Physics FOR Fly Casting – the Einstein Series

by

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As published on TheCuriousFlyCaster.com

(https://thecuriousflycaster.com/)

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About the Series

After becoming frustrated with textbook and online discussion of physics for fly casting I decided to write this series. Along the way I had to line up any normal considerations of publishing, commerciality and popularity included, and push them all over the side of the boat. It was a liberating experience and watching them disappear beneath the waves gave me unexpected pleasure.

I next had to assemble an Advisory Group to save me from talking rubbish. The Group includes physics boffins with an interest in and commitment to, fly casting, prominent casting instructors and some consumer reps – guys who were curious enough to be interested in this stuff and well smart enough to understand it if I could manage to explain myself clearly. Here they are in category and alphabetical order:

Vince Brandon

Gründe Løvoll

Aitor Coterón

Graeme Hird

Mark Surtees

Bruce Marshall

Blake Robertson

They all contributed generously, not least in boosting my confidence by agreeing so quickly to accept my invitation to help and be part of the project. It seems inadequate to say I couldn't have done it without them but it is simply true. That said I accept full responsibility for any stuff ups that have sneaked past the guard posts. I want to thank them all for their generous and invaluable contributions. Without in any way diminishing my gratitude and appreciation of their combined efforts there are a few special mentions it would be unworthy to omit because they switched me onto things I might otherwise have not included or even known about.

Aitor was for some years the closest thing I've had to a casting mentor. Among the many subjects he has enlightened me about was the loop and the relationship between the two legs of the fly line. Thanks mate, for everything, over the years and during the project.

Mark clued me into Impulse, the time dimension of casting and rod preference. It all made good and perfect sense the way he explained it.

Vince persuaded me to include waves and mends at a time when I was thinking seriously of omitting them. His explanation of them and how the relevant physics were important to him, got me over the line with reassurance I had been, after all, mostly on the right track.

The series has six episodes:

- **Introduction**
- **Straight Lines Rule**
- **What the Rod Is and Does**
- **What the Line Does**
- **Other Casts & Other Stuff**
- **Endnote**

Introduction

The mechanics (a subset of physics) of fly casting is something I've been reading about for a few years now. I've also had the pleasure of talking with experts in the field who have generously shared their knowledge and provided guidance. Lastly, an indefensible amount of time has been spent on internet forums, both as a reader and a poster.

Overall the online experience has been interesting – as they say – informative sometimes, frustrating often and seriously helpful occasionally. Everyone seems to come to this subject matter with their own perspective, wishes and attendant expectations. When they encounter a different perspective it doesn't always end happily. This probably helps explain why there is a lot of argument online about casting in general and the physics of it in particular. Arguments don't interest me much.

So, it is best to declare my perspective on all this stuff. I am a fly fisher and not a physicist and have no interest in becoming a (fly fishing) physicist. Fly casting interests me because I enjoy doing it better and because that in turn improves my fishing. Understanding the physics involved fortifies and clarifies my understanding of fly casting. It provides a filter for letting in helpful stuff and for screening out some of the BS. It is a testing board for what seems to be going right and/or wrong with my casting, helping me to accentuate the good and eliminate the bad.

The majority of fly fishers probably aren't too interested in learning to cast better. Fair enough. Only a small percentage, let's say 5%, are interested in what light physics might shine on their casting. When our hopeful five percenters go in search of enlightenment they often encounter posters who know something about physics and who like to fly fish. These folks frequently want to talk about fly casting in the context of physics instead of physics in the context of fly casting. Knowing something about physics gives them authority and status. Knowing something about fly casting not so much. This sets the scene for problems, argument and the five percenters not getting much of what they went looking for.

Am I different? Yes. Am I the guru? No. Have you at last found nirvana? Probably not. What you have found is a guy who can mostly get his head around the relevant physics well enough to write stories about it for fly casters who are interested in reading them. Yep, you're right, it's not likely to go viral!

What's it got to do with Einstein? Well, Albert was very smart and much admired.

Consequently, people have attributed and misattributed quotes to him. One of the popular misquotes is that, “If you can’t explain it to a six year old, you really don’t understand it yourself.” He didn’t say that but it’s a nice idea. Taking up the spirit rather than the letter of it, my aim is to explain this stuff simply enough so that it can be understood by an intelligent sixteen year old who wants to cast better. Please don’t get hung up on the age level. The point is rather that my challenge is to explain complicated things simply, thereby improving the odds of us both understanding it.

Straight Lines Rule

Short Version

Cast in straight lines with straight lines.

The most efficient way to apply a force is in a straight line.

1. Looking down on a caster from directly above (drone view) the forward cast and the back cast need to be in straight lines – at 180deg to each other i.e. good tracking.

2. It also means the rod tip should travel, relative to the horizontal, (caster viewed from side on) in a straight line for as long as possible during a cast. This is the venerable Straight Line Path which casting geeks talk about a lot.

3. Deviations from the straight line in either plane mean that force is both not going where you intended it and, worse, is going in directions at least partly **opposed** to your intended direction i.e. It’s not helping you and it’s fighting you.

4. Same deal with the fly line – it needs to be kept as straight as possible or part of the force you apply will be spent taking up slack or following curves in the line instead of moving the fly line in your intended direction.

5. Newton’s second law of motion states that when a mass is accelerated the Force needed will equal the mass multiplied by the extent of the acceleration. **F=ma**. The tricky bit is that F means a **net Force** or acceleration of a mass **in a single direction**. If you are casting with force going in multiple directions the Force in your intended direction will be reduced by force going in any other direction. The net Force is with you. The rest is against you.

6. This explains why if you cast like a windscreen wiper instead of a spear thrower

your casts don't go very far.

7. Straight lines rule, OK?

Casting in Straight Lines

Pretty much anyone who has read or heard much about fly casting will have come across the 5 Essentials of Fly Casting by Bill and Jay Gammel[1]. (Don't worry I'm not going to do yet another recitation and commentary on the 5 essentials.) I'm going to call them "rules" instead of "essentials" because it fits nicely with the "laws" of physics. It has been said (*and I agree*) that four of the rules are really there to assist with the fifth rule. For some reason that rule normally appears as number 3:

"The rod tip must follow a straight line path."

To get the most from this rule you need to consider the path of the rod tip from two different angles. First, the side on view– imagine you are watching a caster from off to the side of their casting arm. What you are checking out is the path of the rod tip. If it moves vertically, up or down, it has deviated from the Straight Line Path (SLP).

You also need to consider the path of the rod tip as seen from directly above the caster – imagine you have got drone footage. Now you are watching the path of the rod tip to see if it moves horizontally to one side or another of the SLP. Ideally then, the rod tip will travel in a straight line vertically and also in a straight line horizontally. In both cases the closer we are to straight lines the more efficiently we will be casting.

Some physics to back that up. What is the shortest distance between two points? Easy question, it's a straight line. What is the most efficient way to apply a force? Same answer – in a straight line.

Let's take a practical example to demonstrate the point. Say your car has broken down and a friend has agreed to give you a tow. Common sense will/should tell you to attach the tow rope as near as possible to the centre of the friend's car at the rear and to the centre of your car at the front. If, for example, the rope was instead attached to one corner of one car and the diagonally opposing corner of the other car that would be dumb. The cars will go down the road trying to pull each into line. This is nature's way of trying to even things out and apply force in a straight line.

Back to fly casting. The tip of the fly rod tows the fly line. Looking from above, the caster's rod tip and fly line should travel from front to rear and back again in a straight

1 https://www.flyfishersinternational.org/Portals/0/Documents/Casting/The%20Loop/2009.SUMMER.LOOP.PDF

line or single plane. Deviations to the left or right are known as tracking errors. They are bad because they steal force from the cast in two ways. One, force applied by the caster is used up by that sideways line being pulled back into the intended direction of the cast. Part of your casting stroke is used up pulling the line sideways instead of straight at your target. Two, when a fly line goes a bit sideways, instead of straight, more line surface area gets exposed to the air causing more drag force to be applied to the line. Drag is also a thief of casting force whose exploits will be covered in more detail later in this series.

The Straight Line Path

As casting geeks we can get very intense about something called the **Straight Line Path (SLP)**. It is, of course, the path of the rod tip we are talking about because basically where it goes the line goes. In this instance we are talking about vertical rod tip movement as seen from the side. Deviations from this straight line involve fundamentally the same problem of things stealing casting force as we were talking about looking down from above the caster. This time, however, let's delve a bit deeper.

To explore the complexity thrown up by the SLP we need to discuss a law of physics. Some time after an apple supposedly fell on his head Isaac Newton came up with three laws of motion. It's the second one we are interested in here. That law is about accelerating an object and states that the Force required will always equal the mass of the object multiplied by the extent of its acceleration. The formula is **F=ma**.

Seems simple enough. In our earlier example the mass was a dysfunctional car and it needed to be accelerated from standing still up to the speed of the tow vehicle which will be providing the required Force. However, gravity is pulling down on your car and on your friend's car so the Force required has to overcome the effect of gravity on the two cars. It also has to overcome mechanical resistance from all the metal bits that have to turn before both cars can be accelerated up to the right speed. If you were silly enough to attach the tow rope diagonally some force will pulling both cars sideways and some will be pulling them forward. So, the Force required to get your car moving forward and up to speed is a **net Force** – in this case it is the net Force required to overcome opposing forces of gravity, mechanical resistance and that sideways stuff.

Newton's second law is (always) about **net Force** in a **single direction**. For fly casters, the SLP **is** that single direction. Where we want the cast to go is where the SLP is aimed.

Back to towing your fly line, the net Force required to make it travel in the intended direction of your cast has to overcome gravity and air drag. You also need enough force to move the body parts involved in making the cast but let's not get anal about all of the forces working for and against us. The most important thing to remember is that net Force implies a single or resultant direction of acceleration.

If the rod tip always moved in a perfectly straight line life would be easier and simpler but sadly the SLP is a just a handy ideal. In reality you and the rod tip move in a mixture of curved and straight lines. We pull the rod along in a straight(ish) line (*called translation*) and then we rotate it (*rotation*). A casting instructor will tell you you to rotate late in your casting stroke, to delay rotation as much as possible. Why? Because the more we rotate the rod when we should instead be translating it the less distance the rod tip moves in a straight line. At the extreme, our casting strokes will look like the line is attached to a windscreen wiper instead of to the end of a spear thrower (Woomera or Atlatl). What immediately separates a novice caster from a seriously good caster is the amount of time the rod tip is made to stay moving in a straight line during the casting stroke. The one thrashing about, making big fat loops and not getting anywhere much is the novice. Don't laugh– that was nearly all of us when we were starting out.

The SLP is not some precious aesthetic. It is rather the quintessential expression of force being applied efficiently in a straight line. What happens when the rod tip deviates/rotates away from a straight line too much and too early in the casting stroke is:

a) Force isn't going in our intended direction and

b) Much worse than that, any force that isn't going where we want it to is actually going in an opposing direction.

Consider a forward cast. Let's say we are making like a windscreen wiper and we rotate the rod tip through 90 degrees from just back behind the vertical to just before the horizontal. When we start everything is cool but by the time we reach the 45 degree mark about half the force is going forward and the other half is going toward the ground.

Casting With Straight Lines

Let’s consider a Pick Up And Lay Down cast. Imagine ten metres of your fly line is lying on the ground in a perfectly straight line out in front of you. Your rod tip is held low and the rod is in a straight line with the fly line. As soon as you start to lift the rod all of the fly line starts to move. Why? Obviously, because there is no slack in the line.

If there was a big loop of slack in the fly line out to one side when you started lifting the rod the fly end of the line would not move until nearly all the slack was taken up. The tow vehicle won’t move the towed vehicle until the tow rope comes tight.

The Force required to move (accelerate) the whole section of line (the mass) up and back behind you is a net Force – net of whatever it takes to pull the line straight. When you are false casting you might get a big line sack on a back cast. Your next casting stroke forwards will have to take up the slack before the line goes where you want it to go. Ideally, you want to be towing a spear of line in both directions. It doesn’t help when your spear turns into a spaghetti noodle.

A straight fly line being moved is a line under tension. Contrastingly a pile of spaghetti line lying still on the ground is a pile of slack line. Line tension is a useful thing we might talk more about later but for now a line under tension is the straight line that we want to cast with so it’s the opposite of a wavy or slack line which we don’t want to cast with.

If you read through the thread in the following link (*see note* [2]), it might make your head hurt but it shows that although in reality we don’t often cast with perfectly straight fly lines it is undeniably helpful to keep our fly lines as straight as possible.

What the Rod Is and Does – Really

Short Version

1. Fundamentally, the flyrod acts as a flexible lever. It is not, fundamentally, a spring which we load and unload to propel a fly line like a bow fires an arrow.

2. Rod loading was perhaps a useful fallacy but as a description of what we do with the rod it is just plain wrong.

3. Rod levering is what we should be thinking about. A fly rod is a third class lever

2 Ref: Sexyloops Web page: “The Board” subject: less line speed for more distance https://www.sexyloops.co.uk/theboard/viewtopic.php?t=2555

which extends our reach – like a spear thrower does. It amplifies the distance moved by our casting arm and thus the speed at which it moves.

4. Every cast has an energy budget. The energy comes from the caster. For a longish cast about 80% comes from the rod as lever and about 20% comes from the spring effect of a flexible rod.

5. The real advantages of using a flexible rod are that it helps smooth the application of power provided by the caster. There is a lag or delay (at both the beginning and end of a cast) between what the rod butt is doing and what the rod tip is doing. These lags stretch the distance over which the rod tip tows the line and the time during which it is towed. This is kind to our bodies and provides additional energy bang for the casting Force buck.

6. How much delay is too much and too little is the Goldilocks choice each angler makes for themselves. It influences rod preferences. A stiff rod has less delay and a soft rod has more.

7. Good casters also have personal rod preferences but what sets them apart is their ability to adapt their casting action to any rod. You can buy rods you prefer but you can't buy sound casting technique.

Introduction

Why bother? Everyone knows what a fly rod is, how it works and what we do with it right? Well, no, actually. It is very commonly misdescribed and misunderstood and not just by we humble fly casters. The common description is that a fly rod is a spring which stores energy when we load/bend it and releases that energy when we unload/unbend it whereupon the fly line is propelled as a bow fires an arrow. That's why "rod loading" is (supposedly) so essential and such a vital task for any fly caster. And this kind of "thinking" is not just a quaint traditional belief. In casting circles it is taken almost literally as gospel and woe betide any heretic who says otherwise. They will be cast out if not burned at the stake. So gather the wood and break out the matches, here goes me.

Rod Loading

I suspect that rod loading was a useful fallacy in at least two senses. Rod loading is supposed to be something that we should both do and then feel when we do it.

Yes, it does make some sense to talk about “feeling the rod load” but what we probably mean is feeling resistance that helps bend the rod. That feeling provides sensory feedback on our casting movements which is absolutely essential for controlling those movements – or any others for that matter.

Bending the rod helps in another really important way. It shortens the rod temporarily and that makes it easier to stay on the Straight Line Path. Imagine your task is to lightly run the rod tip along the underside of a shelf. The shorter the rod the easier it will be to stay in touch with the shelf. Too easy with just your index finger; much harder with a 3 metre long broom handle.

When it comes to casting mechanics, however, the rod/spring/loading stuff is just plain wrong. So what? Well, because what we do is greatly influenced by what we think we are doing and if I think I am using a spring that boinks the fly line I am likely to make casting boinks instead of casting strokes. Very bad idea. At the very least it is inconsistent and slightly confusing to be told it’s a spring but you have to accelerate smoothly with it – which is actually what you need to do with a flexible lever if you are going to keep its tip moving in a straight line underneath that imaginary shelf.

Rod Levering

At the heart of the rod loading belief system is a terrible misunderstanding about the fundamental nature of a fly rod. Yes, ok, it’s partly a spring but far more importantly and fundamentally it is **a lever which extends our reach** like a spear thrower does or one of those tennis ball launchers people use to entertain their dogs in the park.

Let’s talk levers. Archimedes told us he could move the world if we gave him a long enough lever. Good concept if not entirely practical. Say you want to lift a log but it’s too heavy. Hmm! Have a crowbar and a house brick handy? Put the brick down nice and close to the log. Shove the tip of the crowbar over the brick and under the log. Go to the other end of the bar and push down. Bingo. The log is lifted. The brick is a fulcrum and the crowbar is a first class lever. You have just demonstrated mechanical advantage. You amplified your **effort**.

Move the brick close to the other end of the crowbar (the head) and try pushing down on it again. Hopeless. Now try pushing it down onto the brick with one hand while pulling up with other hand gripping the crowbar a bit further down. Lots more effort is required to move the log – far more than if you tried to lift it again without any lever involved. The weight of the log has been amplified. In tech speak the **load** has been amplified. Now you have the concept of mechanical “disadvantage”. The crowbar is now a third class lever and it works against you instead of for you if you are trying to lift a log.

Don’t be too hard on third class levers. They too are useful and common. Your casting arm, for example, is a series of third class levers and the fly rod is a long one. What it amplifies is the **distance** over which and thus the **speed** at which you move your casting arm. Your advantage is now speed instead of effort.

Lever v. Spring

Let’s now consider the relative contributions of the rod as a lever and the rod as a spring to casting a fly line. A few years back a real physicist named Gründe Løvoll ran the numbers. What he found was that by using a flexible fly rod instead of an inflexible fly rod a good caster managed to get about 20% more tip speed. In other words the spring effect was good for an extra 20% of tip/line speed over a broomstick rod that didn’t bend. Line speed is what we use to beat gravity. Speed comes from the Force we apply which puts kinetic energy into the fly line. It follows that more speed implies more Force.

It is a bit more complicated than this but, simply stated, on a longish cast about 80% of we get from a fly rod is due to leverage and only about 20% is down to energy stored when the rod is bent and then released when it unbends. The exact proportions of lever effect and spring effect don’t really matter to us. What matters is that leverage is by far the major contributor.

Each cast has an energy “budget” to do the job of propelling the line to reach our target. In making budget, the proportion of leverage to spring storage and release of energy changes depending on the type of cast we are making. However, for most people and most of their casting, the rod as a lever accounts for most of the energy put into a fly line. Allow me to explain that a bit more.

The bow and arrow cast is exceptional in that we use spring energy more than leverage but of course that’s a very different beast from a standard overhead cast. With short overhead casts, just the leader and a metre or two of fly line, the rod may not bend very much so unbending contributes very little to line propulsion. As we lengthen the cast the rod will bend more and so contribute more spring energy when it unbends. However, it’s probably not until we go seriously long that spring energy will make a meaningful contribution and even then it’s only about one fifth of the total energy budget. Given this it makes no sense to me to talk about rod loading as the engine and therefore our primary objective when casting a fly line. Leverage is the primary engine of a cast and our objective is using it to best advantage.

What Does the Work?

When you pick up your fly rod you are holding a long flexible stick, a lever, you use to accelerate the paltry mass of the fly line and ultimately the fly tied to the end of your leader. Your flexible stick is towing a string and if you pretend your fly rod is a spear thrower that pulls the spear instead of pushing it, things might Work out surprisingly well.

Remember **F=ma**? Here is another bit of useful maths and mechanics. The movement of the fly line produced by a caster puts kinetic energy into the fly line. In the physics trade that movement is a form of **Work**. The Work done by the caster is equal to the Force applied multiplied by the distance over which it is applied. The equation? **W=Fd**. Yep, the same **F** which equals mass by acceleration so it's still a **net Force** and still headed in a **single direction**.

Like a lot of other work, getting the casting job done requires sustained and focussed effort. Force is always a net force in a single direction so to do our Work we need to stay on track. Anything else is goofing off.

What Gründe went on to show us was something else very nifty about our springy lever. When your hand stops and the casting stroke is done the lever bit is finished but then the spring part does its Work and delivers its contribution to the kinetic energy put into the line. Wonderfully, as the rod spring unloads it continues to accelerate the line. In a long cast it's only twenty cents worth of bang for the casting force buck but it's very nice to have. When the rod straightens fully the acceleration party is over. The line now overtakes the rod tip and a loop is formed. Hold that thought. You will need it for the next episode of the series.

The Real Advantages of Bendy Rods

Now that we have slammed dunked rod loading I hope it is safe to say a few more words in praise of the real advantages of the spring thing. I hesitate because I fear the return of the rod loading zombies but I'd hate for my readers to rush out and swap their beautiful fly rods for a matched set of broom handles with runners and reel seats attached. Don't do it. Here's why.

When we apply force, via the rod handle, the bend we put in the rod helps smooths out the acceleration of the line. Power on. There's a slight lag or delay between our movement and the rod tip/line movement. Power off. When we finish our casting stroke there is also a slight delay between when we stop our hand and when the rod fully unbends. This second delay is much kinder to our body, especially to our wrist and forearm, than stopping the movement of a broom handle.

Let's revisit the vehicle towing example used earlier only this time we will use a snatch strap instead of a tow rope to connect the two vehicles. A snatch strap is somewhat elastic, far more so than a normal tow rope or steel cable. It is often used to recover a bogged vehicle. The tow vehicle is connected up and starts to drive off (accelerate). The strap comes tight but then stretches until it reaches its maximum stretch and about then (hopefully) the bogged vehicle starts to move. This delay avoids a sudden jolt and the towing vehicle can effectively apply more Force, without damaging jolts, than it could with a relatively inelastic tow rope.

When the recovery of the bogged vehicle is completed the tow vehicle slows. At this point the snatch strap will contract again so there is a slight delay before the Force being applied to the towed vehicle reduces to the same level as it would had we been using a normal tow rope. The delays are due to storing and releasing energy in the snatch strap and are similar to what happens when we bend and unbend the fly rod during a cast.

A quick look at the technical stuff before we get to another topic of much debate among fly fishers namely, rod preference. Earlier we saw that the equation for the Work we do to the line was the Force we apply multiplied by the distance over which we apply that Force. **W=Fd**.

When a delay is introduced we start to consider a time difference instead of distance travelled (which, of course, involves a difference in spacial location). Am I about to make Einstein happy by referring to the space time continuum? No, but we are sort of headed that way because our fly rods move both in space and in time. From a time perspective we multiply the Force applied by the time during which it is applied. Now we are calculating the Impulse. It's like Work, only seen from a different dimension – time, instead of space. The bending of the flexible rod stretches the distance over which and the time during which the rod tip tows the fly line – as compared with using a broom handle. This is very handy.

Rod Preference

As you will know different anglers have different preferences in fly rods. Some have different rod preferences for different fishing scenarios. What's that got to do with bendy rods? The stiffness of a fly rod will affect how easily it absorbs the shocks of a take or a run by a fish. A broom handle won't help very much with that.

Rod stiffness or modulus has another really important influence on our casting and therefore on our fishing. A relatively stiff rod will bend less than a relatively soft rod in the same line class. That means that the delays in power on and power off will be different – shorter for stiff rods and longer for soft rods. Each angler faces the Goldilocks choice – how much is too much and too little, delay. Different folks, different strokes, different preferences.

No-one wants a tomato stake and very few like a noodle rod to cast with but there's a lot of room between those extremes. It would be pointless exploring all the variables involved in making an ultimately subjective choice – things like caster smoothness, stroke length for cast length, rate of acceleration and deceleration. However, I can't finish without a word on casting technique and gear choice. Nothing to do with physics but it needs to be said anyway.

Good casters have varying preferences in fly rods. What sets them apart, however, is that they can readily adapt their casting action to get the most from rods of greatly varying stiffness. They can do that because their casting technique is sound. That is, they have such control over their movements, timing and effort, that they can vary both pretty much at will and without duffing a cast. You can buy rods you like better than others. No problem. Go for it. You cannot, however, buy a rod to fix problems with your casting technique. You can't buy casting technique. Marketers are very happy to take the money of casters willing to believe otherwise.

What the Line Does – Really

Short Version

This is where the going gets harder. Sorry, but there is no short version available.

Introduction

There is an awful lot of argument, online and offline, about fly casting, especially about what the fly line is doing and why it's doing it. The lack of agreement and the surplus of

BS which arguments seem to produce are why I decided to write this series.

What follows is my best attempt at explaining simply the things that might matter to a curious caster trying to improve their casting. Trust me, what goes on with the fly line is really quite complex. I'm still getting my head around it all, even as I write the series. Casting isn't either easy or simple, despite what a lot of (usually average) casters will tell you – at least not when you aspire to excellence.

A grasp of the basic principles of line mechanics provides enough knowledge to reach the objective of better casting. Even that doesn't come easily. We will need to sift and separate those principles from the hyper technical analysis and, of course, we will need to avoid stepping in the BS. It follows that this episode won't attempt to give an exhaustive account of the physics of fly line behaviour. That means some things other people find meaningful might get left by the side of my road. As ever, one man's trash is another person's treasure.

What do people notice most when they watch fly casting? The loop. The way that beautiful thing sails away from the fly rod and seems to defy gravity is fascinating. Magic eh? Good place to start the story of loops in fly lines.

Lines and Loops – Part 1

In the previous episode I said:

"When the rod straightens fully the acceleration party is over. The line now overtakes the rod tip and a loop is formed. Hold that thought. You will need it for the next part of the series."

Well, here we are and now you need that thought again.

One last thing before we dive in. For this episode it will be helpful to assume we are considering a standard overhead cast. That might be a basic cast with no hauls and no line being shot or it might include one or both of these add-ons plus others. I will keep you posted on what is in and what isn't.

Loop Formation

As soon as the rod tip slows the fly line begins to overtake it. The rod tip obligingly moves out of the way to avoid a collision. The fly line stays attached to the rod so when it overtakes the rod tip the fly line divides itself into two legs. The upper leg is known as the fly leg. The lower leg is known as the rod leg. The loop, then, is the transition from a single leg into two legs. The loop/transition moves along the line from the moment of its formation to the completion of turnover, the point at which two legs have again become just one.

Loop Propagation, Loop Travel and Velocity

Such a loop, moving along the fly line from the rod tip to the end of the fly line, is said to be “propagating”. The loop also travels away from us. In other words a loop has two elements of motion – propagation and travel. Understanding the difference is important for understanding how to manipulate these things to our advantage.

The two elements of loop movement get be a bit tricky to grasp. Here is how I look at them. When something is moving, say a car along a highway, it appears to move away from a person standing behind it and towards a person standing some distance away in front of the car’s position. In other words these two people have different perspectives or frames of reference for the moving car. We have no problem getting this duality because it is commonplace.

Loop propagation and travel are also two different perspectives or frames of reference. Propagation through the line is an internal frame of reference. The loop is like a wave passing through the ocean. It is the wave that moves and not the whole ocean. The ocean is displaced upwards but it doesn’t move otherwise. Imagine you are the line and a loop travels through you from head to toe.

Loop travel is an external frame of the reference. If you are standing on the beach facing the sea the waves are travelling towards you. Imagine I am casting and you are standing beside me watching the loop sail out across the water. It is travelling away from us.

These two aspects of loop motion occur at measurable speeds and both movements are in a direction. That means we can talk about them as having **velocity**. The velocity of loop propagation (**Vp**) is the movement/speed of the loop through the line. The velocity of loop travel (**Vt**) is the movement/speed of the loop **over the ground**.

Velocity, my friends, is **exactly** what we are trying to produce – line speed in the intended direction of our cast. Remember net Force and Work and how they are applied in a single direction? They are what we use and line velocity is what we want from them. Controlled line velocity, by the way, is the fundamental objective of everything we do in casting.

The loop is where transition happens. The fly leg has velocity (**Vfl**) which is lost as the fly leg progressively turns into the rod leg. During this process loop travel (**Vt**) occurs at half the rate of fly leg movement. **Vt = ½ Vfl**. Like you, probably, my first response to this was "Huh? Why half?". I still don't know why exactly but it obviously has to do with the fly leg having to change direction to become the rod leg via the loop. Trust me on this one, loops travel at half the speed of the fly leg.

When the rod leg remains still after loop formation then the velocities of loop travel and loop propagation will be the same. **Vt=Vp**.

However, when the rod leg moves it will also have a velocity (**Vrl**). Accordingly, our understanding of loop travel needs an adjustment and we need to consider the relative movement and velocity of the two legs. (**Vfl – Vrl**) So our equation becomes **Vt= ½ (Vfl – Vrl)**.

Bear with me while I explore what happens when rod leg moves a) in the opposite direction to the fly leg and then b) in the same direction. I know it is tricky to keep a mental hold on four velocities at the same time – one for each of the two legs of the line, one for loop propagation and one for loop travel. Not my fault though, this is what is going on and I'm just the messenger so don't shoot me ok.

Snap Cast

When we make a snap cast the loop seems to hover. That shows it is possible to have lots of propagation (**Vp**) and very little travel (**Vt**). What's going on? The rod leg has been made to move at least as fast as the fly leg – the exact opposite of what we do in a basic cast where the fly leg is made to move faster than the rod leg. In a snap cast we enhance propagation at the expense of travel.

Pullback

If we use the rod to pull back on the rod leg and move it in the opposite direction to the fly leg it will also affect the relative speeds of the line legs and enhance propagation – though not as much, of course, as a snap cast which is pullback on steroids.

Shooting Line

When we shoot line the rod leg begins to move away from us as well as the fly leg. Now, from the loop's perspective, the rod leg has velocity which adds to the velocity of the fly leg and, of course, the velocity of loop travel over the ground. Again we need to alter the equation slightly. **Vt = ½ (Vfl – Vrl) +Vrl**.

If we shoot line and then check the shoot then we first enhance travel and then enhance propagation.

Hauling

Hauling shows just how sensitive to changes in rod and fly leg velocity loop travel can be. If we haul before loop formation (ideally just before) then we add line velocity into what will become the fly leg – remember at this point the line has only one leg. If we haul after loop formation we are pulling back on the rod leg instead of pulling forward on what will become the fly leg. This reduces travel velocity and increases propagation velocity.

Summary

The take away from all this is that the two legs of the fly line are both connected and related. The behaviour of one affects the other. The loop is the transitional zone between them. In various ways we can change the relationship to our advantage. (Equally, we can do things which are disadvantageous.) For example we can manipulate the velocity of loop propagation and loop travel. In a snap cast we enhance propagation and restrict travel velocity. When we shoot line we enhance travel and, yes, we restrict propagation velocity. When hauling we can do one or the other depending on our timing.

Casting is fundamentally about creating line velocity – speed in the desired direction of the cast.

Lines and Loops – Part 2

Introduction

In Part 1 we considered loop and line behaviour (mostly) from the perspective of velocity – speed in a direction. In this part we will look at loops and lines (mostly) from the perspective of forces which also have directions. In any cast, of course, there is no separation of force and velocity. My reason for separating them as perspectives was to reduce some of the complexity, at least temporarily!

The loop is the most obvious feature of a fly line being cast. Its size and shape can tell an experienced observer quite a lot about what the caster has done during the cast to make a loop like that – i.e. it provides data useful in analysing casting technique. For these reasons and probably others I have missed, an influential bunch of casting people tend have a “loop centric” view of what is going on when we cast. Some of them even consider the loop to be some sort of engine of the cast – the fly leg of line being pulled along by it. I am not one of those people. I consider the loop to be fundamentally a consequence of the force(s) we applied during a casting stroke and where we made the rod tip go.

Push Me, Pull Me, Tension

After the rod finishes accelerating the line and begins to slow down, the line overtakes the rod tip and a loop forms. The fly leg rocks on with all the kinetic energy we put into it and it wants to keep going where it was sent. This complies with Newton’s First Law of motion, namely that an object will remain in motion unless acted on by an external force. Of course, the first external force our fly leg encounters is restraint that comes from us keeping the rod tip more or less still. That resistance is applied to the rod leg and then to the fly leg via the loop – the transition zone.

So, the fly leg is pushing forwards and the rod leg is pulling backwards. That might seem a bit odd at first. I mean, after a standard cast, without a haul or some line shoot, the rod tip has pretty much stopped a little while after we stopped moving the rod butt. How then can it be pulling backwards against something pulling it forwards?

Look at it this way. If we weren’t holding the rod still then it would be pulled forward by the fly line. So we are applying a restraining force opposing the force or kinetic energy of the fly leg. Newton’s Third Law, probably the best known of the three, is that for every action there is an equal and opposite reaction. The fly leg pushing forward is an action. (To be precise, a part of the fly leg that is pushing forward is continually being deviated by the restraint of the rod leg and this is the “action”.) The caster holding the rod still is an equal and opposite reaction, that is, the caster is pulling backwards on the rod leg.

Tension is what happens in a string when two forces pull on it in opposite directions so now we can say that after loop formation some tension is created in the rod leg. Push me from the fly leg. Pull me from the rod.

Hauls

Hauls which end before loop formation add velocity and energy to the fly line. Hauls that end after the rod is stopped add tension to the rod leg and as discussed earlier they enhance loop propagation.

Pullback

Pulling back on the line with the rod would likewise increase tension and enhance propagation.

Shooting Line

Shooting line probably releases some tension on the rod leg and (via the loop) on the fly leg. I say "probably" because I don't know how much tension is maintained by line friction against the guides and the blank and by the resistance of the line being towed up off the ground and out through the rod tip.

Is that it? From my perspective as a fly fisher who likes fly casting and wants to improve my casting the short answer is yes, that's about all I need to know. Like I said at the start, it isn't simple and easy to understand.

From another perspective, say distance casting competitions and the occasional extra long fishing cast there is potentially something else. At the very least it is interesting.

Acceleration of the Fly Leg Later in the Cast

It is true that in a standard cast the rod leg is pulling on the fly leg via the loop and that causes a change of direction. Technically speaking then, force is applied to the fly leg so as to "accelerate" it. To the vast majority of casters and their typical casting this is almost always insignificant. For it to be significant we would need clear evidence of it helping us to make longer casts or any cast for that matter, by actually speeding up the fly leg **after** we finish the casting stroke. I can't offer you such clear evidence.

The most extreme example of a late acceleration phenomenon, when it does become significant, can be observed in a snap cast which is itself an example of extreme pullback.

Watch this video clip called "Fly Leg Acceleration"[3]. It's slo-mo footage of one of my Advisory Group, Graeme Hird, making a snap cast. The rod and line are slowly lifted up and then the rod is snapped down. For the first few seconds the rod leg pulls the loop downwards. At about 8 seconds we see that the rod leg has hit the ground. After 10 seconds, the loop begins to hover and then to climb slightly. The fly leg turns over completely, leader and all, and the leader climbs noticeably at the end. Seemingly, the

3 https://youtu.be/hZnnKJjMUBE?si=ASYxs7vdXJfJ8_r8

only reasonable explanation for this that the fly leg has been accelerated by the rod leg in the common or garden meaning of acceleration. It is has been speeded up.

What this apparently demonstrates is that it is possible for the fly leg to be pulled on by the rod leg hard enough to make it move faster. Later in the video we see evidence of the fly leg speeding up during the last little bit of a standard overhead cast. No question the fly leg is being accelerated by something(s). It could well be the rod leg again. However, it could be other things as well, including remnant kinetic energy in the fly leg now affecting reducing mass (front taper of the fly line and leader). It could even include a bit of help by gravity. The line is falling so the big G is starting to pull the fly leg downhill at the same time as it is still going forwards which would speed it up a tad.

If that sounds like I don't know exactly what is going on you are correct. Next question, who cares? Supplementary question, does it matter, to whom and in what circumstances might it be significant?

Going back to first paragraph of this section then yes, it might matter to someone making very long casts and looking for a poofteenth extra – loop travel and/or propagation. You often see distance casters make a little lift right at the end of the stroke which could tighten the rod leg, narrow the loop a touch, enhance propagation and maybe, just maybe, even increase fly leg speed. I sometimes use them with overhead casts. Graeme also suggests it can be useful in making roll/spey casts and we will get to those later on.

Try it and make up your own mind.

The Opposition Forces

Every time we cast we are opposed by gravity and by drag. Gravity, the big G, is effectively constant. We deal with it by using line speed and by changing the trajectory of our cast like a javelin thrower does – aiming up to optimise distance and counter gravity's efforts to pull us down to earth. For short to medium casts we often aim the backcast up and the forward cast down (in line with the backcast). When we do that the forward cast is partly opposed by gravity and partly assisted by it. The steeper the angle the greater the assistance and the less the opposition.

Drag is rather more interesting to us. Newton's Third Law again. When we push something through the air the air pushes back. Drag comes in two varieties, skin drag and form drag. Skin drag is about the surface texture of an object being pushed through the air. The rougher the texture the greater the drag. Not much we do about that one, a fly line is what it is in terms of smoothness. Clean lines might be marginally smoother than dirty ones but nothing much there to get intense about.

Form drag is dependent on the shape of the object being pushed through the air. The greater the surface area the greater the drag. Now we have something we can work on. The bigger the loops we throw the greater the surface area presented to the air. Narrow loops are more aerodynamically efficient. So are thinner lines.

Secondly, when we make tracking errors – casting outside of a straight line forward and back – we present more line surface area to the air. In distance cycling races like the Tour de France we see a peloton of riders. The guys up front are pushing a hole in the air for the guys behind them. Riding outside the line of the peloton means losing that advantage. Greater drag will be experienced, requiring more effort to keep up with the group.

It is harder to cast into a head wind because the air is pushing harder against our fly line. The answer is not simply more effort. That usually takes us off the right path and into offences against the Straight Line Rule. The answer is **greater efficiency of effort** – better technique and narrower loops to give the air less to push against.

This bring us to another interesting factoid about drag. It is proportional to speed. The faster we go the more drag increases because more air molecules are hitting the line in a given amount of time. This is the same as when we cast into the wind. More line speed away from us or more airspeed towards us creates the same effect – more air molecules banging into the line during the same time period.

In fact if the passage of the line through the air creates turbulence, drag can even increase at the square of velocity. Double the velocity and quadruple the drag. Regardless of proportion, faster lines experience increased drag. This is one of the things that makes going longer more difficult.

Making Waves: Lines and Loops – Part 3

Making Waves

I learned a lot about waves, producing them and controlling them to do interesting things by playing around with a garden hose attached to a tap. Hoses are nice and thick and heavy and waves in them are fairly slow and easy to see. Have a play yourself but take it easy or you might rip the fittings off the hose at the tap end. A heavy rope tied to something solid like a tree or fence post will also work.

Here's where we are going. The hose is **a string medium** like a fly line. Waves travel along string media differently depending on the **density** of the medium and the **tension** it is under.

Tension is produced by opposing forces, forces pulling on the medium in different directions. For our purposes density is about the mass contained in a given length of a string medium. This is referred to as **linear density**. Hence forward I'll talk about density and assume you know it is linear density that we are discussing. Garden hoses have meaty density. They are thicker and heavier per metre than any fly line I've ever used. We can make and watch nice waves with them.

We don't need to understand everything about the physics of waves to improve our casting but the concepts of tension and density can be very useful. Generally speaking waves are good when we intentionally create and control them. Likewise they are usually bad when we create them unintentionally and have no control of them after that.

Let's get the principal bad guy out of the way first and doing that will ease us into some of the technical stuff we can use to advantage.

Tailing Loops

These are everyone's least best friend. Accounts of what causes them vary a bit but most people agree they are caused by the rod tip dipping and rising back up again. This produces a concave tip path and a wave in the fly line.

We can create the dip and rise in various ways but the most common cause is lumpy acceleration during the casting stroke. Speeding up puts more bend in the rod. Slowing down allows it to unbend a bit. Voila – dip and rise which makes a wave. Not hard to see this happening when we go for that heroic bit extra on the delivery cast, rotate too much too early and then run out of gas. That's how I make most of my tails – that in combination with miss-timed hauls which start (rod tip dips) and finish too early (rod tip bobs up).

So, in wave terms, we have created a wave which **disturbs/displaces** the medium – the rod leg of the fly line. As we proceed with the cast the wave rocks on down the line toward the fly. i.e It **propagates**.

Meanwhile we have produced a loop so now we have two legs in the fly line. The wave we made in the rod leg is now propagating in the fly leg. So far, so good and no problem. However, if we made our cast with a tracking error (as well as lumpy acceleration) we could be in trouble. The tracking error makes the two legs cross paths and if the wave is big enough it makes a part of the fly leg dip below the rod leg. As the line paths cross, they can collide and they do collide with maddening frequency.

The wave we put into the line propagates in a direction. The medium is displaced at right angles to the direction of propagation. What we produce then, is called a transverse wave. *Tracking error and a transverse wave in the fly leg = tailing loop trouble.*

Line Tension

Having unintentionally created a transverse wave we are not in control of it. The more net Force we put into that delivery cast the faster our line will travel. The transverse wave will also travel faster. That has nothing to do with line speed but a lot to do with line tension.

Back to the garden hose. Let's assume it's about 20m long. You have one end in your hand and the other end attached securely to something solid. Start by putting a bunch of slack, loops and wiggles, into the hose so that there is now only about 10m distance between the fixed end and the one in your hand. We are going to make a whip action with the hose. Quickly lift up above the holding position, then drop below that position and then lift back up to the holding position. What happens? I guessing not much. A wave was created but it fizzled out well before it reached the other, fixed end.

OK. Now back up until all the hose is straight. Doesn't have to be taut, just in a straight line on the ground will do. Repeat the lift and drop routine. You should feel the weight of the hose as it comes tight during the lift and feel it go light again as you drop. What happens this time? Completely different result. A wave shoots along the hose and smacks into the far end. Quite possibly you will see a return wave coming back toward you.

The point? You have just demonstrated that tension in a string medium makes waves travel faster along it. Yep, you are right, it also means they travel more efficiently assuming you applied roughly the same amount of force to the straight hose as you did to the slack one. Now we have some things we can vary and hopefully control.

Tension, Mends and Such

Anybody who fishes moving streams or even tidal water will need to mend upstream from time to time. Whether you do this in the air or on the water the principle is the same; a mend is a wave and waves travel more efficiently in tense lines than in slack ones. Many mends and casts rely on creating waves and manipulating tension to shape and position the line as desired. Not saying it's easy but it is definitely doable.

If, for instance, you want to aerially mend the rod leg upstream it will be far easier to do this after making a nice tidy cast than if you had made a poor cast with a lazy loop. The tidy cast will create more tension in the rod leg as the moving mass of the fly leg pushes ahead while the rod tip restrains the rod leg. Pulling back will further increase tension. Pushing the rod forward will release some.

We can put a wave into a normal delivery cast and drop the line to the water before the wave has fully propagated to add slack or avoid an object. Wiggle casts are a series of waves dropped to the water before wave propagation is significant. These casts also deliberately induce slack.

Overpowered casts and curve casts can rely on a rebound wave to kick the fly, leader and even some of the fly line down or around at the end of the cast.

You get the idea. Play, practice and use it as you like. This series isn't about making specialty casts. It's about understanding the physics which will help us create and execute them.

Density, Line Tapers and Mass Distribution

The taper of a fly line, floating or sinking, is far more than the outer shape of the line. It is a profile of its volume and, more particularly, of the distribution of its mass. Same material but more of it in one section than in another of the same length means different mass in those two sections. That means the linear density of the line can vary between sections with different tapers.

The implications of this go way beyond how far we can launch one when we wind up from the two bob seats. It has a lot to do with how waves travel along our fly lines. It influences loop propagation or turnover. It affects what a rod feels like when we cast lines with different profiles and different weights – as in AFFTA line designations as well as mass. It affects air drag. In fact there isn't much it doesn't have an effect on. Hence all of the variation in line tapers out there and all the marketing bumpf and BS that goes with them.

Once upon a time if you fished for trout you used double taper lines. Then weight forward lines largely took over. Now “brick on a string lines”, essentially integrated shooting heads, are becoming increasingly popular, especially, it has to be said, with people of average casting ability. But before I descend fully into rant mode let’s go back to waves and line density.

In general terms a wave travelling along a fly line will have less speed in the denser sections and more speed in the less dense sections. How that plays out for us will vary with the profile of the line sections we are casting or mending. A wave moving along a fly line tapering down will move faster as it proceeds. However, a wave moving along a fly line that is getting thicker will slow down. Obviously then a wave in a double taper line can behave differently to a wave in a weight forward line. In a weight forward line the wave might be passing from thinner to thicker and back down to thinner line. That will mean faster, slower, then faster wave speed. At the extreme end, with a shooting head, a wave in the running line will effectively run into a brick wall when it reaches the head.

In summary then. Double tapers are handy to mend. Weight forward lines can be ok and shooting heads are usually complete bastards. What do I like? For most of my fishing I like long belly weight forward lines.

It is a similar situation with loop propagation in that as net Force is used up it is handy to have progressively less mass at the end of the fly line (the forward taper) and then leader. More mass can turnover less mass more easily.

If for some strange reason we tried going the other way – trying to turnover fly line with the leader, the cast would most likely fail. Less mass trying to turnover more mass is a serious problem. That is what happens when we get too much “overhang” into the carry of a shooting head line – or for that matter a weight forward line with too steep a rear taper. You might cast further with shooting heads but will be less able to mend and shape them – brick on a string lines included!

Other Casts and Other Stuff

Introduction

In this Episode we will look at casts other than standard overhead casts, hauling in a bit more detail, how to be with the Force and lastly we will check out some common casting faults and see what physics has to say about them.

On a Roll

We all know that roll casts and overhead casts are different. For present purposes, the essential difference is the extent to which the line being cast is aerialised and allowed to turnover on the backcast. For an overhead cast it's usually all the line. For a roll cast it's only ever a part of it. As we will see that is a very important difference.

The setup for a forward roll cast can be thought of as the equivalent of an overhead back cast – regardless of whether we are making a static or a dynamic roll cast.

Spey casts, by the way, are simply roll casts preceded by a repositioning of the line. I won't give them separate treatment.

All roll casts employ a D loop as well as a normal overhead style loop during the delivery part of the cast. They come in two basic varieties – a static roll and a dynamic roll cast. The fundamental differences between the two types are how much line goes into the D loop and whether the setup (or back cast) involves static line or moving (dynamic) line – hence the names.

With those preliminaries out of the way let's get down to it. Everything covered in the series to date applies to roll casts – straight lines rule even though we are knowingly using a curvy line. The rod is still a flexible lever. A fly line does what it does. We can still make waves and mends and so on. There is, however, a salient difference between a good roll cast and a good overhead cast and that is the **inherent inefficiency** of a roll cast. We have to accelerate the line harder to make a roll cast than we would if we were making a cover at the same distance with an overhead cast.

Let's unpack that by considering the amount of line or mass that we are accelerating with our net Force in the intended direction of the cast. In the ideal overhead cast our casting stroke is moving 100% of the line for 100% of the distance over which we make the stroke – no slack, no tracking errors – fully compliant with the Straight Lines Rule. That's seriously cool efficiency, seldom if ever achieved, but that is still the ideal scenario we aim for and the closer we get the better we cast.

In a roll cast we can never achieve that level of efficiency because we can only apply direct Force to the line in the top half of the D Loop. The rest is having a snooze on the ground or water. It's a bystander waiting to be picked up by the passing parade. However, because the roll cast is inherently inefficient it means that our casting technique needs to be right at the top of its efficiency game to compensate for the inbuilt losses. We absolutely don't want to add to them unnecessarily.

Static Roll

To look at this in more detail let's consider a static roll cast of say 15 metres. We draw the line towards us, reposition the rod and pause. How much line will be in the top half of the D loop (the rod leg) when we start the delivery? I don't know of anyone who has measured this. Optimistic guesstimate? (Depending on the caster's reach and elevation, the rod length and how far back the caster reaches.) It's unlikely to exceed 5 m or 33% of the line. That, folks, is all we've got available to accelerate. That's actually the tow vehicle and the rest is the broken down vehicle being towed away progressively. In this case it is as though we tow the tow vehicle and it tows the towed vehicle.

Back to **F=ma**. We are working directly on only a third or less of the mass we want to cast. Five metres, or less, of fly line has to be accelerated hard enough to tow the other ten metres of line. Only by increasing acceleration can we compensate for the decrease in the mass we have to work with. Only then can we apply the Force we need to cast all of the line as far as we want it to go.

I hate static rolls. Rarely use them when fishing. Never use them if I can avoid it. Time, distance to target and the room behind me would all need to be in short supply.

Dynamic Roll aka Jump Roll

In comparison a dynamic roll cast operates with more live line and less dead line. For a dynamic roll of 15m it's even possible to invert the proportions and get as much as 10m (66%) of line in the upper half of the D loop towing 5m (33%). Even half the line or 7.5m would be a 50% increase in efficiency compared with 5m. Bonus!

The more live line we accelerate directly, the more efficiently we can apply Force. More mass being directly accelerated means less mass being towed or indirectly accelerated. We also want to minimise any resistance by the towed line. That is why we should minimise the amount of line on the water by having an anchor with just enough to hold during delivery. Surface tension in the water, which holds onto the line, is only our friend when we don't see much of him.

I like dynamic rolls. Use them a lot when fishing. No time wasted by false casting. Useful as a pick up cast before an overhead cast. Useful in other ways.

Tension in a D Loop

Did you notice line tension wasn't mentioned and/or wonder why only the top half of the D loop was talked about? Have you heard that tension in the D loop "loads the rod"? Excuse my bluntness but you really shouldn't listen to that crap. It won't help you and it just ain't so. For donkeys years people went on about how there is tension in the line between the anchor of a roll cast and the rod tip. That tension, bless its venerable socks, supposedly made it possible to cast because it loaded the rod.

Back in "What a Rod is and Does – Really" we canned rod loading. Some years ago Aitor Coterón, another member of my Advisory Group, kicked tension in the D loop out of the park. He made some videos (sadly, no longer available) which showed that during a roll cast, even on a very low friction surface, the anchor stays put until late in the cast when it finally starts to slip. That could only happen if there was very little tension in the bottom half of the D loop.

Blown and Misaligned Anchors

When we blow the anchor it's not so much line tension that we lose but some of precious net Force in the direction of our cast. How? Because the part of the line that slips backwards goes in the opposite direction to our cast so it exerts an opposing force. That adds to the inefficiency of the cast and we can ill afford the cost of Force theft.

Anchors that are not aligned with the direction of the delivery cast likewise steal Force. They are the on water equivalent of an aerial tracking error and offend against the Straight Lines Rule.

Lifts and Pullback

As with overhead casts you will often see good casters employ a small lift and some pullback as the finishing flourish to a roll cast. As explained in the previous episode this could tighten the rod leg, narrow the loop, enhance propagation and maybe even increase fly leg speed.

Hauling – Why, When, How

Hauling has been mentioned a few times in different sections. Let's pull some of that together and look at hauling in a bit more detail. Hauls are very useful to fly casting in a variety of ways – not all of which are relevant in a discussion of physics for fly casting. In this instance, however, I think it is ok to stretch the boundaries a little because hauls are important enough and not widely understood well enough.

Why Haul?

Among other things, hauls share the Work done on the fly line between the rod hand and the line hand. Both hands can now contribute to accelerating the fly line. That means we can use less Force applied to the rod and thus a shorter stroke than we would in a non-hauled cast achieving the same line speed and distance as a hauled cast.

Put another way, using the same stroke distance as we would for a non-hauled cast we can get greater line speed and distance, with or without shooting line. That means better control. Effort is the enemy of control and control is accuracy's best friend.

Hauling can give us tighter loops because the stroke length can be reduced and rod flex (bend) and counterflex (bend the other way) will also be reduced. Less of a windscreen wiper arc during rotation will mean narrower loops. Tighter loops mean less opposition from drag.

Hauling can even save time and false casting when covering a fish.

Try this. In a practice session pick a target at what for you is a medium/long casting distance. That is, at a distance you can reach but not too easily. Imagine your target is where you would put the fly to cover a fish. Cover your target fish alternately with hauled and non hauled casts. If you can't notice a difference then change to a more distant target. If you still don't notice a difference it could be your hauling technique needs a bit of polish! Going the other way, try practicing without hauls for a substantial part of the session. If you are a good at double hauling, losing it for a while will probably expose faults in casting technique that hauling otherwise made up for.

When and How to Haul

Hauling accelerates the line if we do it before loop formation. Ideally then you would haul so as to optimise the combined line acceleration produced by both hands. That would mostly likely be when the rod, after translation, is rotated at the end of the cast. This is also sometimes referred to as the "power snap".

The usual advice from casting instructors is to "haul late" and that is good advice – as late as you can actually, before the rod tip slows enough to allow a loop to form. Remember that hauling before loop formation means you are hauling on what will soon become the fly leg.

If you haul much too early before loop formation the rod tip can dip and rise again.

This can create tailing loop problems. The tip dips when haul force is applied and rises when the haul is finished. That might not be such a problem if the rod hand was putting in some extra bend during the haul, another reason why we want to haul and reach peak rod acceleration at much the same time.

If you haul at least partly after loop formation then you are now pulling back on the rod leg instead of forward on the “fly leg”. This will enhance loop propagation velocity but diminish loop travel velocity. You will get zippier turnover but less distance.

The text books and videos will tell you to use short hauls for short casts and longer ones for longer casts. They will also tell you to use a down/up motion so the line you pull down is returned up while there is enough speed and energy in the line to avoid creating slack during the return.

Newtonian physics has no problem with that advice. However, when you have acquired good hauling technique I would encourage you to experiment and improvise. Use different contributions between rod and line hands to take your shots. Use different haul speeds and haul lengths and see what happens. Personally? I vary these things when working to produce just the tempo and combination of movements I want for the type of cast I want to make. A gentle and considered dry fly presentation is not the same as snappy nymph shot to a fish which just drifted obligingly within reach. Different fish, different folks, different strokes, different hauls. Find what works and feels good for you.

The Force And How To Be With it

A couple of years back, I wondered if anybody actually knew how much force it took to propel a fly line so I asked: *WTF*? i.e. *What’s The Force*? The answer was that the force applied at the rod tip to produce a measured casting distance is roughly 1 Newton for each 4m of the cast. So a 20m cast needs about 5N of Force during the rotation phase. This is a surprisingly small amount.

To put that in somewhat more accessible terms, one Newton is about 100g of weight. Say my shopping is in the car boot and the two bags weigh 5kg in total. I lift them out, exerting a force of about 50N. That same amount of force applied by the rod tip would theoretically enable me to make a 200m fly cast.

The force required during translation is even more ridiculously small being about 1N (100g) for a 20m cast. It doesn’t matter whether the numbers I have just quoted are precisely correct. The point is that fly lines weigh very little so it takes very little force to move them and that is both good news and bad news.

The good news is we can cast a long way with not much Force at the rod tip. If we measure the Force at the rod butt instead of the tip, the Force is about twice what it is at the tip but it's still far smaller than we typically **feel**. That is because most of what we are feeling is the mass of the flesh and bones that we move in order to accelerate the rod butt and rod tip.

The bad news is far less obvious, seldom discussed and rarely attended to. It comes in two parts. First part, in making a 20m cast we actually apply a relatively small Force in the direction of our cast, say about half a kilo's worth at the rod tip. Accordingly, the kinetic energy we put into the line is also relatively small.

Second part, and here comes the crunch, since we don't put much energy in, even small losses of energy (out) can have **very costly** consequences. Force thieves like tracking errors, slack, drag, mistimed hauls and so on aren't just pinching a few energy scraps from the table, they are making off with the family silver.

I suspect our underestimation of the energy-out losses is aligned with both the overestimation of energy-in required to make a cast and a deep instinctive reliance on more force to go further. The combination is toxic to casting excellence.

Now, I know, it's possible to put extra effort into a shortish cast and still get a decent result but that doesn't disprove my point or restore faith in extra effort being the answer to extra distance. Yes, you can overpower a short cast and make it lay out faster but try that with progressively longer casts and it will inevitably end in tears. Soon enough, previously hidden problems with our casting technique will become ever more serious and apparent and we will end up with collapsing loops and piles of spaghetti at an embarrassingly short distance from our feet.

If power was the simple answer all the winning competition distance casters would be shaped like body builders and they aren't. Keep your eye on Maxine McCormick, a casting phenomenon. As a teenager she is dominating accuracy competitions. If she keeps at it for another ten years and gets into distance competition. Look out. Obviously, the secret of her success is not strength, it is **efficiency**.

I'm not saying power is completely irrelevant but rather that a long cast won't work with extra effort alone. What it needs instead is extra purity of applied force so that net Force isn't depleted too heavily by losses to Force thieves. This in fact is what underpins almost all aspects of good casting technique and if it doesn't then it's the technique model that needs adjustment. Trust me, there is far more to be gained by preserving net Force than there is in trying to increase it with extra effort. Straight lines will always rule and **efficiency** will always trump exertion.

Casting Faults – Mechanical Failures

A great deal of the traditional ideas and methods for teaching fly casting seem to be concerned with correcting faults. I don't want to go too far down that track, especially because I believe it's better to teach people to fly cast than to teach fly casting to people. However, I would like to demonstrate how understanding the mechanics of casting can help with a few common faults. It's by no means all we need know but it's useful.

Heaving

When I'm out fishing I often get to watch other people cast. The two most common things I notice are fat loops and overpowered casts, often in combination. To fully understand the many problems that heaving (overpowering) causes we would need to draw on knowledge about human movement, biomechanics and neuroscience. Hmm. A little beyond the scope of this project, but let's see what we can do with the physics stuff – well, mostly.

Applying casting force efficiently means we optimise the net Force and minimise the forces applied in other directions. As we have seen, the required casting forces are surprisingly small so it is very easy to overpower – to heave – without realising it. Heaving leads to early rotation and/or over rotation which violates the Straight Lines Rule, yet again. Heaving leads to tailing loop troubles. It adversely affects accuracy. There are lots of reasons why we shouldn't heave. Ok, got it, but **why do we heave**? Simple question with complex answers, most of which have nothing to do with physics. Having spent years assiduously trying not to heave, at all, I now think I know some of the reasons why we do it.

First, when we need to throw things further and/or faster we instinctively throw them harder. More power is our default solution for all kinds of problems – it's the get-a-bigger-hammer syndrome. After a lifetime of confirming instinct while playing sport, skipping stones or expressing frustration with hand tools it becomes a very hard habit to break.

Second and related to the first reason, I think part of the heaving problem comes from a lack of feedback. Imagine you are given a golf ball and a ping pong ball and asked to throw each of them into a hoop lying on the ground 10m away. No practicing, one shot for each ball. My money is on the golf ball. Unless you are used to throwing ping pong balls, i.e. your systems are calibrated for the task, they will be harder to throw with the right amount of force than something much heavier like a golf ball. Very hard to judge how hard to throw something so light we can barely feel its weight in our throwing hand.

Most fly lines don't weigh very much. We want to be able to feel some resistance, to feel the rod towing the line. What happens when we don't feel that? We speed up trying get back in touch. Results? Lumpy acceleration, force going all over the shop, casts descending into complete failure. Slack in the fly line often creates this sort of problem. We can carry a lot of line in the air provided the sequence of false casts keeps us in touch. When it goes wrong and we start chasing slack we start to overpower and it becomes very difficult to recover.

Heaving is a problem in itself because it leads to lots of opposition forces which steal from our precious net Force in the direction of the cast. I suspect it is also a problem because we do it to try to compensate for other shortcomings in our technique. Here it becomes a fault combining with the other faults to make an even bigger mess.

Fat Loops

We throw wide loops when we make the rod tip travel in wide arcs instead of straight lines. In other words wide loops are evidence that we have broken the Straight Lines Rule and haven't used our casting force efficiently. The usual suspects for too much rotation are not enough translation before rotation, too much wrist movement during the stroke and not stopping the stroke high enough. Wide loops also present more surface area of line to the air so drag is increased, further diminishing efficiency.

Now we have an inefficient casting stroke that isn't putting the fly where we want it. The answer? Of course, more force, right? Nope. Heaving will probably make things worse rather than better.

Yes, it's true that sometimes we might choose a wider loop – say downwind casting or casting multiple flies that love to tangle. However, that's not an excuse for fat loops. It's a choice made by someone who can vary their loop sizes at will.

Endnote

We have covered a fair area of casting that is illuminated by physics, especially by mechanics. They are not the only sources of light. Others include biomechanics, how we learn and perform movement, learning and performance insights from other sports and on it goes. Physics is great for understanding the requirements of casting efficiently. With this knowledge we can form more accurate mental models, develop better BS sensors, identify what's useful and analyse our casting faults. However, like everything, its usefulness is limited and let's not forget the people who prefer to learn by doing rather than thinking.

Even for someone like me who needs to have a bigger picture into which pieces of the puzzle can be assembled, physics is not the only useful approach nor is it the final arbiter of what I do and don't do when casting. Whatever casting mechanics might prescribe as the ideal way to cast in terms of efficiency I absolutely reserve the right to do something else because it works or simply because I enjoy it. I can't break the rules of physics but I am not their haplessly obedient servant.

Let's take hauling for example. How we share the load between rod hand and line hand is up to each of us. I might not want or be able to time the haul to finish a few milliseconds before Rod Straight Position, which is ideal for going long. I might not be making a long cast. I might want a different tempo of movement in one or both arms that I find pleasant and helpful to accuracy. I might simply enjoy creatively playing around with different contributions of Force between rod and line arms. The ideal might be very significant if I am trying to win a distance competition but a pain in the arse if I am trying to make a quick cover at short to medium range. It has been said that in music improvisation is the privilege of the master and the bane of the novice. We need the structure of technique and technical rules to play classical music but without something more the music dies at the hands of the player. Great casters do not look like robots. They have mastered technique sufficiently to be able to express themselves.

Great casting is graceful and at its heart graceful movement is economy of effort – just enough and no more. Grace and efficiency make a very happy couple. They are an example of the relationship between Art and Science as rediscovered by the West during the European Renaissance. Contrastingly, mathematics and improvisation are not a match made in heaven. Determining what is mathematically ideal leaves little room for creative interpretation. Take what you need from physics.

On a personal note here is what I have taken from it. Going back to the first paragraph of this ***Endnote***, I said physics was "*great for understanding the requirements of casting efficiently*". Lest the deep significance of that pass by unnoticed and unrecognised here is my go at stating the essence of fly casting in a single sentence:

"*If you want to fly cast beautifully, accurately and long you have to cast efficiently.*"

If I had only a single word it would not be "force" or "effort" or even "technique". It would be **efficiency** because that is where all things in my sensibility, practise, learning and knowledge converge. Understanding the physics of casting has not revealed that insight to me but it has confirmed and affirmed it to an extent I could not possibly have imagined when this project began.

N.B.