Casting Physics Simplified

This paper provides two part overview of physics as it applies to fly casting. It is intended as an introduction to basic physics for those who do not have a background in the subject or as a refresher for those who have but would like a quick review.

The concepts discussed in part one of this paper include:

- scalar and vector quantities
- vector mathematics
- velocity, acceleration, force, momentum, energy
- potential and kinetic energy
- conservation of energy

Who is this paper intended for?

People who want a refresher or haven't studied these concepts and would like an introduction.

Part One

Scalars and Vectors

First let's take a look at scalar versus vector quantities. In order to understand the difference between speed and velocity we need to understand the difference between scalar and vector quantities.

By definition, a scalar quantity is one that has magnitude, or a measurable amount such as miles per hour, only. A vector quantity is one that has both magnitude and direction.

Speed is a scalar quantity. Velocity is a vector quantity.

Why is this important? Imagine that I leave my home city of Calgary and travel at a speed of 60 miles per hour for three hours. Where am I at the end of three hours? Without knowing the direction I'm traveling in I could end up in Edmonton, Montana, British Columbia, or even Saskatchewan (well – almost in Saskatchewan).

Now let's do the same exercise but specify that I am traveling due north, i.e. I travel at a velocity of 60 miles per hour due north for three hours. Where do I end up? Unfortunately for me, I would be in Edmonton.

Other examples of scalar quantities are time, speed, temperature, density, mass, energy, and volume.

Examples of vector quantities are velocity, acceleration, and force.

To recap: A scalar quantity is one which does not depend on direction. A vector quantity is one that has both a magnitude and a direction.

Vector Mathematics

Another aspect that differentiates scalar and vector quantities is the mathematics required to combine vector quantities is a bit more complex than combining scalar quantities.

As an example, imagine that we are standing on a frictionless surface and there is a 10 mile per hour wind blowing. After a while we would end up sliding across the surface at 10 miles per hour. Now if the wind speed increased by 10 miles per hour we would eventually end up being blown along at 20 miles per hour. When talking about speed we can say that 10 miles per hour plus 10 miles per hour equals 20 miles per hour.

Now let's change things a bit. Let's say that the wind is initially blowing at 10 miles per hour due north. If the wind speed increases by 10 miles per hour in a due northerly direction then we will end up traveling at 20 miles per hour due north. Our speed is 20 miles per hour, our velocity is 20 miles per hour due north.

But what if the wind is initially blowing 10 miles per hour due north and now a cross wind of 10 miles per hour due east is added? How fast are we going now? What direction are we going in?

If we look at the representative diagram we can see that our direction would be north east. In addition we could measure vector C to determine its magnitude. Another way to determine the magnitude of vector C is to use Pythagorean theorem, i.e. In a right triangle the square of the hypotenuse is equal to the sum of the squares of the other two sides.

In mathematical notation:

In this case the magnitude of C is approximately 14 miles per hour.

To recap: To add scalar quantities we simply add the magnitude of the quantities. To add vector quantities we can draw the two vectors on a graph and measure the results, use Pythagorean Theorem, or use trigonometry to determine the resulting magnitude and direction.

Acceleration and Velocity Defined

Velocity is the combination of speed and direction. When we say the velocity of an object is constant we mean that both the speed and direction of the object are not changing.

Another definition for velocity is the rate of change of position. If we know the position of an object at a specific time and at some later time we find the object has moved to a different position, then we can determine the change in the object's position and, since we know how long it took for the object to move to the new position, we can determine the average velocity of the object. Note that this is the *average velocity* since we don't know the path that the object traveled to get to the new position. The object may have actually traveled to the new position indirectly.

Acceleration is any change in velocity. If either the speed of the object is changing AND/OR the direction of the object is changing then the object is accelerating. If the speed remains constant but the direction is changing then the object is accelerating. If the direction is constant but the object is speeding up then it is accelerating. If the direction is constant but the object is slowing down then the object is accelerating.

You may want to say the object is decelerating, and you would be correct, but physicists prefer to call this negative acceleration so that they don't have to keep using different symbols when a negative sign will do the trick, e.g., if an object's current speed is 10 mph and we decelerate at 10 mph per second (assuming deceleration in the same direction we are traveling so we can avoid vector mathematics for now) we could calculate the object's speed in one second using deceleration as:

$10 + (-10 \times 1) = 0$

or using negative acceleration:

$10 - (10 \times 1) = 0$

In this example the difference is minor but in more complex examples it can become tedious to try to keep track of the various signs.

To recap: Velocity is a combination of speed and direction. Acceleration is any change in velocity. If an object in motion changes its speed or direction then it is accelerating.

Force

The Most Important Equation in Fly Casting

$$F = m \times a$$

Where:

F = force
m = mass

a = acceleration

i.e.: Force equals mass times acceleration.

What this tells us is that if we see an object accelerating through space and we know the mass of the object then we know how much force is being applied to the object. Not really exciting in that context but let's rearrange the equation a little bit:

$$a = F / m$$

Now we can see that if we apply enough force to an object to move it, then we can tell how fast that object is going to be moving at any time after we begin applying a force to the object.

Some things to consider here:

- Once we get the object moving it will continue to accelerate if we continue to apply force to it. It doesn't matter how small the force is, as long as any force is applied to the object, the object will accelerate.
- If no forces are applied to an object that is currently in motion it will continue to move in the same direction and at the same speed forever. Another way of saying this is – an object in motion tends to stay in motion unless acted upon by an external force. In the real world no object maintains the same velocity forever because we cannot completely escape external forces such as friction or gravity.
- One way to cast our fly line farther is to get it moving faster. To make it move faster we can apply force for a longer period of time. The velocity of the object is directly related to how long we apply force to it, i.e. if we apply the force twice as long then we double the velocity of the object. Another option is to apply a greater amount of force. If we apply a force to an object then after 1 second it will be moving with a given velocity. If we double the amount of force we apply to the object then after 1 second its velocity will be doubled. When we are casting a fly we are limited to the how long we can apply force because we can only move the rod tip a certain distance before we "run out of arm". What if we make one cast with the maximum rod tip travel we can attain and then repeat the same cast but apply twice as much force? How much faster will the rod tip be traveling at the end of the second cast? We can use the equation that relates distance to acceleration as follows:

  $$d = ½ at^2$$

  Where:

  d = distance
  a = acceleration
  t = time

  A little manipulation and we can see that:

  $$t = (2d/a)^{½}$$

  This tells us that if we double the acceleration over the same distance we decrease the amount of time we are applying the force to roughly 70%. This means that the rod tip velocity we attain at the end of the cast is 140% of the velocity we achieved when applying half as much force. Note that this does not take into account that the rod flexes during the cast and unloads at the end of the cast.

- If something we measure doesn't change over time then we say the value being measured is constant. For example, if a car travels at 60 miles per hour for some period of time then the car is said to be traveling at a constant speed of 60 miles per hour. If the force and mass are constant then the resulting acceleration is constant. We use the term “time varying” when something doesn't stay constant. You could say that an object which is experiencing acceleration is experiencing time varying velocity. If the force or mass of the object is time varying then the acceleration will also be time varying.
    - How could the force change or be time varying? Think of applying pressure to your car's gas pedal gradually – the harder you press on the gas pedal the greater the force the engine will apply to the drive train and the greater the acceleration you will experience while sitting in the car. You could have an increase in negative acceleration by gradually pressing on the brake rather than the gas pedal.
    - How could the mass change? Think of the space shuttle at launch time. As soon as the rockets are ignited they go to full on and stay full on until the fuel is exhausted. The force applied to the shuttle is constant while the rockets are on but the fuel is burned up within a few minutes resulting in a constant decrease in mass while the rockets are on. This means that the acceleration is increasing since the mass of the shuttle is decreasing.

To recap: If you apply enough force to an object to get it to move the object will accelerate as long as force is applied to it. Take away all forces and the object will continue to move in the same direction at the same speed forever. The acceleration an object experiences can be predicted with the equation $a=F/m$.

Kinetic Energy

Once we have an object moving it possesses kinetic energy. The amount of energy is defined by the equation

$$E_k = \frac{1}{2} mv^2$$

Where:
E_k is the kinetic energy of the object
m is the mass of the object
v is the velocity of the object

Conservation of Energy

In a closed system, i.e. one in which energy cannot enter or leave, the total amount of energy in the system remains constant. Energy can be converted from one form into another, such as when kinetic energy is converted to heat, but the total amount of energy remains the same. While we would need to expand any system in the real world to include the entire universe in order to have a truly closed system we can sometimes find systems that act like a closed system for brief periods of time.

A whip or fly line can approximate a closed system at times, especially when a crack sound is generated as the loop travels down the line or whip. If we are not shooting line then just like the whip the mass of the moving part of the line decreases as the loop moves to the end of the line or whip. But since energy is conserved the velocity of the whip will increase. The cracking sound occurs when the speed of the moving part of the whip exceeds the speed of sound and breaks the sound barrier. The same thing happens when a fly line makes a cracking sound. It should be noted that whips are intentionally designed to crack while fly lines are not. The mass, very noticeable taper, and low internal resistance of the whip make it relatively easy to generate the cracking sound. Fly lines have much lower mass, less noticeable tapers, and relatively high internal resistance all of which make it more difficult to make a cracking sound with fly line.

If we are shooting line then the mass of the moving part of the line is increasing and results in the overall velocity of the line decreasing. You can't shoot line and cause the line to crack.

Momentum

In a sense we have already discussed momentum. Momentum is the property of an object to remain in motion, or at rest, when there are no external forces acting upon it. In other words - if no forces are applied to an object that is currently in motion it will continue to move in the same direction and at the same speed forever. If the object is currently not moving then it will not move unless some external force is applied to it.

Momentum is defined by the equation:

$p = m \times v$

Where:

p = the momentum of the object
m = the mass of the object
v = the velocity of the object

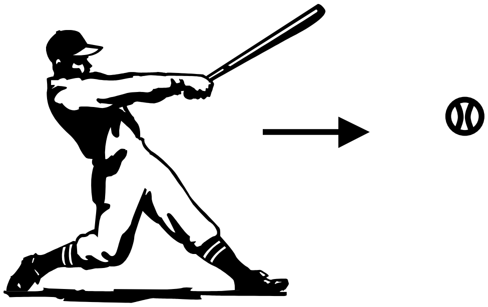
Momentum is sometimes referred to as inertia, or more properly – inertial mass. Momentum gives us an idea of how difficult it would be to slow down, or stop, a moving object. We can see that if two objects are moving at the same speed the object with the greater mass will require more effort to stop. It’s one of the reasons that one can cast a heavy fly line farther than a lighter line.

Because momentum is based on velocity it is also a vector quantity.

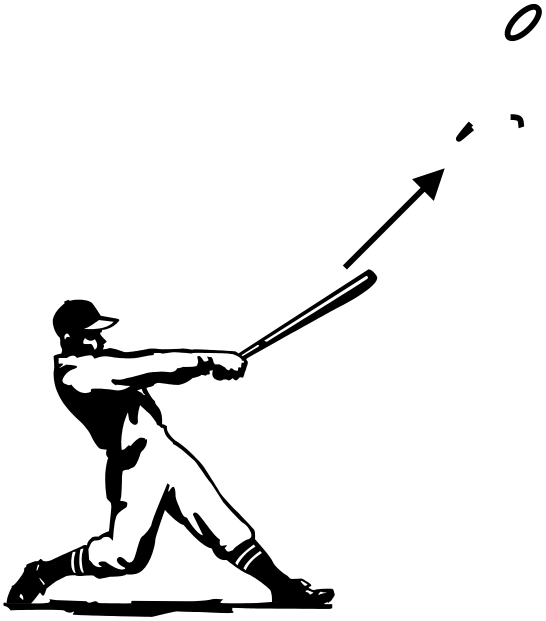
Vector Mathematics Revisited

Mathematicians and physicists like to use vectors because it simplifies certain calculations.

For example, imagine hitting a baseball. If we hit the ball squarely so that it travels horizontally we can see that all of the baseball’s momentum is directed horizontally and we can perform various calculations to tell us how fast the ball is moving, etc.

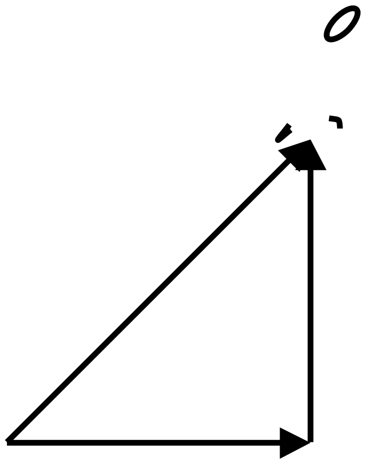


But what if we hit the ball upwards at a 45 degree angle? The ball will be traveling horizontally as well as upwards but how fast will it be traveling horizontally?



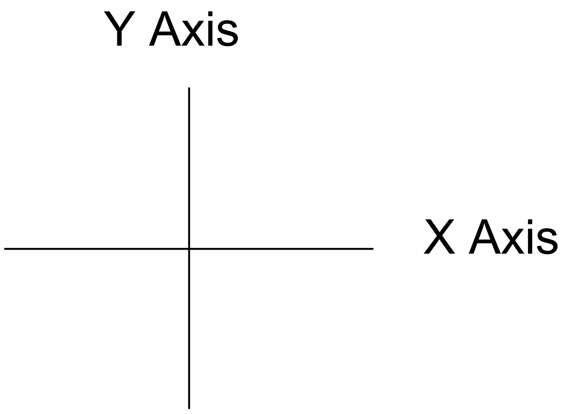
If we rely on intuition we would be tempted to say that, since the ball is traveling upwards at the same speed as it is traveling horizontally the horizontal speed must be half of the total speed but that would be wrong.

Instead, consider the following diagram. In this case, if the length, or magnitude, of the vector going up at a 45 degree angle is 1 then the length of the horizontal and vertical vectors will be roughly 0.7. You can calculate this by using the Pythagorean theorem (i.e., the square of the hypotenuse is equal to the sum of the squares of the other two sides), by using trigonometry, or simply by measuring the sides of the triangle.



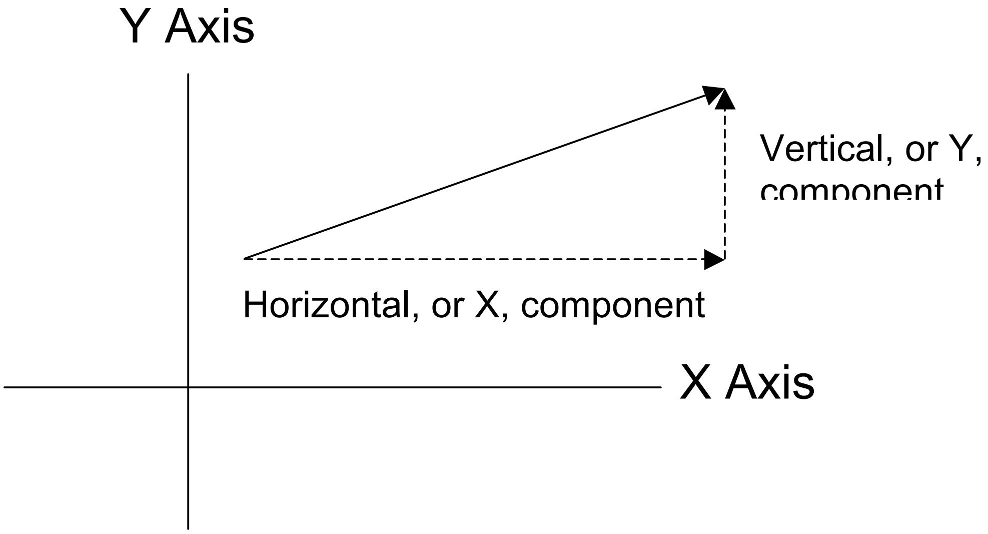
Now that you know the velocity of the ball in the upward direction you could calculate how far it is going to travel before striking the earth. For example, if the upward portion of the ball's velocity is 64 feet per second, the force of gravity will slow it down by 32 feet per second every second. In other words, in 2 seconds the ball will stop traveling upwards and will begin to fall. Since the force of gravity is constant the ball will take another 2 seconds to return to the earth (more accurately to the height at which it was hit but we will ignore this for the sake of simplicity). So it takes a total of 4 seconds for the ball to reach its peak and then fall back to earth. During this 4 seconds the ball was also traveling horizontally at 64 feet per second so it traveled 256 feet. By separating the horizontal and vertical components of velocity we are able to determine the horizontal distance the ball travels without a lot of complex calculations.

If you remember all of those boring graphs you were forced to draw in school you will remember that the axes of the graphs were labeled with the X axis representing the horizontal direction and the Y axis representing the vertical.



Any vector that we draw on the X and Y axis charts can be represented by a combination of a horizontal and a vertical vector. The horizontal and vertical vectors are called the components of the original vector.

A vector



To Recap: A vector can be broken up in to component vectors. Using components can simplify some calculations.

Part Two

In part two of this paper we will talk about angular or rotational mechanics and frames of reference.

So far we've talked about linear mechanics – the type of physics associated with things that move, or try to move, in straight lines. But what about things that rotate, or spin, or travel in a circle such as a spinning top, the movement of the earth around the sun, or the loop in a fly line?

When something is traveling in a circle, like the tip of a propeller blade, then it is constantly changing direction and, by our previous definitions, the object is constantly accelerating. If we try to represent the movement by component vectors then the component vectors are constantly changing as well. This can make calculations regarding the movement of the object very complicated.

Another concept we will discuss in part two is frames of reference, i.e., how or where we look at a system in order to simplify our understanding of it.