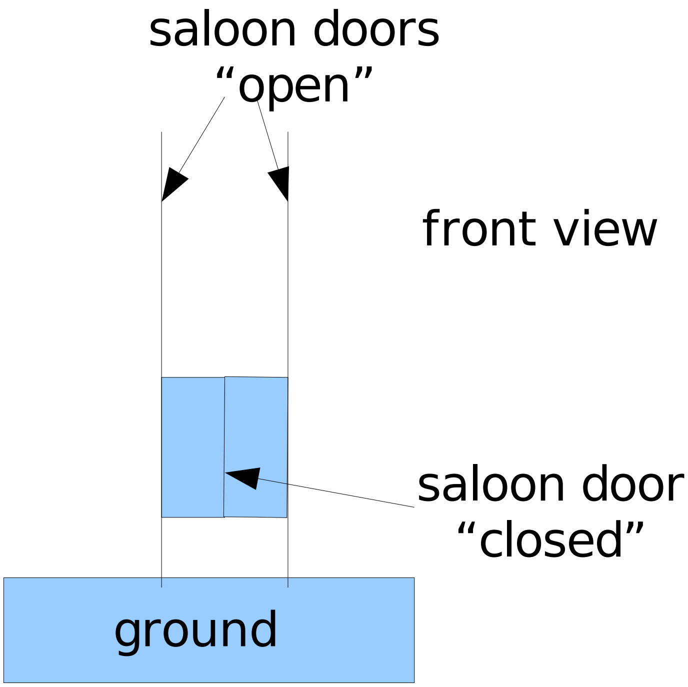
So, what if we flap the vanes so that rotation doesn't affect them?

Take two wire frame wheels. Join them with a wire at the axle. Use three spokes per wheel to connect axle to rim. Imagine standing in front of the wheel as it rolls towards you, now, use the spokes to hang saloon door style flaps. When the door is closed, it blocks the wind and creates the leverage we need. When the doors swing open, they swing until the lay flat along the wheel hubcap. This would remove the flaps almost completely from the airflow when we want them out of the way. The axle area could be completely open, no need for a solid cylinder for the flaps to lay against, maybe just a wire axle to join the two wheels.

Here is what it might look like from the side:



Here is what it might look like from the front:



We could then mount a pressure switch along the spokes that get pushed up when the wheel rotates that spoke towards the ground. When the switch is pushed into the wheel (by the weight of the wheel), the flap closes. When the switch is released, the flap opens. Making the flap light and designing a switch that activated with light pressure would be important (or making the wheel really heavy, but not have a lot of aerodynamic drag, so to put enough weight on the switch). Maybe we make the doors twice as wide and extend out beyond the spokes. Then their center is under the spoke and pivoting them might be easier.

However it is implemented, we can see in this saloon-door version of the tumbleweed that we would get the leveraging we want only on the bottom of the wheel, at a radius of about half the ground wheel. The end result should be to accelerate the wheel faster than the tailwind.

All we've really done is replace a parachute on the end of a long rope with some flaps that put parachute like resistance at the bottom of the inner wheel.

So I do some more poking around the web and find that anemometers in general have an efficiency around 1/3rd. That means in a wind moving at 6 fps, the tips of the vanes are moving at 2 fps. If they're this inefficient, then that means getting it to work at low speeds might be really hard. A flapping anemometer might be more efficient than a nonflapping one, but I'll assume low efficiency is still the rule.

This means that we've got to make sure that the flaps we do have work well just to get 1/3 efficiency.

Which I must say is rather depressing. And this is supposed to be fun. So, lets switch over to full-on crazy-fun mode for a little while. The original design with the propellers looked like a rube goldberg machine to me when I first saw it. So, why not take rube goldberg and run with it to some insane level? Lets assume the most rube-goldbergish device that runs directly downwind faster than the wind is the device that “wins”.

So, we need to bring out the imagination factory. For this. Don't actually go out and buy these components at Home Depot. Just use the imaginary lumber and other parts you carry around in your imagination.

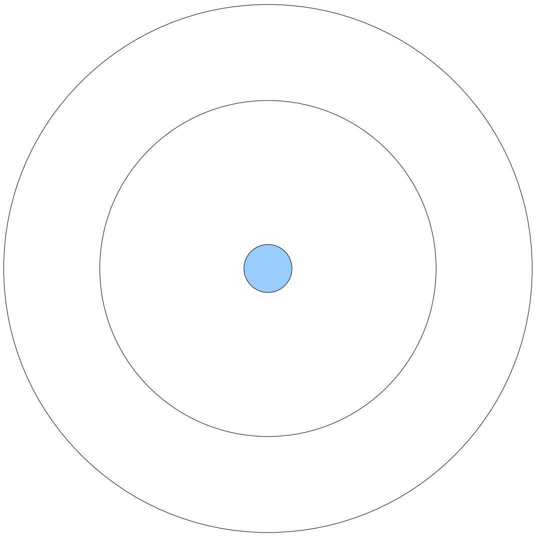
Lets go back to the “tumbleweed with a parachute at the end of a rope” idea and turn it into a cart. The tumbleweed idea is cool, but the fact that we have no stationary platform to hang a telltale or float a balloon so we can see the windspeed will be problematic if we ever want to video this thing in action. Also, the tumbeweed doesn't have a place to sit, which is really important when we convert this thing to mega-size. So we need to convert the tumbleweed-rope-chute into a “cart” type of design.

The first piece is a tumbleweed wheel. A ground wheel at one diameter, and an inner pulley at half that diameter. We'll eventually wrap a rope around that inner pulley wheel and tie our parachute to it, but just start with a tumbleweed wheel. If we're going big, imagine using something like one of those big wooden cable spools that electrical power companies use. They're about four foot in diameter, the inner axle is about two foot in diameter, and the wheels are about three or four feet apart.

Now, through the middle of that big tumbleweed wheel, we need to put an axle on it. A piece of PVC pipe of the correct diameter (or maybe a round wooden post) and have it be six feet long so it sticks out the sides of the tumbleweed. The axle will be stationary, and the tumbleweed wheel will spin around the axle. Imagine some ball bearings of the proper diameter between them if you want. Because the parachute at the end of the rope was in front of our stand-alone tumbleweed, we'll make the tumbleweed-pulley the rear wheel of our cart.

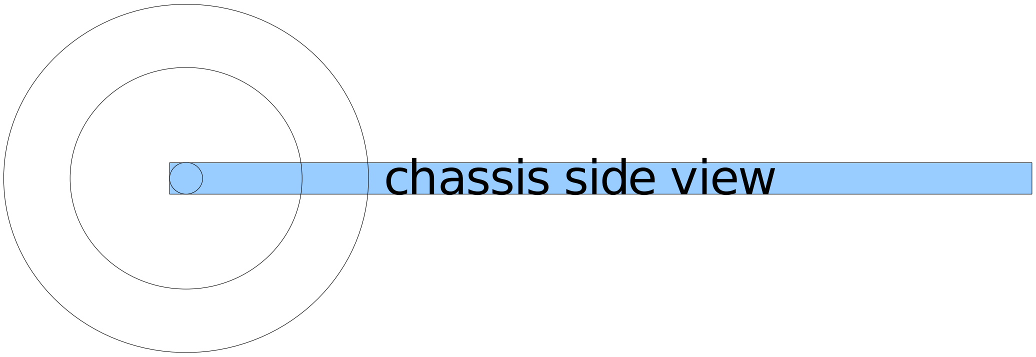
Here's the tumbleweed pulley, the rear wheel of our cart. It looks pretty familiar. The only addition is the dot in the center which represents the axle.

We'll use shaded (blue) areas to indicate non-moving parts of the frame of the cart.

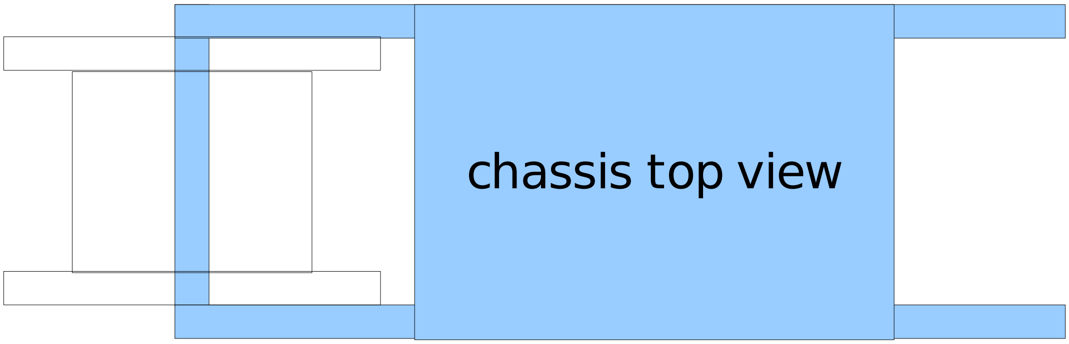


For the chassis, we'll imagine some 2x4's on either side of the tumbleweed going from the axle to fourteen feet in front of the axle.  (yeah, 14 feet is nonstandard, but you've got the imagination for it, right?) On top of the 2x4's, in front of the wheel, lay a 4x8 sheet of plywood, and nail it to the 2x4's. We now have an "H" shaped chassis. From the side, all we see is a 2x4 beam. But from the top, it looks like an "H".

Here's the side view of the rear wheel with chassis:

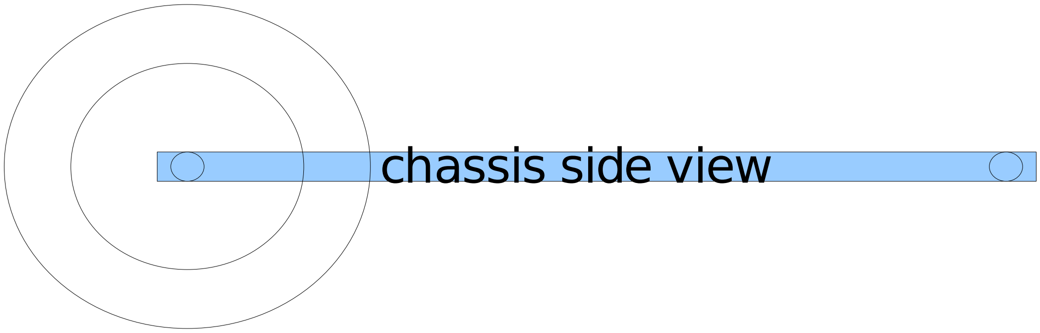


Here's the top view of the rear wheel with chassis:

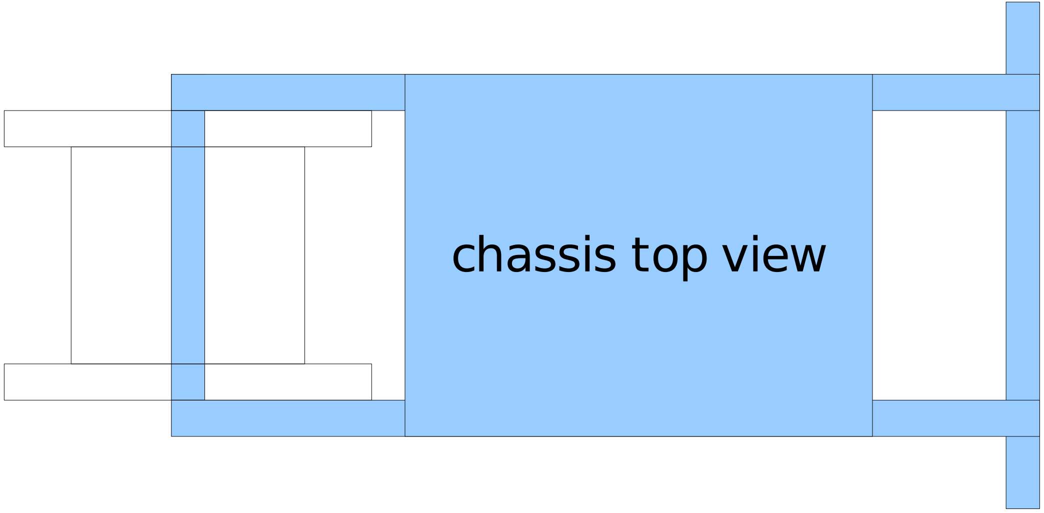


Now, the front end of this thing is interesting. We want a ground wheel that is free spinning from everything else. lets put an axle on the front end while we're at it, and have it stick out beyond the chassis a bit.

Our side view doesn't change much:

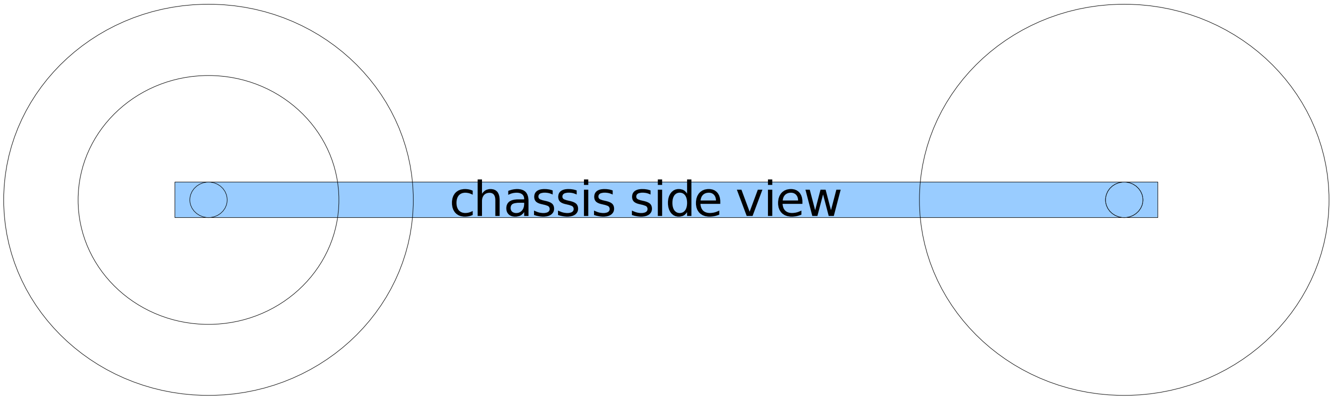


But our top view gets a bit odd.

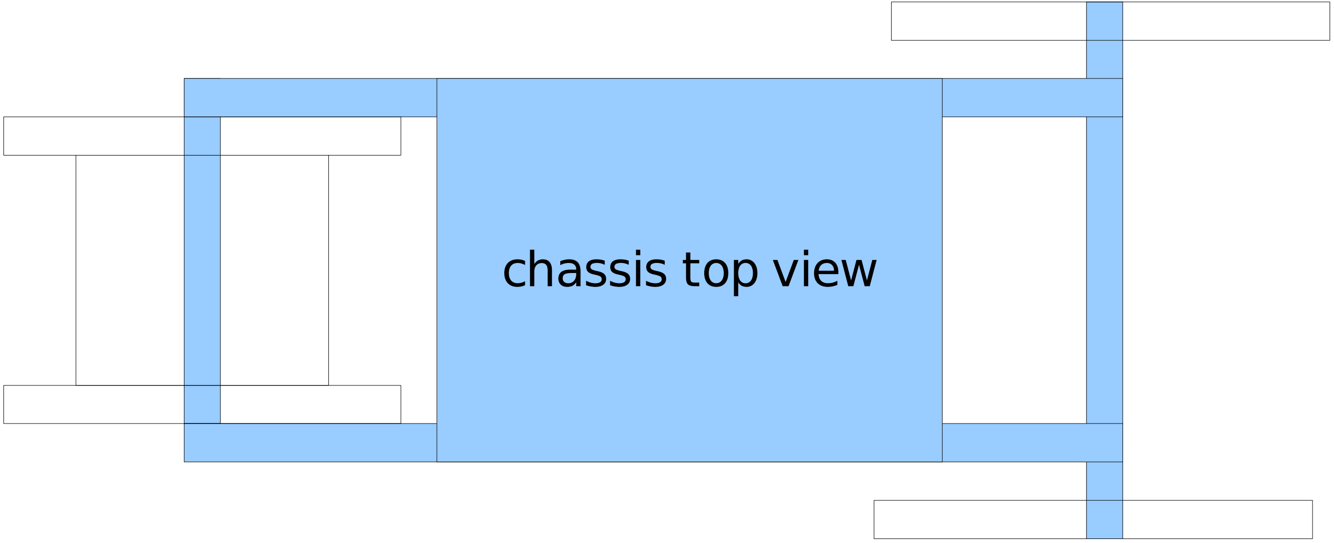


We now need to mount two free spinning wheels on the front axle. We can put them on the outside of the chassis to make clear they're not attached to anything else.

side view:

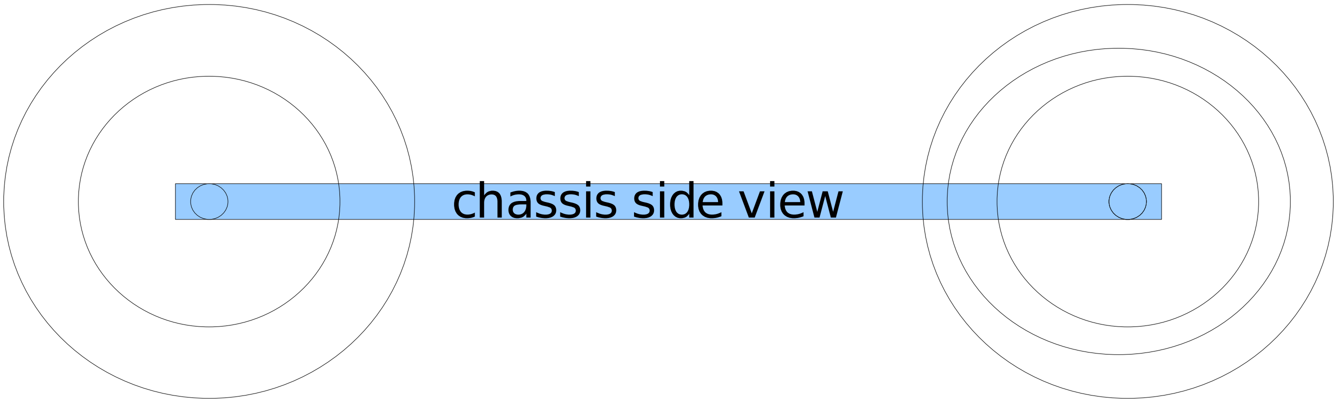


top view:

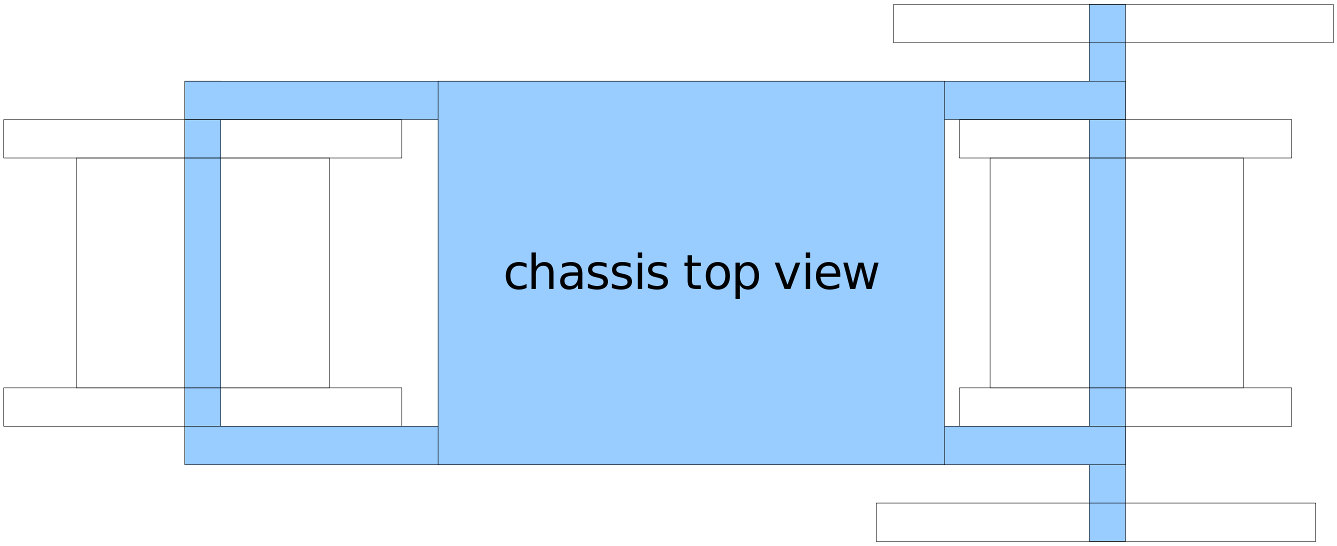


Now, imagine we get another one of those big electrical spools we used for the rear wheel, except we take a sawzall to it and cut the out wheels down by a foot, so they're only three feet in diameter instead of four feet like the rear wheel. Now imagine we mount that to the front axle.

side view:



top view:



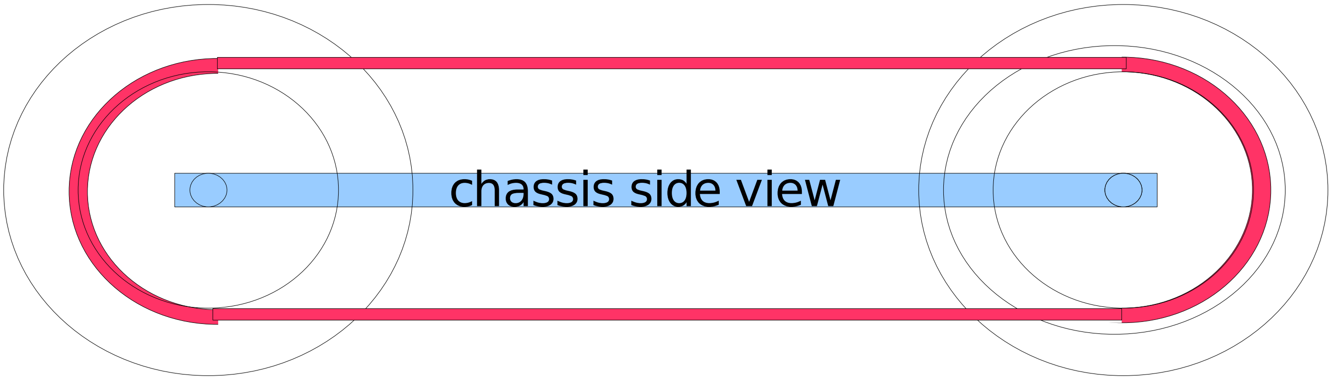
Note the spool in the front doesn't touch the ground so it spins freely on the front axle. The tires on the outside edge of the front axle spin freely as well, including spinning independent of each other and independent of the spool in between them. The front tires just keep the cart from nosing into the ground (and you could use them for steering if you want)

Now, get some rope. We want enough rope to go around the two spools. We do not want the rope to slip on the spools when we pull the rope, so make it tight, to the spool. If it helps, you can imagine that the rope is a chain and the spool is a sprocket. We're only concerned about the rear sprocket/spool slipping, so the front isn't as important.

We'll use the color red to show where the rope is.

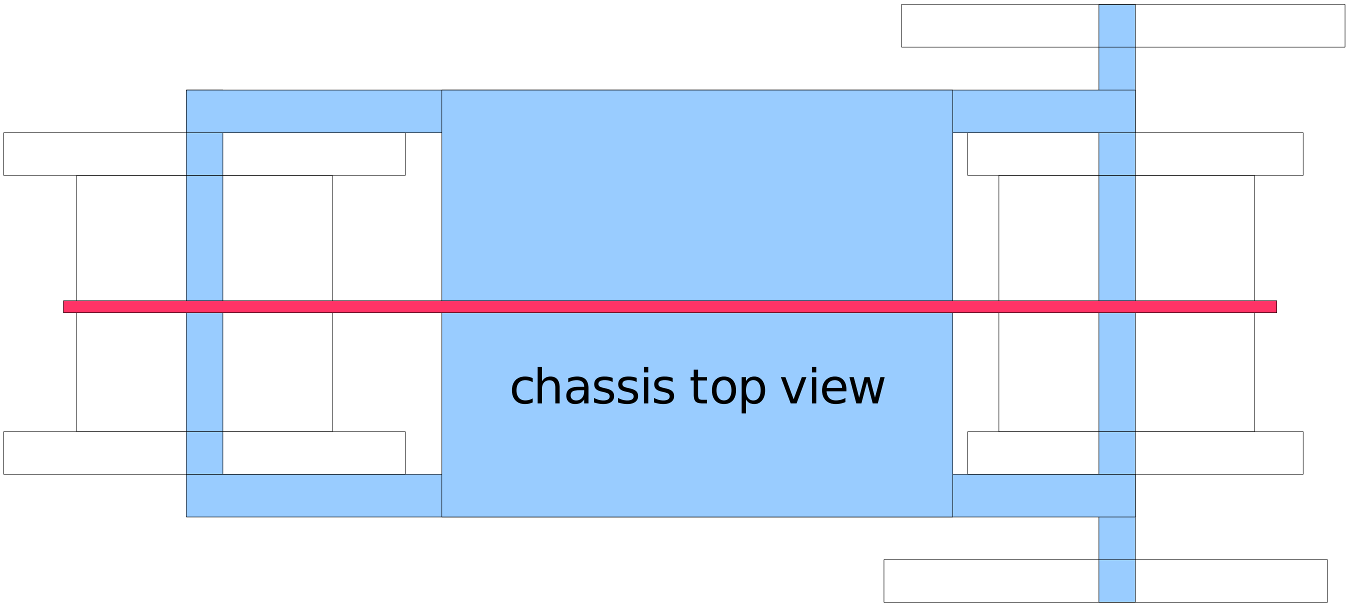
The side view shows that the rope goes above and below the chassis without touching it. It avoids the chassis because it curves around the spools.

side view:



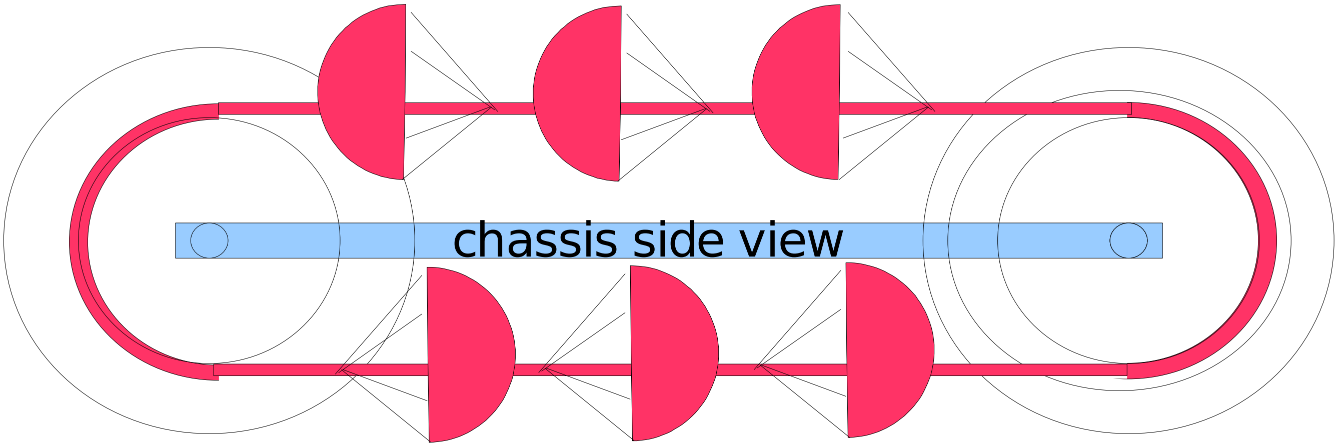
The top view shows the rope going down the centerline of the vehicle, over the chassis. The rope underneath the chassis isn't visible because it is directly under the rope on top.

top view:

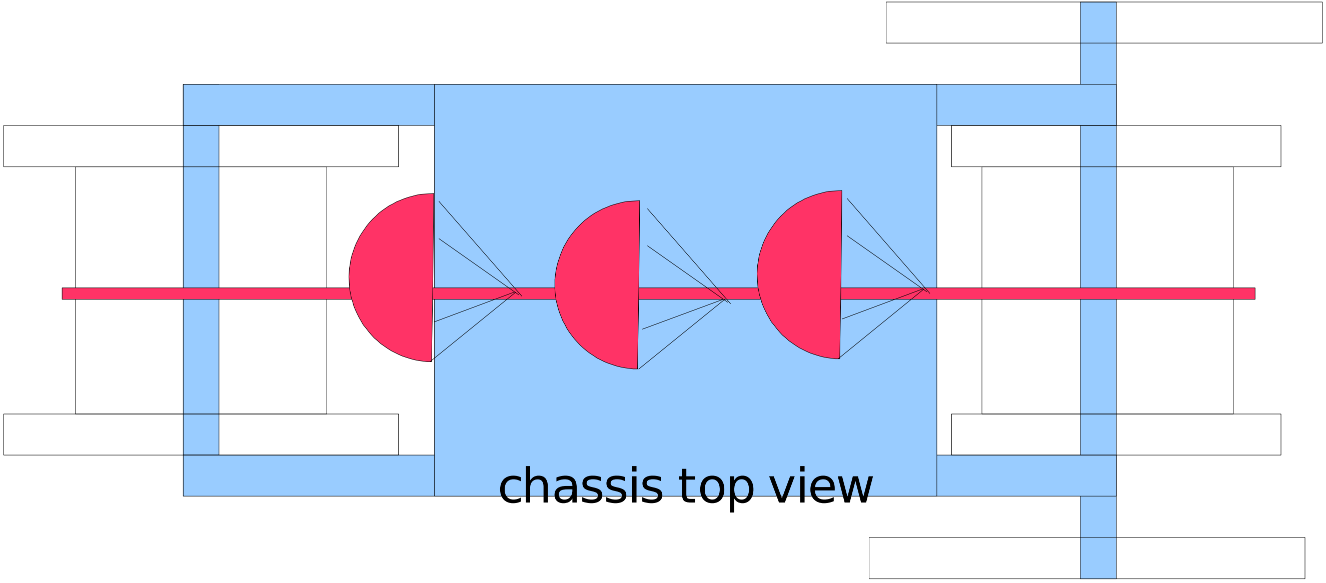


Now, imagine some parachutes. They'll be just under two feet in diameter when open and they'll have a hole in the center of the canopy so our red rope can go through the hole and keep them from falling onto the ground. Make them so they can collapse easily, that way when they hit the spools, they'll simply collapse and swing around the spool to come out the other side.

side view:



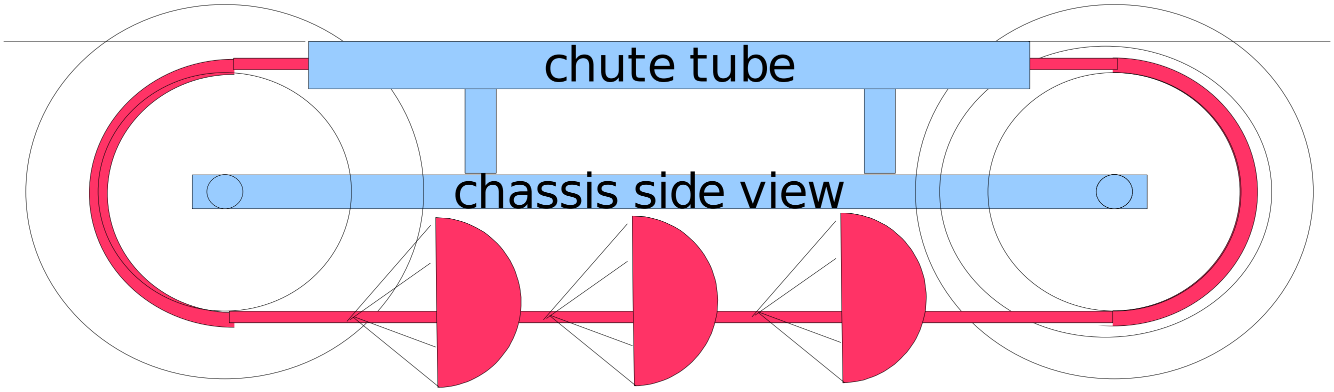
top view:



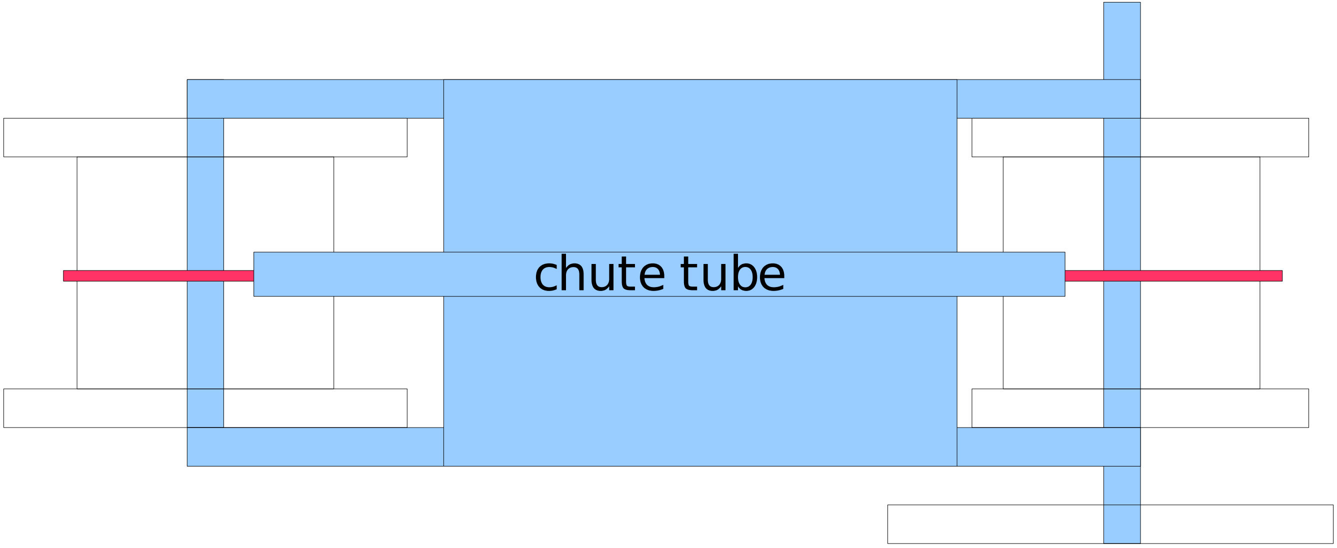
What have have at this point is a cart equivalent of the fixed vane tumbleweed. And the fixed vane tumbleweed stalls out when it reaches exactly the speed of the wind. The solution for the fixed vane tumbleweed was to make the vanes flap. We need to make the parachutes “flap”.

Imagine  that on the chassis we mount a fixed tube that goes around the top rope and forces the chutes to collapse when on the top portion of the rope circuit. On the top of the tube, we'll have little wire antenna stick out in front of the spool to help collapse the chute and let them slip into the tube where' they'll stay out of the wind stream.

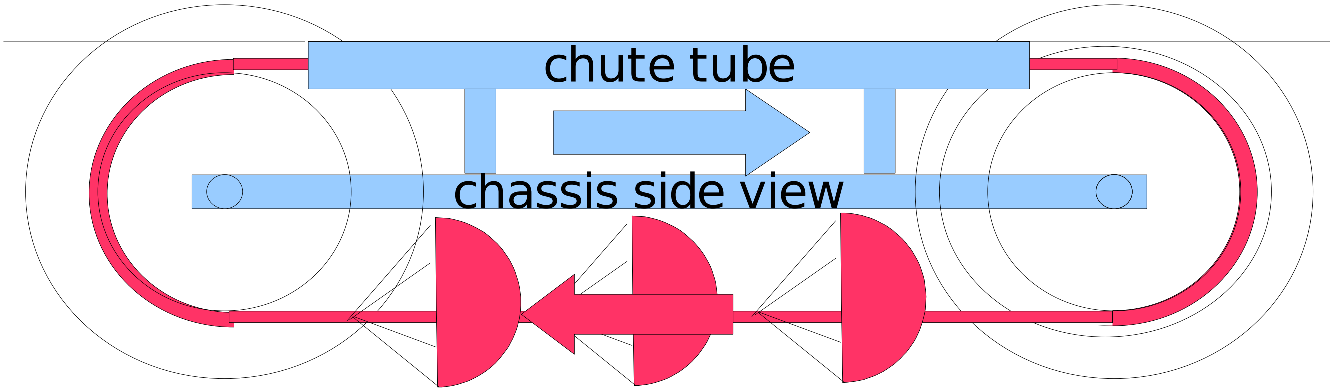
Here's the side view:



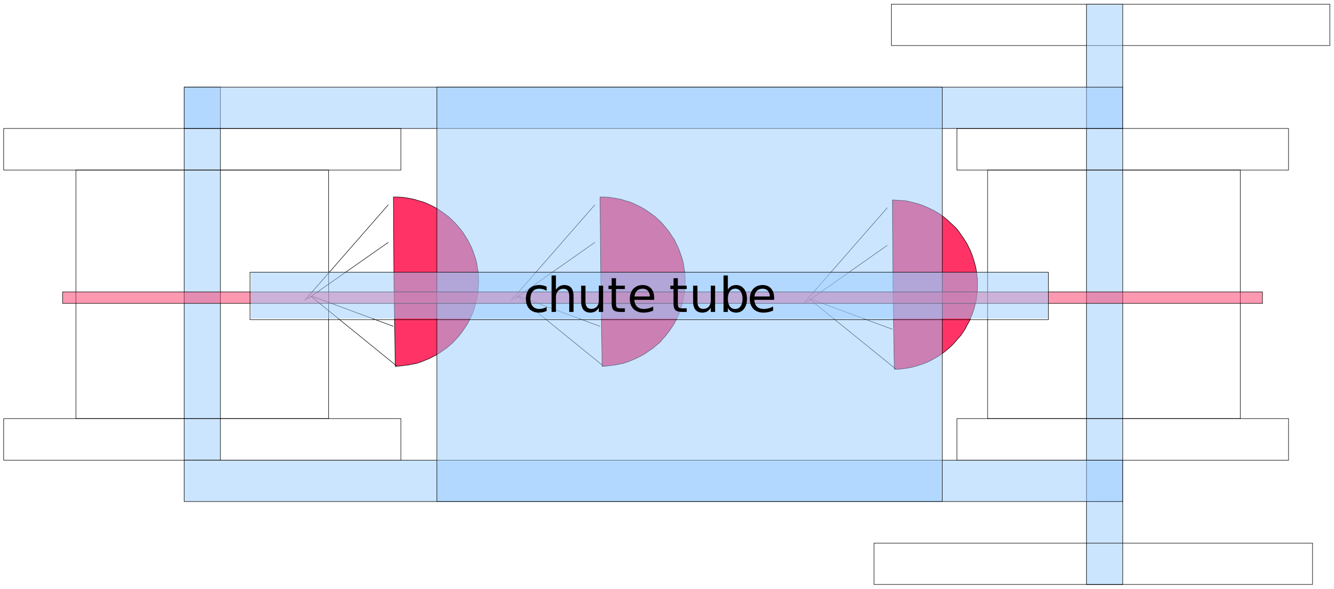
here's the top view:



Side view again:



Since the chutes are only open when they're under the chassis, we can show them using xray vision:



Looking at the side view, it seems fairly clear that we've implemented a tumbleweed being pulled by a rope with a parachute at the end, but now we've managed to overcome the limitation of having to carry the parachute far ahead of us before we release the brakes and start rolling forward. The chutes keep cycling in front of us through the chute tube and then opening up at the bottom of the spool to be reeled in.

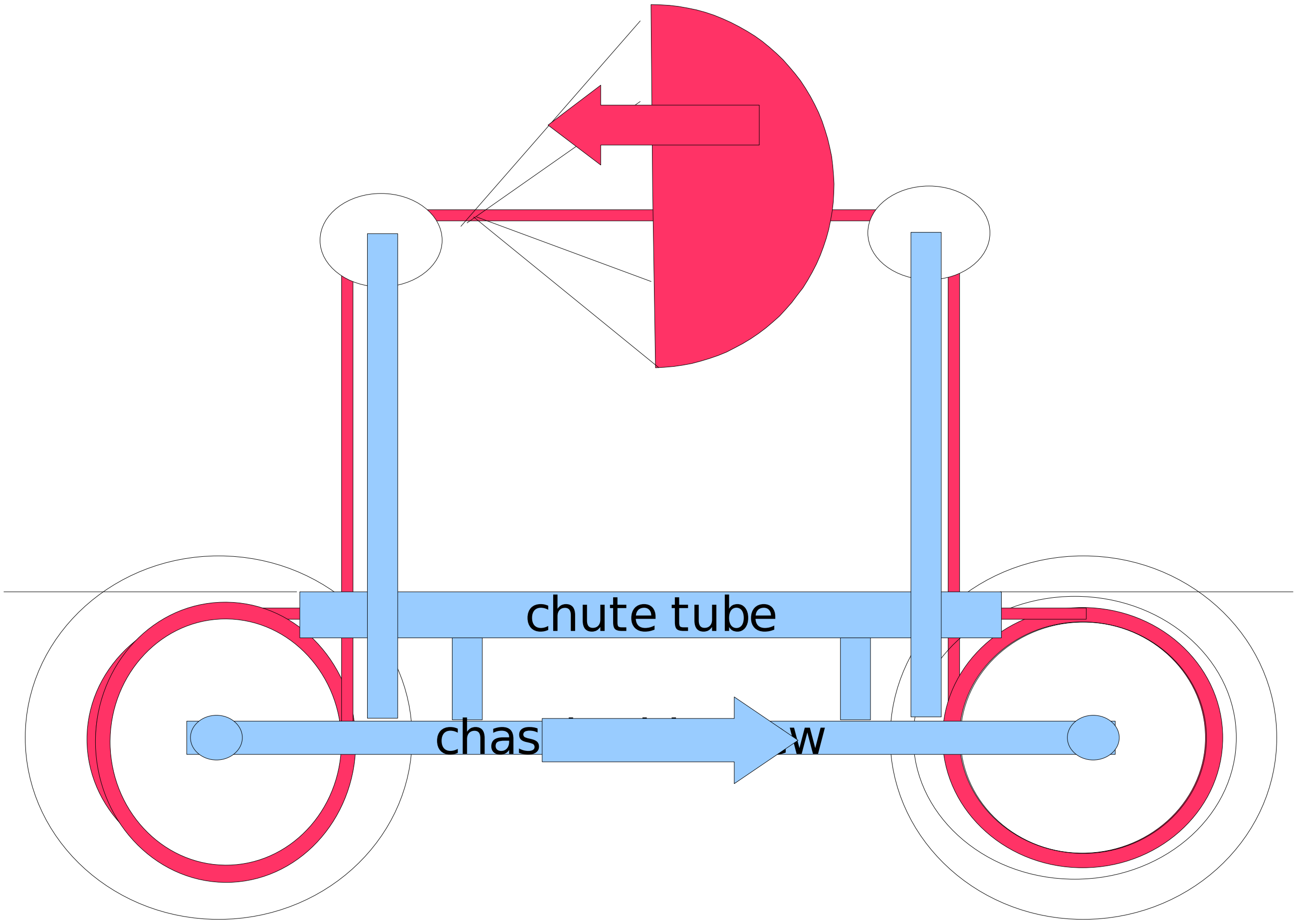
The parachutes on the bottom go from the front of the cart to the back. Since we've already proven that the tumbleweed-rope-chute thingy can run directly downwind faster than the wind (The time-lapse for the tumbleweed-rope-chute), we already know that this new parachute-pulley-cart can do it too.

The size of the parachutes is limited by the diameter of your ground wheel. You could mount more spool-pulleys and have them spin on axles mounted to the chassis, and do it in such a way that rope that used to go under the cart with open parachutes instead goes through more pulleys and ends up above the cart. High above the cart. Since we have an extendible chassis, we can make the frame as high as we want and so we can make the chutes as big as we want.

Mount some poles sticking up from the chassis and put some pulleys on the end of them. Then thread the rope up to them and mount as big of a chute as you want.

Tumbleweed-Parachute-Rope Cart

Here's the side view:



If you want to megasize it even more, turn it into a stretch-limo chassis and make it a hundred feet long. A huge sailing land barge where Jabba the Hutt hangs out when he's cruising on the Salt Flats on Dantooine. (Do they have Salt Flats on Dantooine?)

With the wind blowing left to right, the cart will move forward (to the right) and the open chutes will move to the left. Just like our tumbleweed with the chute at the end of a really long rope, or even our yoyo that we pulled on the string.

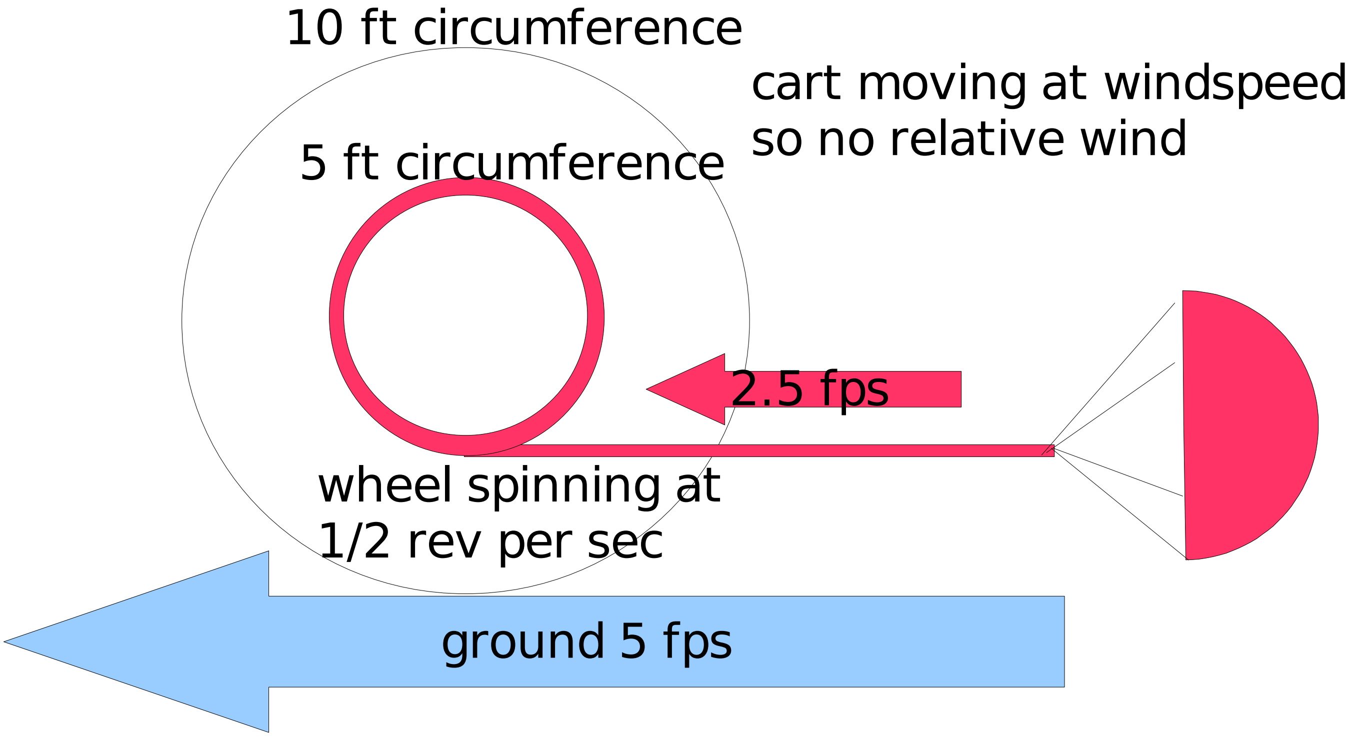
Did you make it this far? If so, congratulations. If not, you might want to try reading through the steps to construct the cart above because we're about to show how it's exactly like a propeller cart. And if you don't understand the chute-pulley-cart, then you won't understand how it translates into a propeller-cart.

## Tumbleweed-Parachute-Rope Cart at Windspeed

So, imagine our chute-pulley-cart is running directly downwind as fast as the wind. Mount a chair on the chassis as its humming along and look around you.

You're not feeling any air movement over your cheeks. But the rope over your head is still moving from front to back, pumping air to the rear, and pulling on the rope wrapped around the rear wheel, our original tumbleweed gear. And as the chute pulls on the tumbleweed wheel, it makes the wheel want to turn faster.

Just as a quick review, this matches exactly what you would see if you could somehow mount a chair on a tumbleweed moving at exactly the speed of the wind.  This diagram shows a 5 fps wind acting on a tumbleweed running at exactly 5 fps.



The end result of the above diagram is that the reeling in of the chute causes the tumbleweed to want to roll faster. So we start going faster than the wind. The only difference between this diagram and that of a chute-pulley cart is we add a number of pulleys and other things to move the parachute up and to loop it around and never have to worry about running out of rope. Which is to say, the chute-pulley-cart at the speed of the wind looks the same as the tumbleweed-chute-rope vehicle.

## Converting Parachutes to Propellers

The interesting thing is that when I look at the rope-pulley-parachute-cart, I see the parachute moving backwards, pumping air backwards, and I see how it is a linear version of a propeller. The parachute is driven by the rotation of the axle. This rotation moves the rope, which causes the parachute to move backwards. The parachute moving backwards causes the parachute to move air and therefore engage the airflow. And this allows the tailwind to push on the parachute and add a tension on the rope, and this tension feeds back to the tumbleweed drivewheel, which pulls the drive wheel forward, and accelerates the cart.

If you translate linear motion of the parachute to rotational motion of a propeller, the description is identical.

The propeller driven carts use a propeller which is driven by the rotation of the axle. This rotation causes the propeller to spin. The propeller spinning causes the propeller to move air and therefore engage the airflow. And this allows the tailwind to push back on the blades of the propeller and increase the torque, which feeds back through the axle and drives the wheel forward, accelerating the cart.

If you take a cart and push it on the ground in an enclosed room with no wind, the parachute still moves backwards, the propeller still turns. Energy is transferred from the wheels to the parachute or propeller. But the net gain of energy is zero (if you consider friction as lost energy, then energy is lost).

If the parachute or propeller doesn't move, the air isn't engaged. Think of the tumbleweed design with the saloon doors, and then imagine that the doors always remain open. The wheel rolls forward with whatever momentum it has, but it doesn't engage the air, so it eventually rolls to a stop.

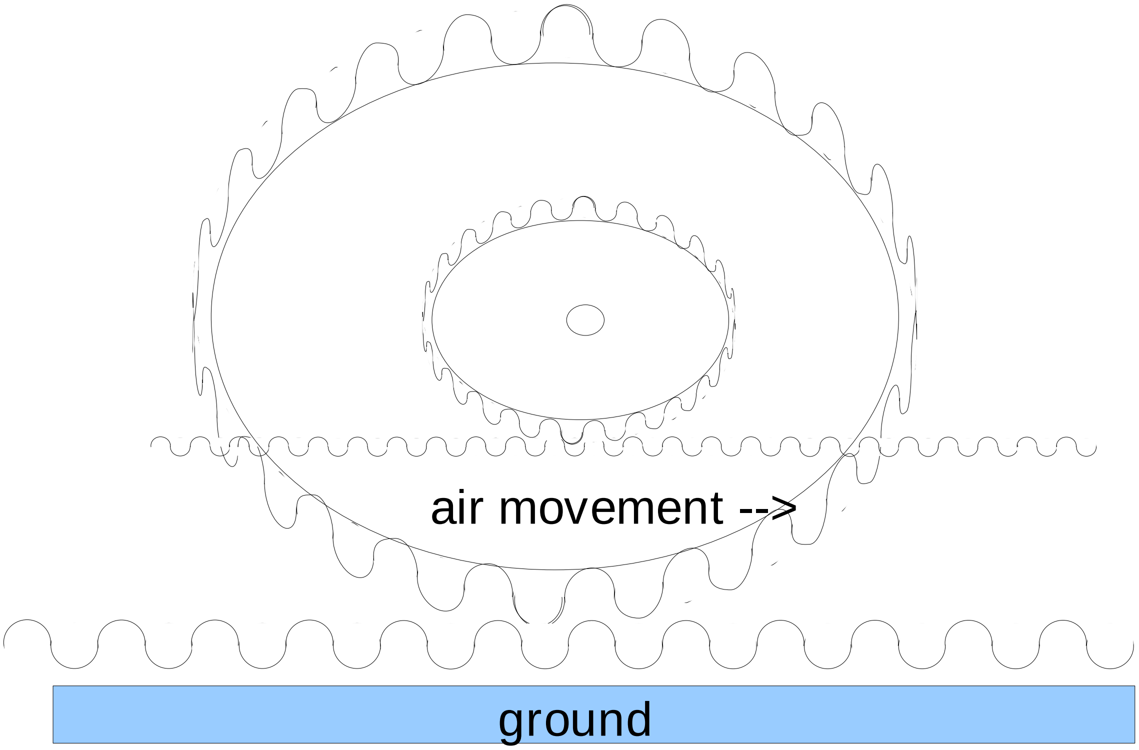
But the act of moving the parachute or propeller causes it to engage the air. And if the air is moving with a tailwind, it means that tailwind can engage the parachute or prop and affect the wheel it is connected to. The act of closing the saloon doors on the tumbleweed allow the doors to engage the air, and then the air can leverage the wheel forward.

I believe it is this weirdness that trips up a lot of people.

They see the cart roll forward, and they see the rolling causes the propeller to spin. And yet they know on some level that the wheel spinning the propeller cannot add energy to the system, so they believe that the cart could not go faster. But it isn't the wheels spinning the prop that makes the cart go faster. It's that the prop is spinning so that the tailwind can engage the prop and then the air can leverage the wheel of the cart forward, that makes it go faster.

In our yoyo-rope-parachute gadget, if you took the inner wheel that the rope is wrapped around, and made it the same diameter of the rope, it wouldn't go faster than the wind, because the parachute wouldn't be reeled backwards by the rope anymore. It would lay on the ground and get wrapped up when the yoyo rolled over it. If there is a tail wind, the parachute may be able to engage the wind, but the parachute won't be able to use that wind to leverage the yoyo forward.

So, what does the propeller look like? Here is our original gear diagram:



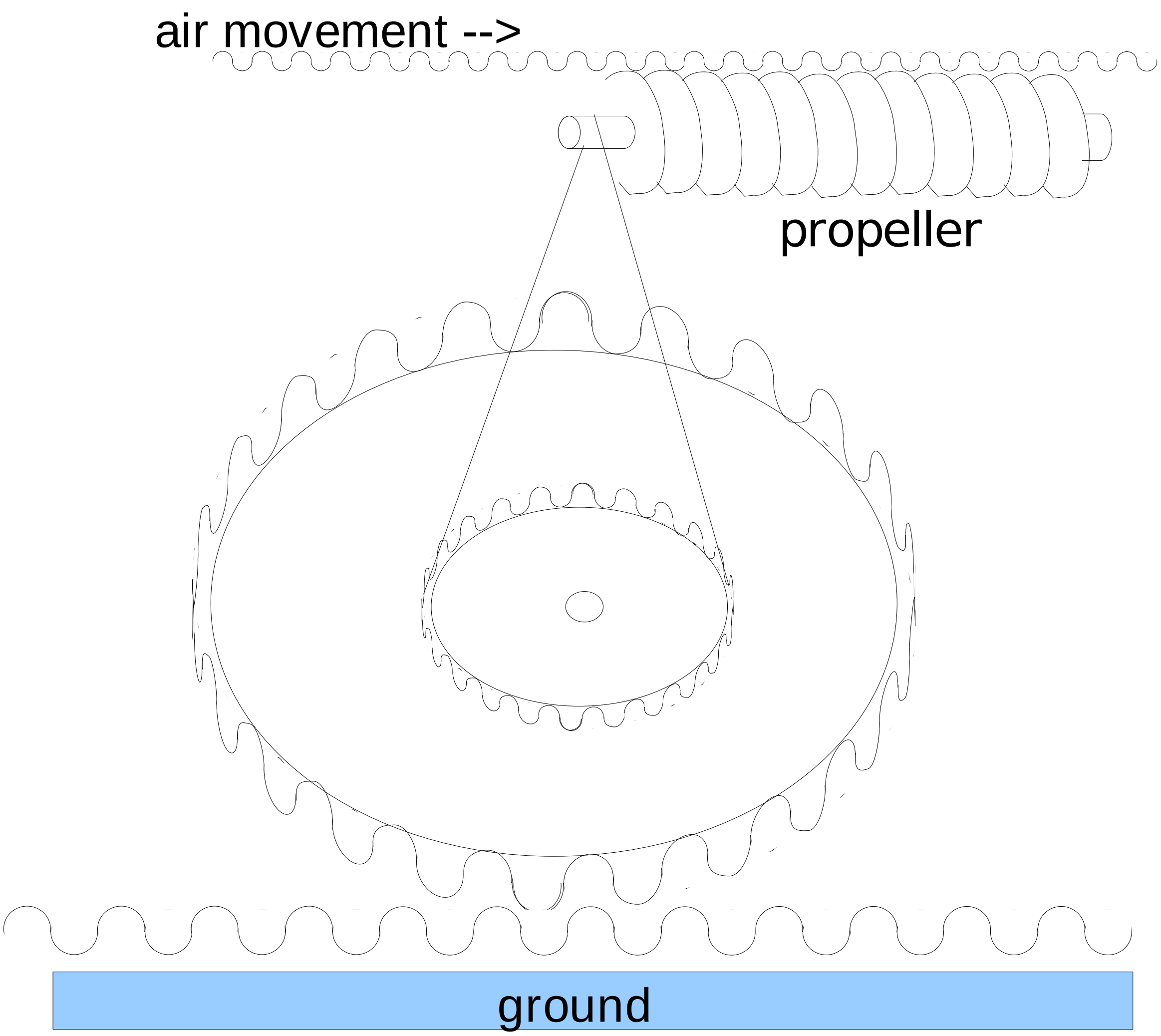
Propellers work with very fine pitch compared to the gears shown above. If the wheel in the above diagram has a circumference of 10 feet and an inner circumference of 5 feet, then one revolution will equal 10 feet of forward motion.

With a propeller, it's more like you might advance an inch per revolution, so to advance ten feet, you might have to rotate the prop a hundred or more times.

While a parachute pulled by a rope is like a conveyor belt for air, a propeller is more like an auger pushing air. We can visually represent a propeller as an auger that engages the gear that is the “air”.

## Gear Drawing of Propeller Cart

Here is the gear diagram redrawn with a propeller equivalent:



If we push the wheel gear forward, the “prop” starts spinning. Once the prop starts spinning, it engages the “air” gear at the top. If the “air” gear is moving forward relative to the ground, that will push the entire vehicle forward faster.

One thing that is hard to visually represent is the fact that the “prop” gear can “slip” through the “air” gear. But if you imagine that the bolt/auger is the propeller and the top flat gear is air, then you should be able to keep in mind that the force the air exerts on the prop may be a function of how much that prop is “slipping” through the air.

Fixed pitch props are like fixed pitch augers. They will want to advance at a certain rate. But while the auger can't leave the bolt without breaking, the prop can slip through the air as the cart advances. It just might mean the air doesn't push with as much force on the propeller.

The reason that this slipping is important is because the auger is tied to the cart, and depending on how fast the cart is moving ,the wind may be moving over the prop at a big speed, but the prop may not be translating all that movement into acceleration for the cart.

What accelerates the cart is the part of the wind that pushes on the auger and puts a torque into it that goes through the belt and accelerates the ground wheel. Don't think of the arguer as simply a flat sail. It's that the wind pushes on the prop and twists it, twisting the wheel forward, that causes the cart to go faster than the wind.

## Conclusion

I hope this document sufficiently explains how the propeller cart works so that someone completely unfamiliar with it can read this document and see that such a cart can go downwind faster than the wind without violating any laws of physics. The goal is that by the time you finish reading this, you know it can work without having to resort to physical construction.

If you do want to build one, hopefully this document gives you at least enough of an explanation that you could assemble one based off of a plan. If you'd like some detailed plans, Jack Goodman put together a one page text description of a propeller cart that he built here:

http://www.ayrs.org/DWFTTW_from_Catalyst_N23_Jan_2006.pdf

And hopefully, this document explains the theory of operation well enough that you might be able to tinker with the design, make it better, or at least intelligently change things and still have it work properly.

At the very least, you get that it is possible and are just a little bit confused about implementing it. If that's so, then great. Building a kit and playing with one might you get over that last hump.

If you are still completely confused, google “Directly Downwind Faster Than the Wind” and you should find some threads about it, some videos about it, and maybe you'll find someone who has an explanation that helps you understand the cart.

If all else fails, and you still don't understand any of this, well, then perhaps your destiny lies along a different path than propeller carts.

It's an interesting gadget. but the world won't end if some people don't understand it.

Enjoy,
Greg London

## Bonus features

### Sail Barge:

This is an entry into the most rube-goldberg-est design for a machine that goes downwind faster than the wind. It is a take on the parachute-rope-cart. Since there are problems controlling the parachutes and making them open and close quickly and all that, I decided to see if I could come up with a design that would use “sails” of some kind. This is what I came up with.

The sails are square sails. They have some kind of rods going through them at the top and bottom of the sails. The rods go side to side through the sail and connect on either side of the cart to two different chains. The rods for the top sails connect to one set of chains. The rods for the bottom sails connect to another chain.

The chains are like a bicycle chains. They are maintained in position by gears with teeth. Both top and bottom chains are the same length. The bottom chain has to go through some extra gears to allow the top part of the sail to catch up.

When the sails come out one end of the cart, they quickly open to their full height and move back in a linear fashion following the chain. At the end of the cart, the chains take a path that quickly folds up the sail and wraps it around and goes inside the cart.

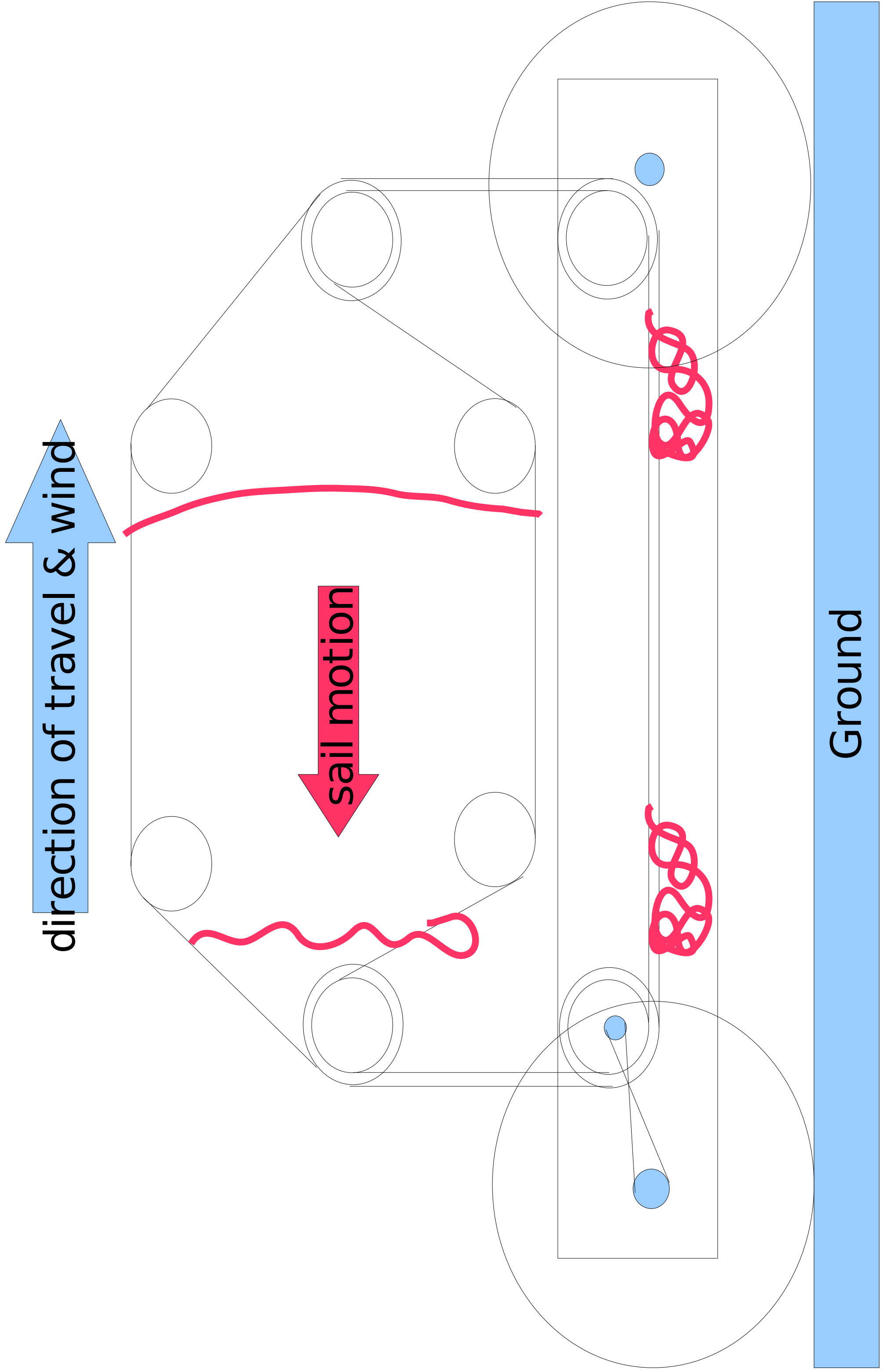
The chains and the sails avoid colliding with each other by making sure the bottom part of the sail connects to a chain that always remains inside the other chain. Because the top chain is the same length as the bottom chain, but the top chain must go high above the cart, the bottom chain must have a number of switchbacks to keep it in line with the top and prevent the sails from getting pulled apart.

This design is completely scalable. You can have as many sails as you want. You can make the sails as wide and as high as you want, and you can make the cart as a whole as long as you want. You just need to make sure that everything is strong enough as you scale upward.

You can see in the diagram in the next page two different tracks of chain, upper and lower, corresponding to whether it is attached to the upper or lower portion of the open sail. The upper chain is always “outside” of the inner chain. The lower chain is always “inside” the upper chain. This allows multiple sails to be placed on the track and not have them interfere with each other.

At points where there are two gears rotating about the same point, the lower track is always the smaller diameter pulley. And the smaller diameter pulley (lower chain) is always closer to the centerline of the cart than the larger diameter pulley (upper chain).

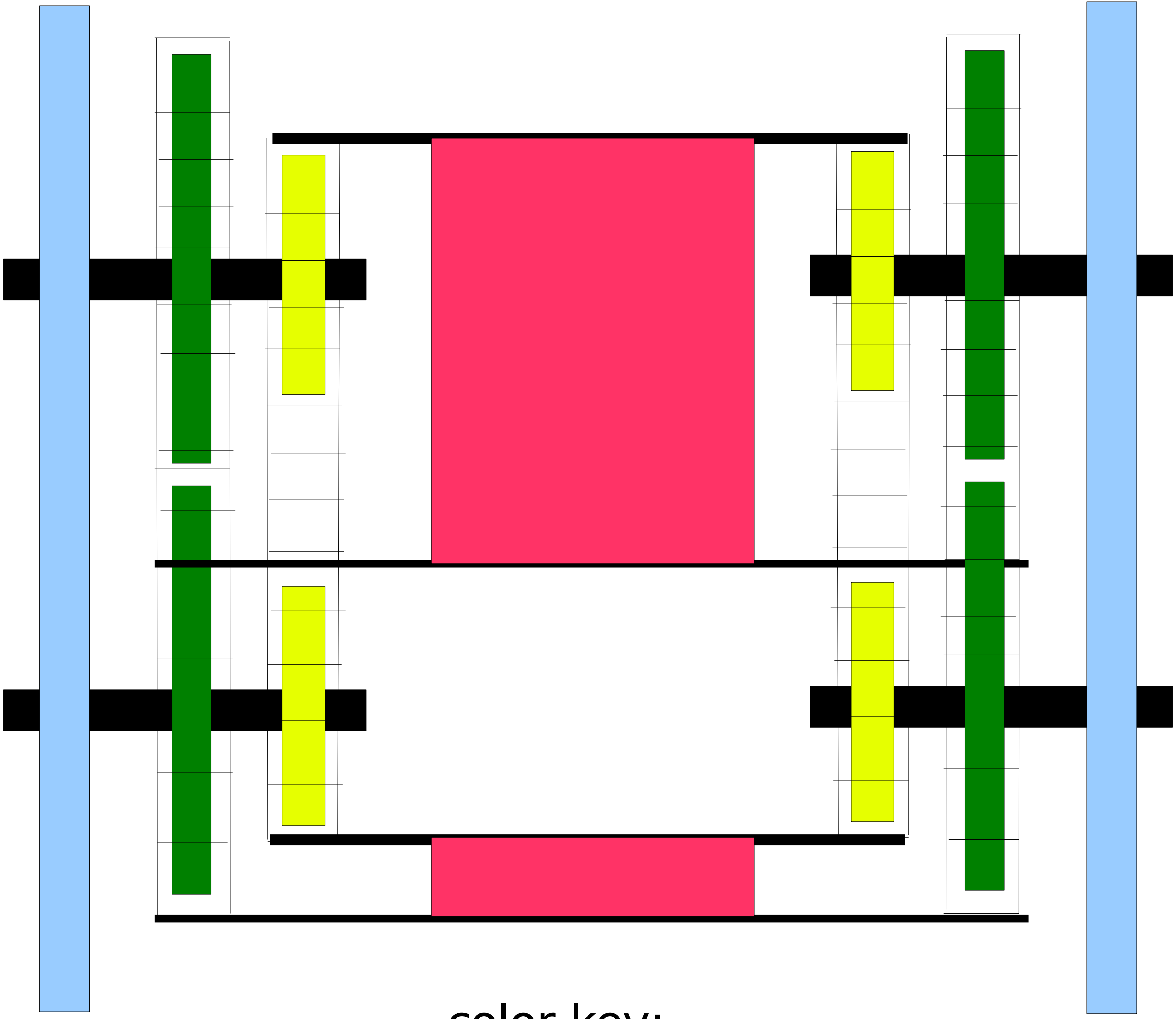
Here's a sketch in landscape format:



The cart has to have a bottom to prevent the sail from dragging on the ground at the bottom of the path. At this point, the top and bottom connection points of the sail are right next to each other and the sail will go limp.  This is equivalent to “flapping” the anemometer closed in the tumbleweed or closing the parachutes in the parachute-rope-cart.

When the chain emerges from the front, the points remain near each other until the get to the front, high pulley. At that point, the chains take separate paths, upper and lower, which causes the sail to open while moving backward. A simpler design would have had the sail open and go straight up. But that would mean it would be open, but not moving backwards for a time, which would add drag.  Worst case, with the above design, the sail is closed and hanging in the wind until it opens. Hopefully that doesn't add too much drag.

This is a front view looking down the chassis to show how the chains and gears relate to one another. Note this doesn't show the actual track of the chains because they end up moving around too much, but it does show that the lower/inner gear (yellow) is always inside the upper/outer (green) gear. It also shows how the sail attaches to the chain with fixed rods and how that keeps the sails from running into each other or blocking a chain.



color key:

red: sail cloth
yellow: lower (inner) gear
green: upper (outer) gear
blue: chassis

I haven't built this design. It was more a matter of seeing if I could get the chains to avoid each other, and they do in this version. It might be possible for something like this to work if implemented using bicycle gears and chains, and a sail that is a few feet on a side, assuming the chassis is light enough, and the sail is made out of something like kite material.

The design is offered with no guarantee that it'll work. Just that it could work if you make everything light enough and with low enough friction. However, if someone wanted to supersize this into a machine that would be big enough to carry a person, I image this would be the one way that you might be able to do it. You could just make the sails bigger until you get enough push to make it work. Make the sails big enough to pull a person under normal circumstances, then maybe double it to cover the friction you'll add, then use the above design to see if you can stay ahead of the wind.

I wouldn't recommend trying this unless you had some disposable cash to burn through, because, like I said, this would take some calculations and some experimentation to get right.

## The Electro-Cart

This is just a weird idea that may or may not help people understand the propeller cart. It's an exercise in showing that conservation of energy is respected by the cart.

What we do is use the ground wheel to drive a generator. This creates electrical power. We then use that power to drive the propeller. Once the propeller is moving, the tailwind can add to the backward thrust of the prop, and make the cart move faster than the wind.

I have no idea whether generators and motors would be efficient enough to make this even work in even a “pull with a string to make it work” demo. But it might help someone who thinks about the cart first and foremost from the point of view of conservation of energy.

The wheel transfers some of its energy into the generator. This robs some kinetic energy from the cart, slowing it down, and generates some electrical energy. This electrical energy is then used to drive a propeller that is turned by an electric motor. Because the propeller is spinning, and creating backward thrust, any tailwind will add to the forward thrust of the propeller.

The issue of building this would be that I'm not sure if there are any generators and motors that are really, really efficient, and are designed to operate on the sort of micro power that we're talking about here.

You can push one of these carts in a room with no wind and they still coast for a few seconds, which means there isn't a lot of friction on them. which means the generator can't put a lot of friction on the wheel to make electricity. It has to generate electricity but allow the wheel to spin, only tapping off a fraction of the electrical power.

you could push an electro-cart in a room with no wind, and the wheel would generate electrictity, and the electricity would spin the prop, and you'd want to make sure that the generator is putting only a little bit of resistance on the ground wheel that the cart still rolls forward for a few seconds with a push in a still-air room.

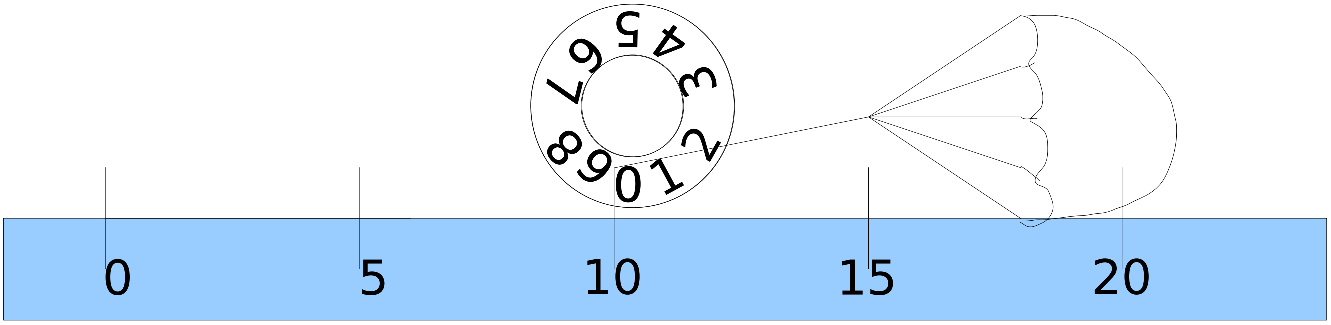
Anyway, the point isn't to build one of these. The point isn't that its even possible to build one. The point is really to present the propeller cart from the point of view of someone who might be thinking of the cart in terms of energy transferring around.

If it takes N energy units to generate electricity, but it allows the wind to push M units of energy into the cart, and M is greater than N, then the cart would go faster than the wind.

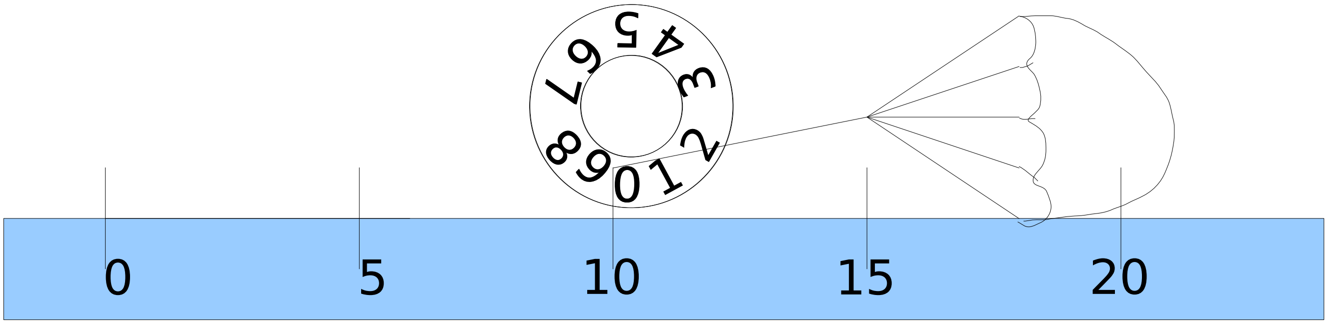
## Flip Animation of Yoyo Rope Parachute

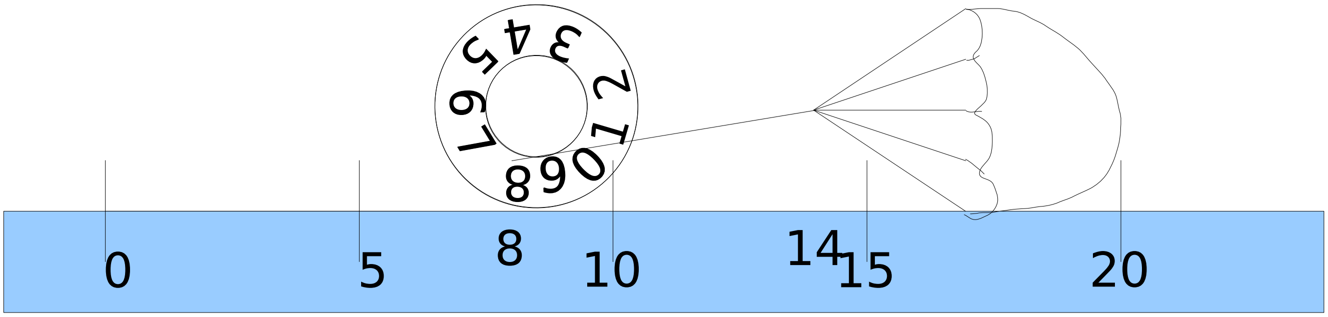
The following few pages can be used as a flip chart animation sequence showing a tumbleweed being pulled by a rope with a parachute at the end. Lift up all the pages of the animation, and then let them drop and you can watch the “video”.  If you want to see it without print it out, I put the same images at the top of the page too, so you can zoom to page width on your monitor, go to the last image, and then use “page up” to quickly go through the images.

If you've already gotten to the point of understanding the tumbleweed-rope-parachute thing, then skip this section.



last frame of animation

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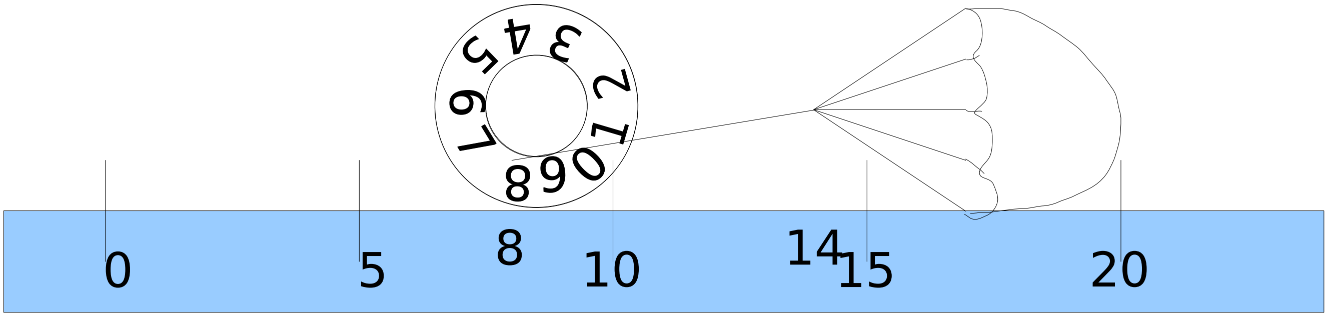
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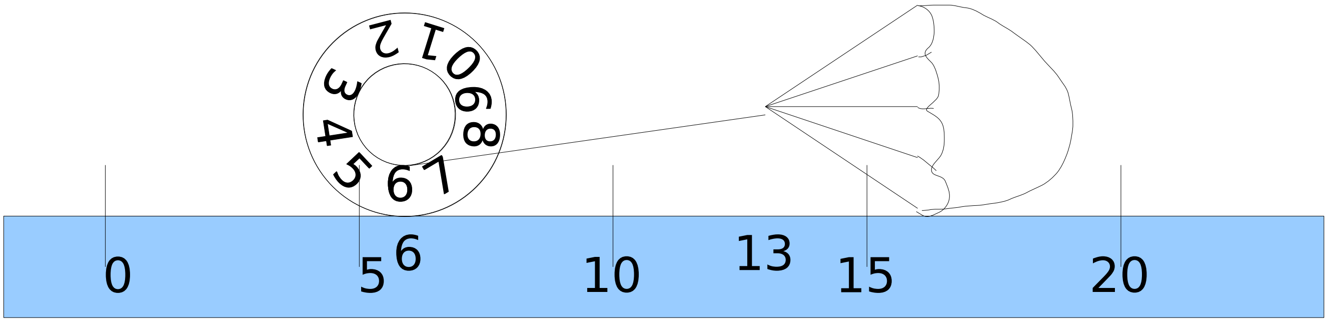
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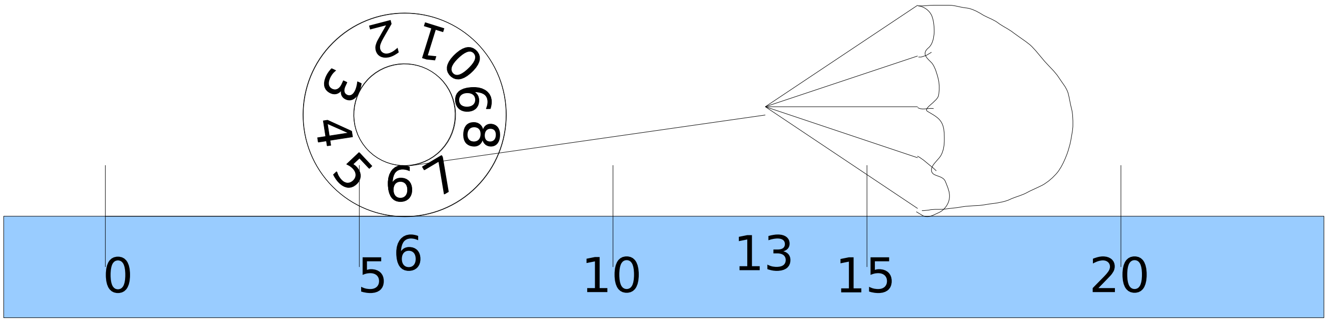
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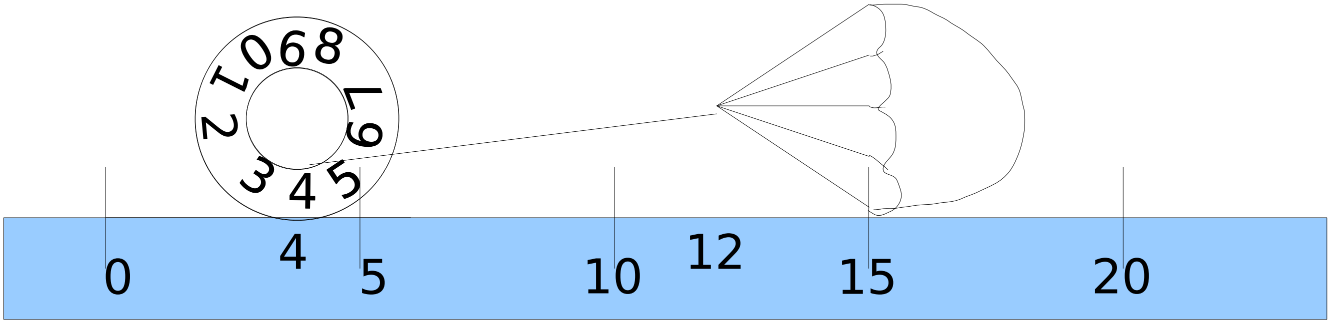
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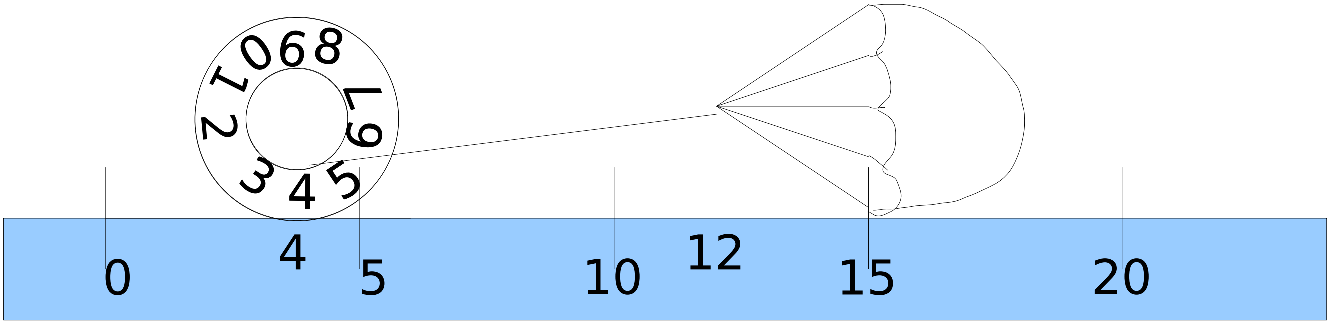
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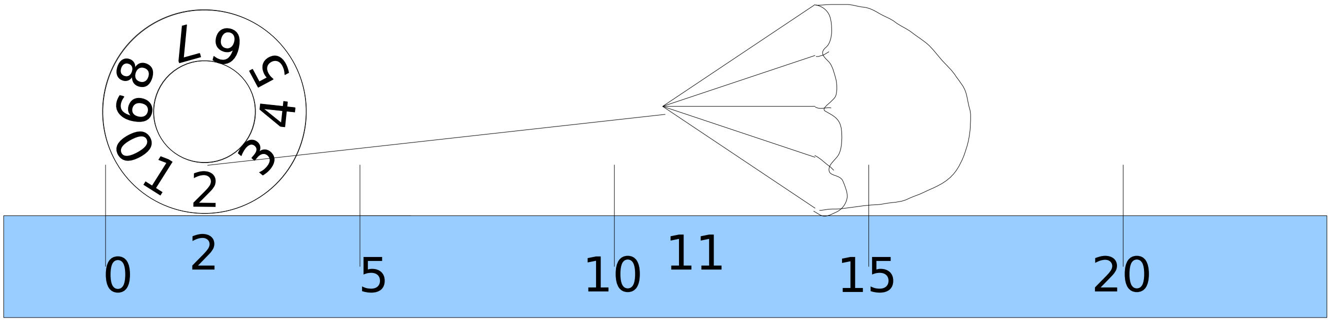
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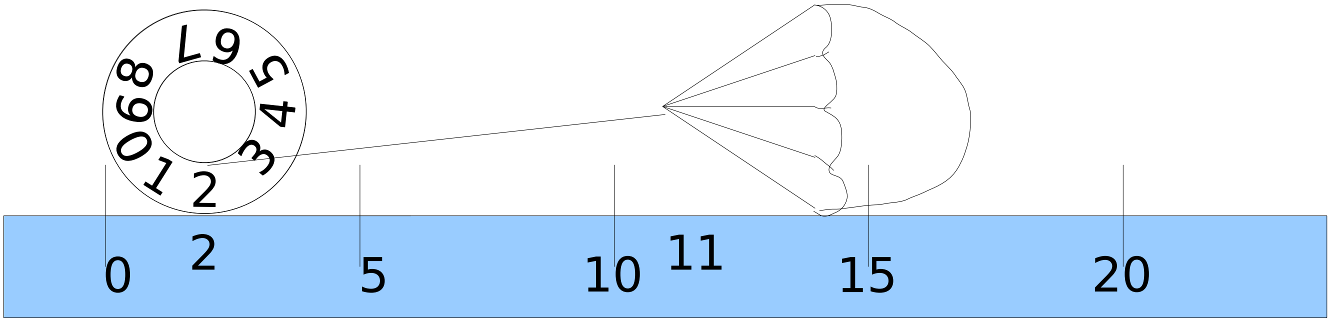
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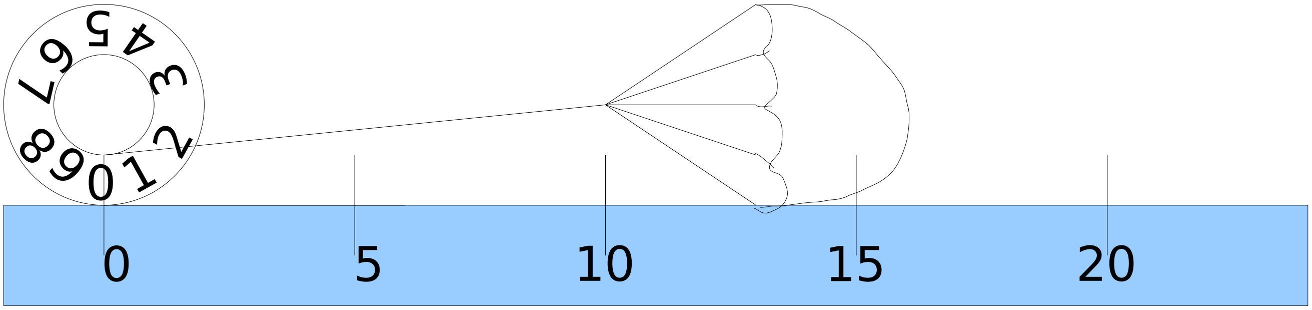
2
11
0
5
10
15
20



start animation