Fly Casting Physics – 2010

I have enjoyed reading the many posts revolving around fly casting physics. First a compliment to Gordy – Gordy always shows amazing thinking and offers a great deal of supplementary information over the range of topics arising on the message board. Honestly, I don't know how he is able to contribute so frequently and so much! Many of the past commentaries demonstrate great insight from the writers into the factors affecting casting and how to achieve improvement in the casting of students. However significant errors are being propagated with regard to explaining and understanding the physics of fly casting and my intent in this document has several objectives. The foremost one is to correct some of the most significant errors in understanding //description of casting physics. I have written about this numerous times in the past and a good deal of the material to follow has been covered in the past and apparently has not been fully absorbed. This write-up in some cases will augment past discussions with simplified examples to allow readers to more fully connect with and understand the effects//physics being discussed. So, hopefully the physics of basic false casting will be explained in a manner not requiring an engineering degree of the reader in order for the reader to perform a critical and convincing review.

I especially want to get this out with at least a little time for your review before the FFF Conclave. I plan on being there and hope we can have some interesting discussions about casting. I hope to pick up a few casting pointers as well as personal discussion of some of the points I tried to make here. So please try to connect with me if you are at the conclave. I'm looking forward to seeing old friends and also making new friends.

Also in this write-up I'll go into several other areas beyond fly casting physics. In past commentaries I have tried to introduce new **terminology** which I believe **speaks to the critical factors in casting**. I'll repeat these and provide some discussion of them to give notions as to why I favor the proposed terminology and hopefully encourage you to consider there use. The words/terms are chosen to demonstrate or define key events//effects which arise in fly casting. I will be presenting a discussion of structural dynamics of a fly rod as it relates to fly casting (although I am trying to limit this and prune out as much as possible yet still make unassailable arguments validating the important points). Next, a good (some would say, the best) way to test and ultimately prove scientific assertions and concepts is with the insightful use of measurements//records taken during real casting. I will be presenting or discussing the best experimental data I have come across including: 1) high speed 3-D tracking of reflective "markers" on a fly rod, including the rod tip (I am the caster for the data – incidentally, this data has been made available in the past as part of my more detailed past discussions of fly casting physics), 2) the data that Perkins//Richards published some years ago when

the Casting Analyzer was an experimental device, and 3) some strain gage data we took which demonstrates the **root cause of tailing loops**.

Fly Casting Physics – The common first and foremost problem//error arising in describing what happens in fly casting is the notion of the hard stop. As everyone on this board is aware the prevalent rhetoric is that the caster executes a "hard stop" commencing around peak rod load and ending around rod straight position (RSP) – that is, during rod unloading. Sometimes you hear people referring to a necessity to "stop the rod so it can unload". I have read where this has been compared to applying the brakes on an automobile. In fact, the caster's hand **never** attempts to stop the rod during rod unloading and **exactly the opposite** is true. **After peak rod loading is achieved** it is more as if the fly rod is in control and the caster is merely holding the rod as you will see as I proceed. Being able to see//understand this comes from being able to absorb and interpret the experimental data, and a basic//elementary understanding of the rod's structural dynamics.

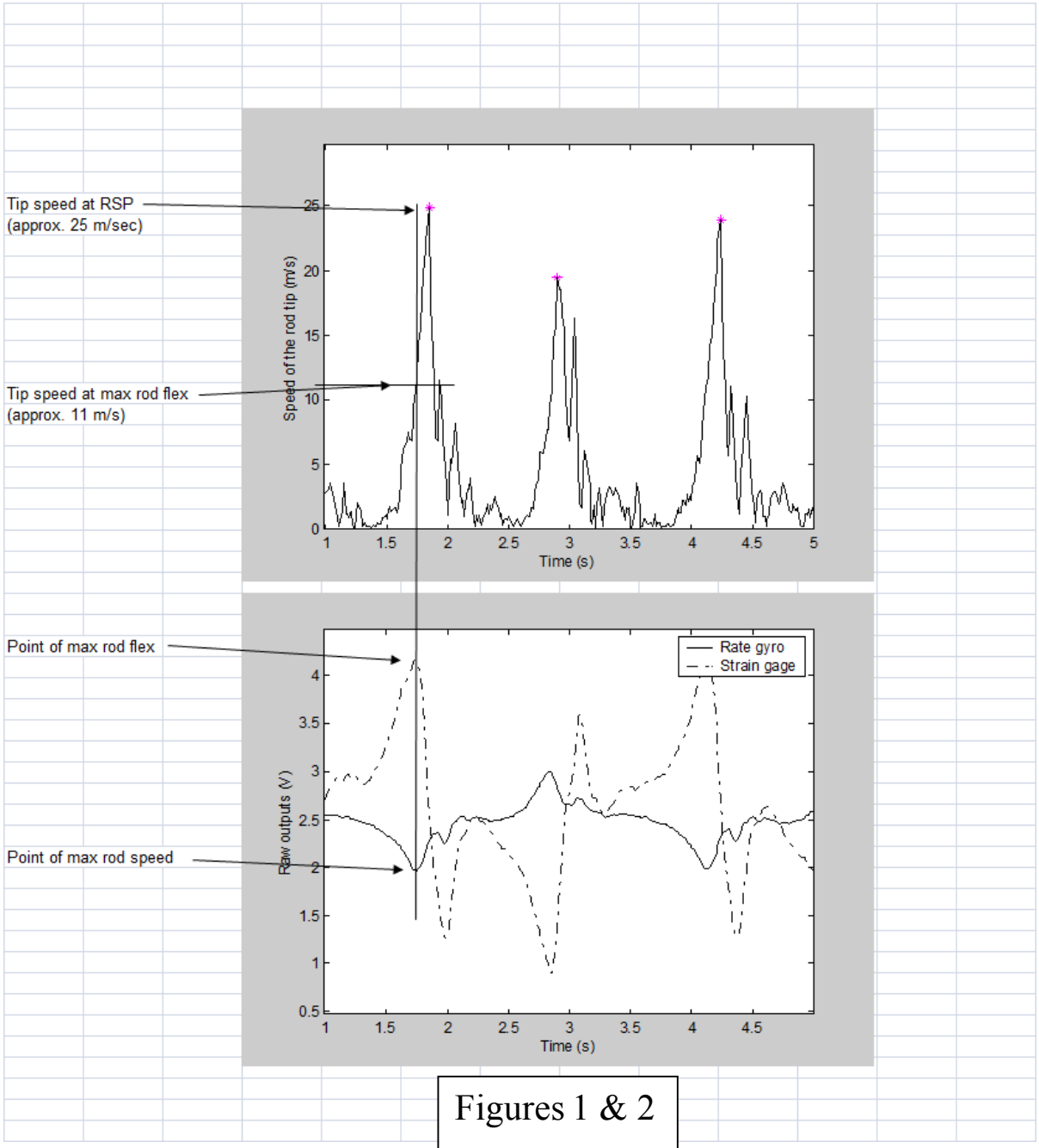
Fortunately, it can be easily shown that prior to RSP the caster never exerts retarding moments//torques on the rod and this fact is intuitively consistent with everything most people would believe about fly rod behavior during casting. (I presume that stopping has the conventional meaning – in stopping a car the forces are directed toward the rear which is opposite the direction in accelerating, etc.) I want to introduce the engineering concept of a "transducer". A transducer is a sensor producing a data record which can be used to determine some other quantity of interest. For example, the Perkins//Richards Casting Analyzer uses a device//sensor to directly measure the angular velocity time history of whatever the device is affixed upon. This device "transduces" angular velocity. For this proof that there is no "hard stop" and in fact no stopping at all the transducer of interest is the common strain gage (except possibly for the clock, the most used sensor of all time). A fly rod acts structurally in a manner engineers refer to as beam behavior. Any mechanical or civil engineers in the readership will have had some contact with static beam bending theory in their undergraduate education. We are interested in dynamic beam response which has **many facets which I will not delve into here**. However a physical understanding, trusting, and being able to use **static beam bending concepts takes the instructor//caster a long ways toward commanding the physics of fly casting**. Suffice it to say that the dominant stresses in the wall of the rod//beam are primarily longitudinal (along the rod length and this is the reason the rod is wrapped//manufactured such that the fibers lie in a longitudinal orientation). With knowledge of the longitudinal stress//strain on the surface of the rod at the appropriate circumferential location it is merely algebra to compute the moment being carried//transmitted in the rod. The equation is

Moment = (longitudinal stress at surface) x (moment of inertia of cross section)/ (radius of rod cross section)

Consequently if strain gage records are recorded during casting, the moment//torque at the strain gage location is directly transduced. What is of interest to us is the moment//torque {{I use the duel term moment//torque because engineers seldom use the term torque and laymen seldom encounter the use of "moment" as it is used in engineering – I do not want to offend either group.}} the caster's hand applies to the rod and how that varies during the cast. If a hard stop were being executed then the moment//torque applied by the caster's hand would need to be zero when starting the hard stop and then take values with the opposite sign that occurred during rod loading. To record this moment//torque the strain gage is located on the rod surface just above the hand//rod butt. This is a very common technique to measure mechanical stress at important locations, determine forces and/or moments//torques. It works because the torque on the rod's internal cross-section at the strain gage location is very, very nearly equal to the net moment applied by the casters hand. I have attached some strain gage records we took (see page 9) – just note the general form of the records. Also the article by Perkins/Richards of many years ago has very nice graphics which better show the details of what I am describing. What you see is that the strain increases (rod loading), hits a peak value (the maximum applied moment as well as the maximum rod flexure/deflection), then the measured strain decreases as the rod straightens during unloading, the strain changes sign (goes from positive to negative or vice versa) when counter flexing begins, and so on. To understand what moments//torques the caster is applying to the rod butt all you have to do is look at the strain gage record and recognize that **you are also observing the applied moment**. It is true that the moment decreases from its peak value while the rod is unloading but of course **the sign does *NOT* change so the moment direction does not act in a retarding way**. This is **absolute proof** that the caster is doing his upmost to load the rod while it is unloading. This diagram below is from the hallmark Perkins//Richards article. Bruce's graphics in the magazine article have more graphics than I was able to comfortably place here. Perhaps Bruce could provide an electronic source for his article or perhaps post it somewhere – my apologies for not being to reproduce everything properly in this document. In his article Bruce and Noel clearly and correctly mark the phases (rod loading, peak rod flexure, rod unloading, RSP, etc. **I completely agree with the details of what is shown on their diagrams.** Where disagreement exists is that in that article they characterize the rod unloading phase as a "hard stop" where it is very clear the caster is still applying positive moment//torque on the rod. As I will discuss later, because of a never before discussed structural dynamics effect of fly rods the caster's actual efforts to continue loading the rod are strongly underrepresented in the data – I will explain this later – he is trying

very hard to load the rod during rod unloading. Even if the rod strain had changed sign it would not necessarily mean the caster was not trying to continue loading the rod.

I mentioned earlier that the idea of a hard stop is more or less completely contary to most casters intuitive understanding of how a fly rod should function. If the



Figures 1 & 2

caster is casting forward the rod is bent backward during rod loading **and during rod unloading.** Therefore if you are asked the properly worded question "what is your hand doing to the rod butt during rod unloading//straightening" your response would almost automatically be that the hand is applying a torque to the rod in the same direction as during rod loading – no reversal//stopping here. What else could it be doing?? So in that sense, inspite of the often repeated hard stop talk, it is clear that the hand is not placing forces on the rod to stop it – the foot is still on the gas and not on the brakes.

In the next graphics (Figures 4 & 5) you can pretty well see that in pictures that show fly rod deflection, the fly rod moment//torque does not change sign until right around

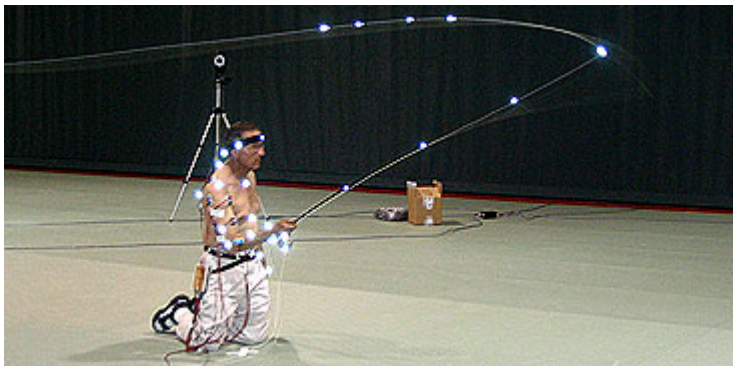


Fig. 3

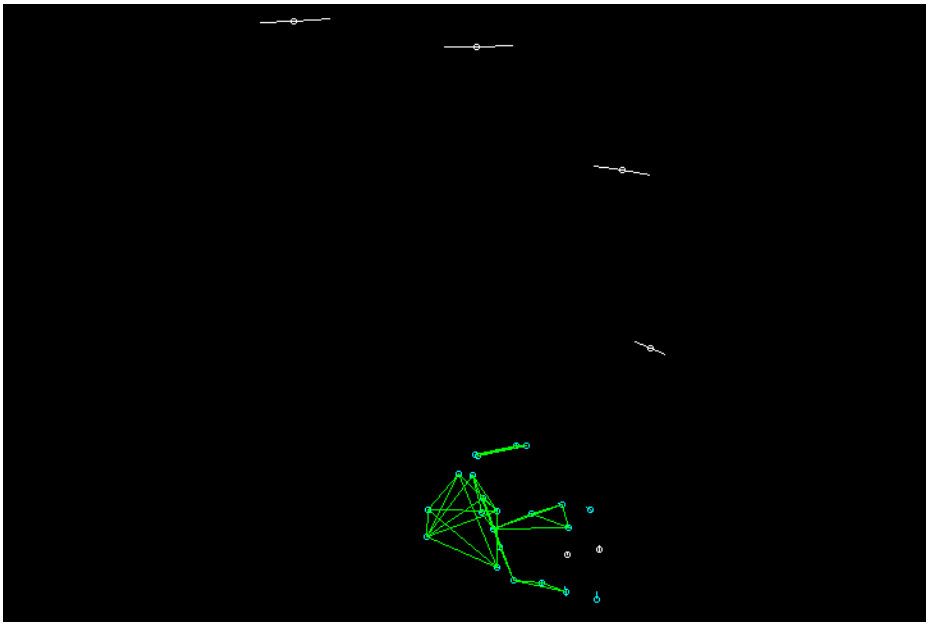


Fig. 4 – Maximum Rod Loading

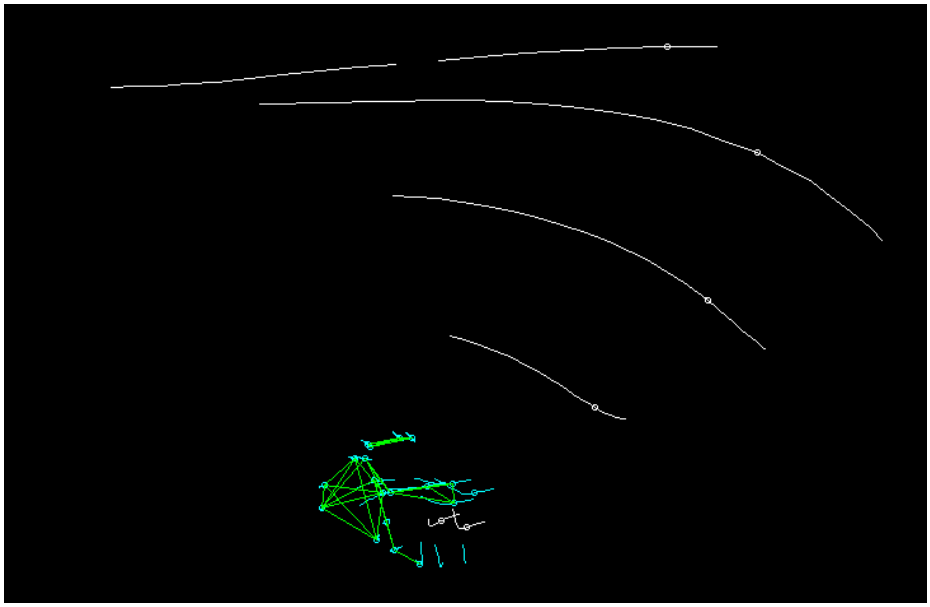


Fig. 5 – Traces of markers on fly rod

RSP. There are 6 markers on the rod – the highest marker is at the tip top and there are 2 on the rod butt. With a little imagination you can identify the two on the rod butt. The first image is at max rod loading (the image suggests 7-8 feet of rod deflection – amazing, I think) and the second has white dots showing how the rod is deflected close to rod straight position. It seems pretty clear that at both points in time that the caster is applying moments//torques in the same direction. I had markers all over my body which also show up in this graphic (see picture). The last graphic tracks the motion of markers on the rod and note how flat the tip is moving – it looked like there may have been 11ft of nearly straight-line tip trajectory. **Achieving this is very dependent on continuing to rotate the rod butt during rod unloading** which comes from thoughtful review of the marker tracings . Looking very carefully at the pictures you can see that most of the straight tip motion occurs during unloading and had the rod rotation been stopped at max rod loading it would have been a disaster (rod tip would have risen above the flying fly line). So good casts are very dependent on **not stopping** the rod. **So, I think I've made my points about hard stops not being a reality based on experimental data and the most basic notions of fly rod behavior**. Any future discussion should center on the points made above – is the rod bent back? Does being bent back mean that the caster is still applying accelerating moments? The answer is yes to both remarks.

Well, you could ask what happens when a cast is made and how were casters deluded into believing about hard stops?? The following is a fictional process for making casting decisions while casting with a conventional fly rod and line

- Decide length of false casts and how fast a line speed is desirable
- Decide total angular rod rotation and stroke you will use
- Make the false casts consistent with your decisions and within the rotation range (power application range) you have preset in your mind and during the cast will come a point where the rod deflection//loading hits a peak. If you are truthful about maintaining the rotation range then you can't do much about where in your range of rotation peak rod load//deflection occurs – for both high speed and lower line speed casts the peak rod deflection will be around the same point//angle. The higher speed cast will achieve a higher level of rod loading but at about the same rod butt angle. If you need to really alter the cast then you need to adjust the decisions above. For example, if you aren't reaching your target you can increase the total rod rotation thus adding more energy to the system.
- If you are a high performing caster you naturally maintain a "poised" wrist (one of the terminologies I like which will be briefly mentioned later) and

apply wrist input during period when peak rod loading occurs. I believe that to apply power through your wrist your body must be braced (muscularly) and many muscles contract//stiffen in the bracing process. For pupils that are having a hard time progressing through "rod waving" I have them place a hand around my right triceps and fell the muscle contractions. Then I tell the pupil that I want him to be able to produce the same contractions and he can check by placing his left hand on his own right triceps. There was a nice picture of Steve Rajeff on a web site I thought was his own (?) in which I have no trouble visualizing he has most of his body stiffened preparatory to using his poised wrist. One possibility is that the preponderance of these contracted muscles at the time of peak rod loading and rod unloading is to make it plausible to the caster that he is trying to stop something where in fact it is the direct opposite case.

- More casting physics – once the rod starts to unload it loses some of the flexural bending it had at peak rod load. This provides a negative contribution to the rod butt angular velocity. In fact it must provide a mighty large negative contribution because you see from the Perkins//Richards data that the angular velocity at the rod butt decreases (the 2nd figure shown above and angular velocity is called "rod speed" in the figure) in spite of the angular momentum of the system increasing (the system angular momentum has to increase because the net external moment continues to contribute angular momentum – which from the casters viewpoint is a good thing). **So the spring back of the rod has such a strong effect that it actually eliminates most of the angular velocity of the rod butt**. This also means the caster has to work extra hard to load the rod during unloading because the rod is trying to run away from his hand when it is unloading. (My apologies if some of this is hard to keep up with because, in this case, it's the first time I've tried explaining it.)

A little commentary on the Casting Analyzer follows. What a wonderful tool – but I hasten to add the rod angular velocity is ***not a fundamental*** quantity because the rod bends and unbends. This structural dynamics effect causes the rod butt angular velocity to change independent of the casters input. You cannot use gyro sensor as a transducer for the moments//torques the caster is applying or to assess whether the caster is trying to load or stop the rod. Just because the angular velocity of the rod butt decreases when the rod is unloading does not mean that the caster is applying a retarding moment – from what I said above, it means that the rod unloading is reducing the rod butt angular velocity. It's a great ***empirical*** tool

– “this outstanding caster has this angular velocity trace when he’s casting and mine does not look the same so I will experiment until I can reproduce his angular velocity trace”. That is the spirit in which you can use the CA system to help improve your casting. I trust Bruce and Noel when they say the best casters achieve constant angular acceleration (I assume that means constant angular acceleration during rod loading). But that is an artifact that can come about because several more fundamental factors combine to yield that measureable response. The strain gage, as I discussed earlier, is an accurate transducer for the moment applied by the caster unto the fly rod.

Terminology - Now I’ll mention some terms I like using when communicating with other casters or students

1. Rod waving
2. Kickback
3. Preload
4. Poised wrist
5. Line reversal loading
6. Window washer casting motion
7. Casting Artifacts

Rod Waving is a stage most learning fly casters pass through. It is the first necessary stage to pass through and is characterized by rod waving on both back casts and forward casts. Some folks have considerable difficulty getting beyond rod waving. To get beyond rod waving the idea is to maintain a poised wrist until wrist motion is called for at which time considerable musculature needs to be contracted//stiffened to provide bracing out to the wrist. Interestingly even fly fishermen who have handled fly rods for decades will largely wave the rod on their back casts. Maintaining a poised wrist on the back cast is a rather unnatural action (how many nails have you pounded when they are behind your back?) and it’s much easier to simply perform a fast rod wave for the back cast. For myself, I find it necessary to remind myself not to wave on the back cast, to maintain the poised wrist, stiffen my muscles, and rotate the wrist. If I don’t remind myself I slip back into waving. Being honest, for all but long casts it doesn’t really matter. When you watch a large population of casters you’ll see many with very wide loops on the back cast and much tighter loops on their forward cast. If the caster waves on the forward cast then much improvement is achieved by conquering this limitation – for the back cast it’s not nearly as important. Earlier I mentioned that it is helpful for students to understand that musculature is employed at the time when

wrist rotation occurs so I use the technique (having student sense my musculature activity) I mentioned earlier.

After conquering rod waving the student may have no other real difficulties, but in reality many individuals experience trouble with what I call **"rod kickback"**. For some very experienced casters their false casts may be good enough but the final forward cast demonstrates a somewhat (or sometimes a strong) tailing loop. In theory, it may be possible to throw a tailing loop without kickback but I have never observed it. It doesn't take long to see examples of kickback if you are in a large group that is casting. (In fact at a conclave 3-4 years ago they had a special program centered on bamboo rods and 20-30 individuals were casting. It seemed like almost every caster was showing kickback and tailing loops.) I have spent quite a bit of effort on several occasions over the last 5 years explaining kickback and how to demonstrate it in a controlled environment. I'll summarize here – start your rod 2 ft from a soft object which will not hurt the rod if the tip bumps into the object. The rod should be stationary, and then give your wrist maximum jerk as to move the tip away from the soft object. The bending of the rod will move the rod tip back toward the soft object before the rotation at the butt eventually takes the tip in the forward direction (so the tip moves backward and then forward). Anyone with average physical skills and a rod which isn't terribly stiff should be able to get 1-2 feet of kickback. With something like a bamboo rod more would be achievable (I'm making it sound like I've measured these things – I haven't, but I have eyeballed them). Even if the rod tip doesn't move backward in casting it can slow down due to kickback and that cannot be a good thing either (loss of tension = generation of slack line). Judging from the message board I gather that kickback is another thing that continues to go unnoticed in spite of all the references to tailing loops. **{{I am going to take a tally so I can easily remember what casting effects have been brought to the reader's attention here - (1) the caster continues to apply torque and also purposefully continues to rotate the rod butt a large amount during rod unloading, (2) rod spring back during unloading causes the rod butt angular velocity to actually decrease even while the caster is continually applying torque – rod spring back is apparently a dominant effect in the physics of rod dynamics and casting (and affects the correct interpretation of rod butt angular velocity measurements, (3) the tip does not necessarily follow the rod butt as when kickback occurs which is the cause of tailing loops, (4) below I bring up the notion of linear momentum//line reversal loading ((this is the increased rod loading occurring when the line's direction of motion is reversed at the front of the loop)) which affects cast timing}}** In my own case I know I wasn't observing it until I specifically practiced looking for it – I expected to see it and when I looked I was

able to find it especially on casters with significant tailing loops. On the next page is strain gage data which tells a story about tailing loops. Before discussing these casting records it is best to talk about rod preload.

Rod preload is the solution to kickback and tailing loops. If you have another passionate caster who can help you the following experiment can be performed. Have your friend hold the rod tip so it is initially flexed 6, 12, 18, etc. inches. He must hold the tip so that when the rod butt is jerked he releases the tip. At some point the rod will stop kicking back and you see the impact of preload. In my mind this is akin to the often cited plea that the caster should use a smooth or progressive loading//acceleration but the recommendation is now much more specific: don't put the pedal to the metal until you are already rolling with enough speed. If a tailing loop occurs it means more rod deflection//**preload** must be in place before the major power application occurs. The 2nd plot below has two overlapping records of casting with 40 ft of fly line beyond the rod tip. One is of Alex Yudell a former student of mine (incidentally, Alex did the work with the strain gage experiments – setting up the gage, the circuitry, the portable recording equipment and taking the measurements in the field – what a great partner!). Alex was demonstrating a significant tailing loop on his forward cast. The other is of me casting without tailing loops.

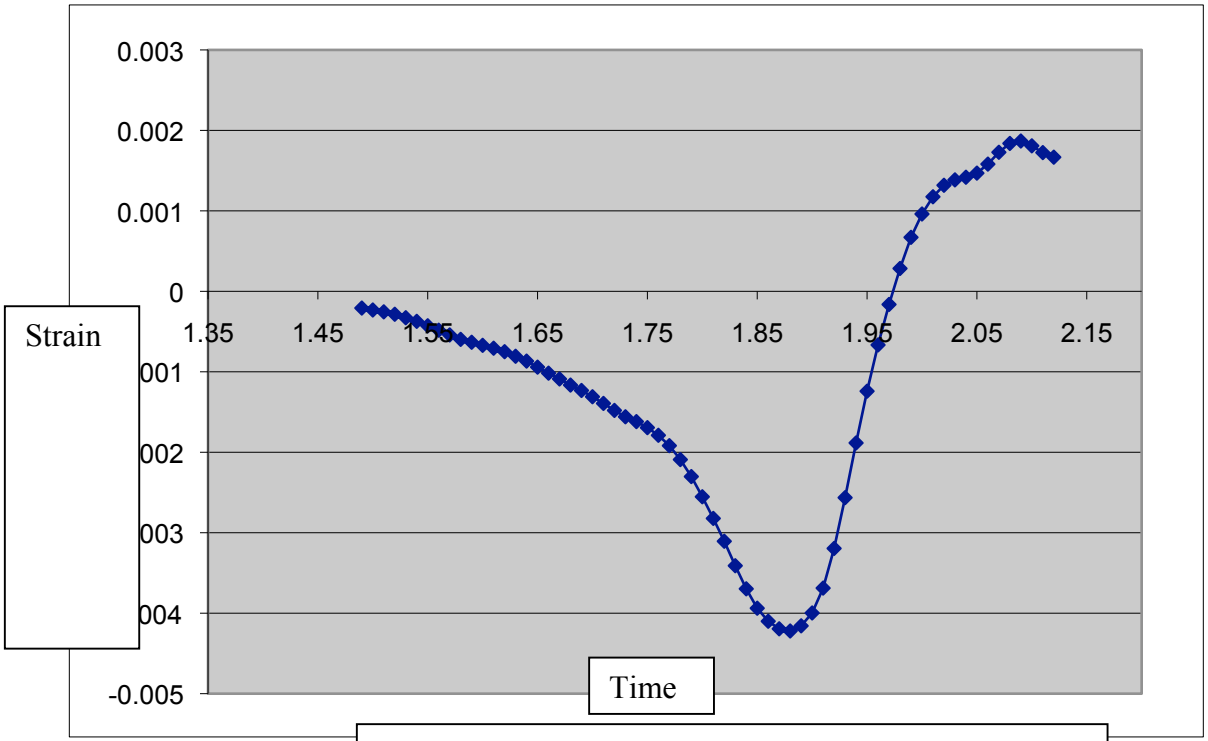
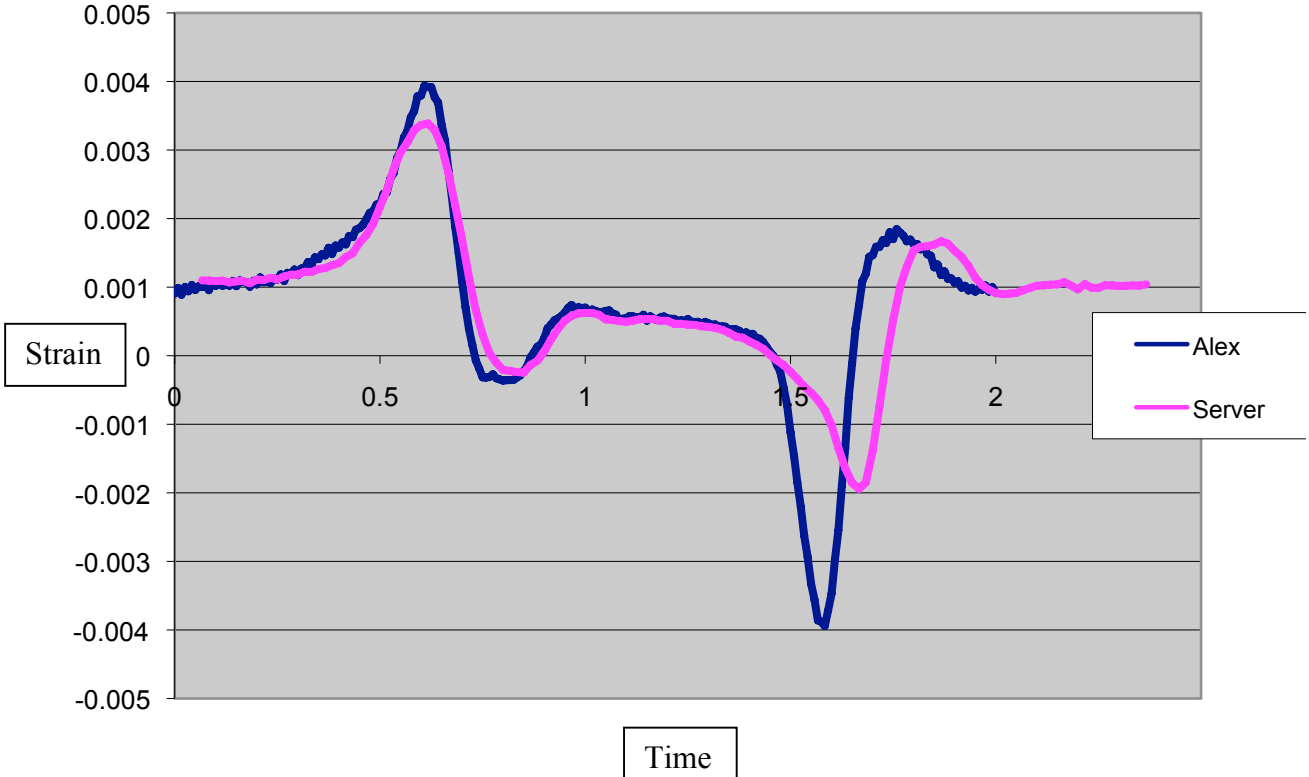


Fig.6 --Detailed strain vs time with good preload

Fig. 7 -- Alex vs Server at 40 ft
Kickback Evident



The negative values of strain correspo e forward cast. Alex's back cast did not show a tailing loop but his forwar khibited a consistent significant tail. I could visually observe the kickback o l tip and on the strain plot you can see why – almost a total lack of preload. he time marks on the plot and proceed to 1.5 seconds. The blue rec n the larger peak strain) moves with a steep slope right from the start of rod loading at 1.5 seconds. There is no preload here when maximum rotation input to the rod butt is applied and kickback is the response I expect and saw. The greater the effort applied by the caster the steeper the strain-time curve in the data. My data record shows the forward cast with the strain increasing first with a shallower slope and then when wrist power is fully applied the slope increases. About half of the total rod flexing occurred in preload and then the major rotational effort was applied. The prior plot is for a different experiment but shows the details of preload and subsequent higher caster effort. Notice the time marks where preload occurs from 1.55 - 1.75, then 1.75 – 1.87 where the slope is much steeper and maximum effort in rotating is being applied,

and finally 1.87 – 1.97 seconds where the rod unloads. Alex immediately caught on to the lack of preload, adjusted his casting stroke and eliminated the tailing loops. This was verified with subsequent measurements on his casting.

I've mentioned a "poised wrist" several times already. A wrist that is poised simply means that the wrist is in a position when all its ability to rotate is still intact//available. For the forward cast the rod will be perpendicular to the forearm when the wrist is poised. One wants to preload the rod with arm rotations and translation while keeping the wrist poised and then when preload (and also appropriate rod butt angle) is achieved apply the high effort rapid wrist rotation. One feature of most **rod waving** is the wrist and arm segments are rotated simultaneously in a relaxed fashion leading to lack of a loop and slow line speeds.

I don't think I can get into momentum//line reversal loading in the detail it deserves. (A close friend has suggested that, to him, "line reversal loading" was a confusing phrase and that he preferred momentum reversal loading. I am going to take the suggestion and use momentum reversal loading from this point on.) From what I read the community is more or less unaware of it or its significance. Providing you are casting with a flexible fly rod (I mention this because a video of Steve Rajeff on the ACA website casting a shooting head clearly shows him using a rod with very, very little flex – so it is possible.) you have two effects available for loading the rod. One is the momentum added to the bare rod during loading and the other is the **momentum change** of the fly line. The second quantity can be significantly increased by reversing the direction of motion of the fly line particles when casting. So having a fly line head which is moving backward smartly when you are casting forward is a method of leveraging the physics. The simple physics involved demands that when momentum reversal occurs the tension in the fly line has to be increased and the tension at the rod tip increases causing greater rod flexure. In fact good casters unknowingly (or knowingly) use this mechanism for increasing rod loading. I have a video of Lefty Krey where it looks like he starts his forward cast while the end of the line traveling back is just above his head. A good condition is if the line straightens about the time that maximum rod loading occurs – this provides you if the largest amount of rod loading, equivalent line speeds at the moment of maximum rod load, and the greatest increase of line speed during rod unloading. Allowing the line to straighten or almost straighten before starting the next casting phase is poor practice. When I want more distance, I have to remind myself about this for starting the back cast because it's so easy to want to watch the loop more fully unfold. For me starting the forward cast early enough is much more natural because I don't watch the loop.

My time is running out so I need to close this document. I especially want to get this out with some time for your review before the FFF Conclave. I plan on being there and hope we can have some interesting discussions about casting. I hope to pick up a few pointers as well as discuss some of the points I tried to make here.

Best regards – Server Sadik