

The Mechanics of Fly Casting 5

By Bob Bolton

This article is being written well after Mechanics of Fly Casting 1-4. In that time I have talked with many more experts and I have found a lot more information. The first find was the work of Dr. Bill Hanneman on his Common Cents System of fly rod rating. It can be found on <http://www.common-cents.info/> . The website outlines a method of fly rod rating, the first part of which follows closely and predates the first four articles of this series. If you study CCS, you will find the first measurements made on a rod in order to rate it are based on static loading of the rod and converting it to a number called ERN. Although the methodology in determining this number is slightly different than “Mechanics 1-4” the approach is the same. That is, measure the static deflection of the rod and rate it against other rods. There are other elements the CCS system but, for now, this is the most centered to this discussion.

Regardless of your technical opinion, Dr. Hanneman’s method has resulted in the largest fly rod database available in the world, to my knowledge. And because of minor differences in procedure, it would seem silly to reinvent the wheel if this data base is satisfactory. The data has also been picked up on another web page. This web page is <http://www.sexyloops.com/> and the page that also has a common cents data base is [http://www.sexyloops.com/eric/database/rodtab
lesorted.php](http://www.sexyloops.com/eric/database/rodtablesorted.php) .

Now one of the more interesting plots that can be made from this data is the ERN number obtained from measuring the rods static stiffness and the rod rating given by the technical expert of the rod’s manufacturer. This looks like Figure I below.

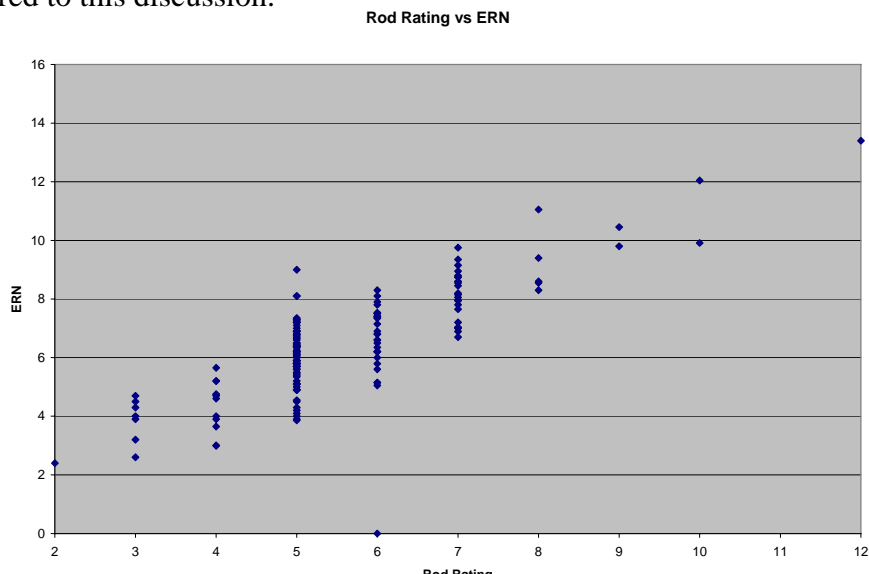


Figure I.

The plot shows a general trend of higher rated rods having a higher ERN. This follows the general guideline that heavier lines require more energy to cast them so they need to be stiffer in a static sense. This is in agreement with the procedure outlined in “Mechanics 1-4” of this series. However, there is quite a spread in the ERN value for each rod rating. Even though the ERN was somewhat influenced by rod length in how the number was arrived at (amount of deflection is dependent on rod length), it appears something more entered into the manufacturing expert’s opinion of the required rod rating. If we translate the ERN to a work term by multiplying by the rod length to get a Ft-lb equivalent, the plot looks like Figure II below where :

Work Rating = ERN X Rod Length

The plot immediately smooths out. So it is evident that that we must convert ERN to a Work Index when using it or we must limit it’s

application to rods of the same length. But it is certainly usable for any reference to a rods **static** load carrying ability and there is no point in reinventing any wheels here. So this article will use ERN or ERN work Index to refer to static strength henceforth.

But the vertical scatter in the plot of ERN Work Index (Figure II.) still shows vertical scatter. So there is more to the raters opinion than just static strength. Discussions threads on the Sexyloops website continually hint that there is more. These discussions tent to point towards a dynamic component. Discussion threads on the Board are populated with Topic’s and Reply’s on this subject. Information from contributors like Magnus Angus and Grunde Løvoll and others have many interrelated thoughts and analysis relating to dynamics. So I thought I’d take their ideas and add my \$.02. None of this would have been written without their ideas.

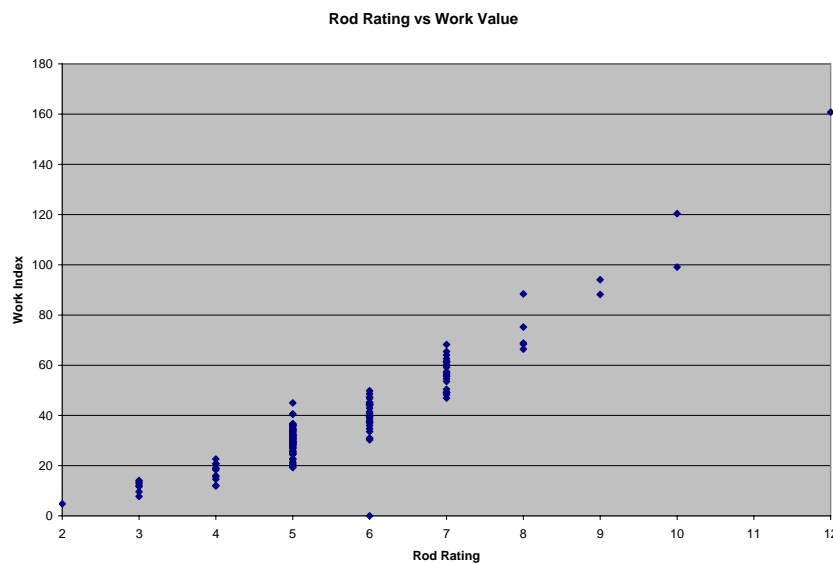


Figure II.

Static's and Dynamic's

I am going to try to break down the simple forward cast into it's static components (represented by ERN and other static techniques) and parts that are purely dynamic. Now I admit, right off, that the entire cast is a dynamic event but I will try to show how static techniques can be use to represent part of the cast. It is very important to see that I am initially using only a simple 35 foot forward cast in this analogy. Techniques for long distance casting such as long casting strokes, hauling, and using the rod counter flex to generate loop morphing are a horse of a different color and will not be discussed until the end of the article. I know all you long

distance guys are going to disagree but humor me for now and I will explain later.

Looking at Figure III. , We can see a simple forward cast. Starting at RSP (rod straight position) at the end of the back cast, the rod is loaded by flexing the rod against the nearly stationary line and applying a load. I we assume the rod is weightless, the only force on the end of the rod is generated by the flexing of the rod against the nearly stationary line behind it (to the right of the picture). If the rod was weightless, the flexing of the rod closely approximates a rod loaded in a fixture with weights hung on the end. This is the position that ERN applies too. If the rod was being held in the hand horizontally with weights hung on it, the feeling in the casters hand would mimic

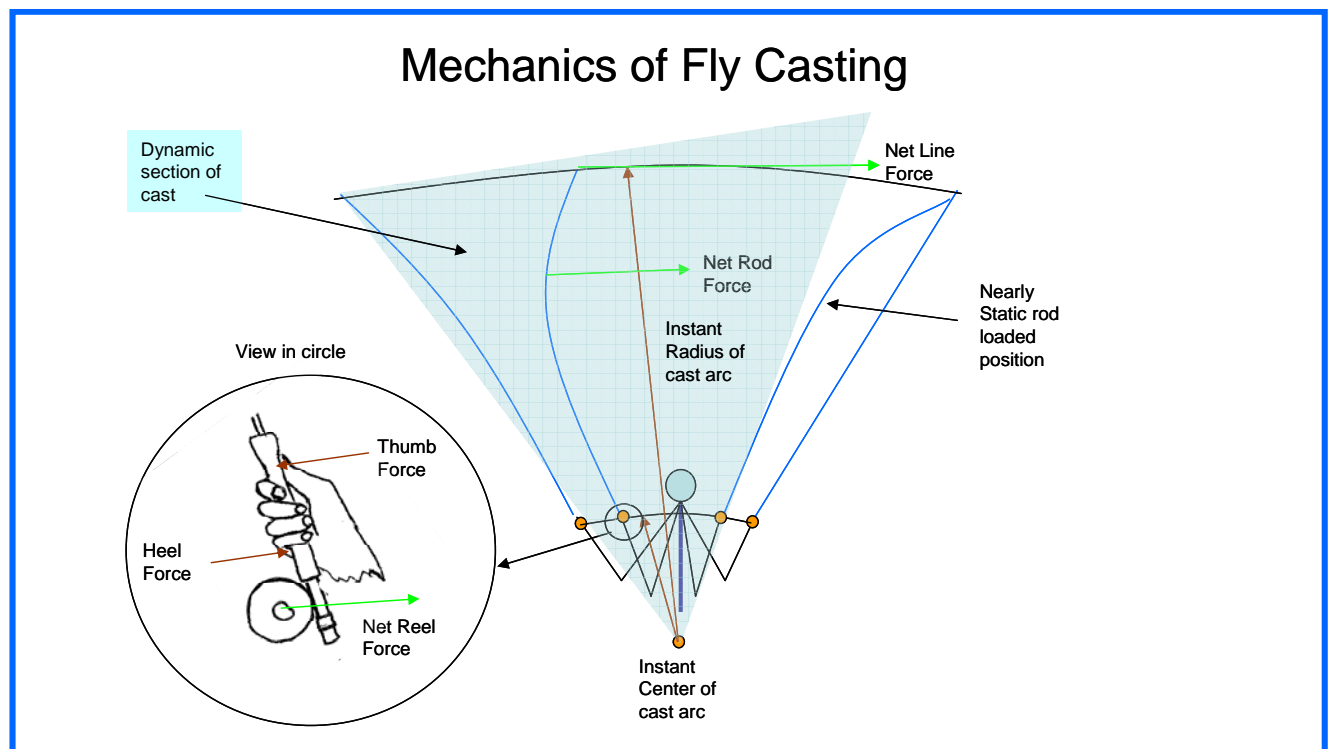


Figure III.

what is felt in this starting position. This is the rod's **static** stiffness and is the only part of the cast that relates exclusively to ERN.

Handle Metrics

Now I am going to introduce a new term. We can call it "Handle Metrics" for want of a better term. Inside the circle(Figure III.) there is a representation of the casters hand. This is the only place that the caster connects to his rod and it is all that he really "feels." All the rest of the system and the forces generated therein, are visual or perceived only and are not "felt." Try to imagine casting in the dark to get the idea. The forces of the casters hand on the handle are broken down into a force at the

thumb and at the heel of the hand around and on the little finger. Admittedly this is an oversimplification, but it will do for now. The force on the thumb and heel generate a net force in the cast direction and a moment to keep the rod traveling around the instant center of rotation somewhere just below the caster's elbow. Once we break down the forces on the rod and reel, a summing of forces and moments will generate the feeling the caster will have at his hand.

Understanding the following two curves may require a review of Figure IV. in the first article of this series. Looking at Figure IV. the bright red dot represents this point in the casting curve. This curve is idealized in that once this point is reached, the rod flex and

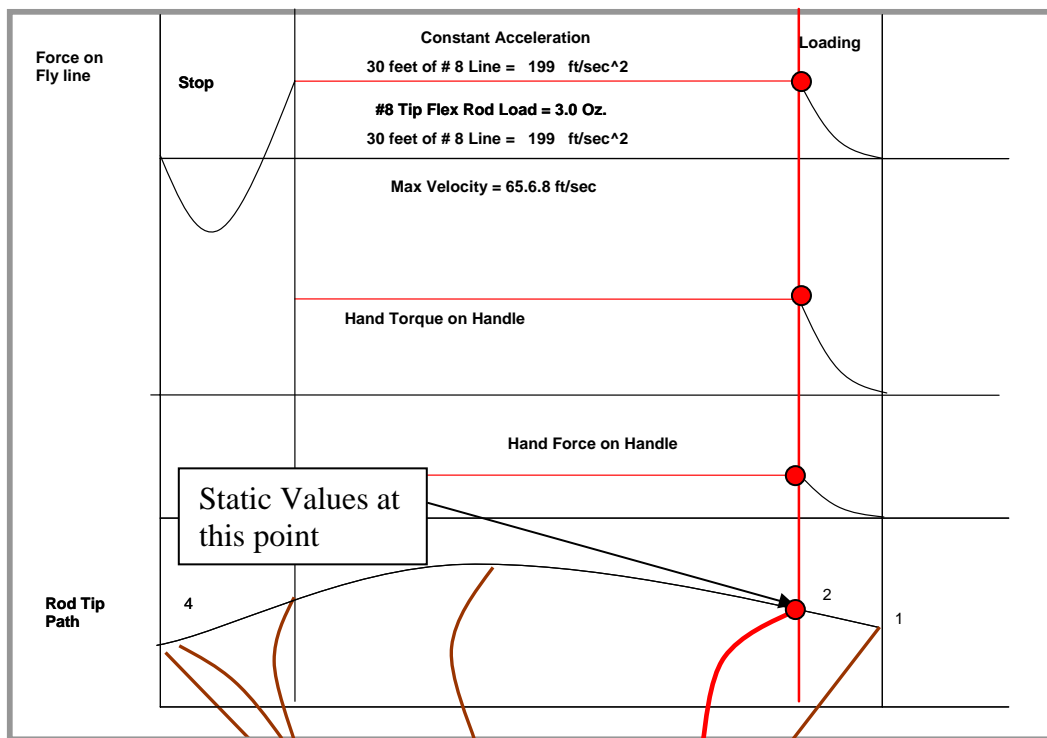


Figure IV. Static Loading Assuming Zero Rod Mass

therefore, the load, remain constant through the rest of the stroke. This will result in a constant acceleration with velocity increasing smoothly and linearly to the end of the cast. It is a parameter good casters strive for but it is unlikely they would be this ideal.

If, then, the rod was without mass, the static load would be all the hand would feel at loading and would be all the hand felt through the remainder of the forward cast. And if this was all that was felt, material modulus, section modulus, and rod taper could meld in any combination what-so-ever and as long as the static load was met, the mix would matter not. But we all know this not to be true. So what else then?

Looking at the rest of the diagram, we can see the forces on the rod as the cast is executed. There will be a force at the end of the rod which is accelerating the line which was already accounted for in the static loading. There will be also forces distributed down the rod which are a function of the rod mass and the rod mass distribution (thanks Magnus for bring that to my attention). And finally, there will be forces associated with the weight and motion of the reel. If we know the force at the end of the rod required to generate the energy to complete the cast, we will know the acceleration - ($a=F/m$). If we break up the rod into segments and know the position of each we can ratio the acceleration from the tip by it's radius from the instant center of rotation and by

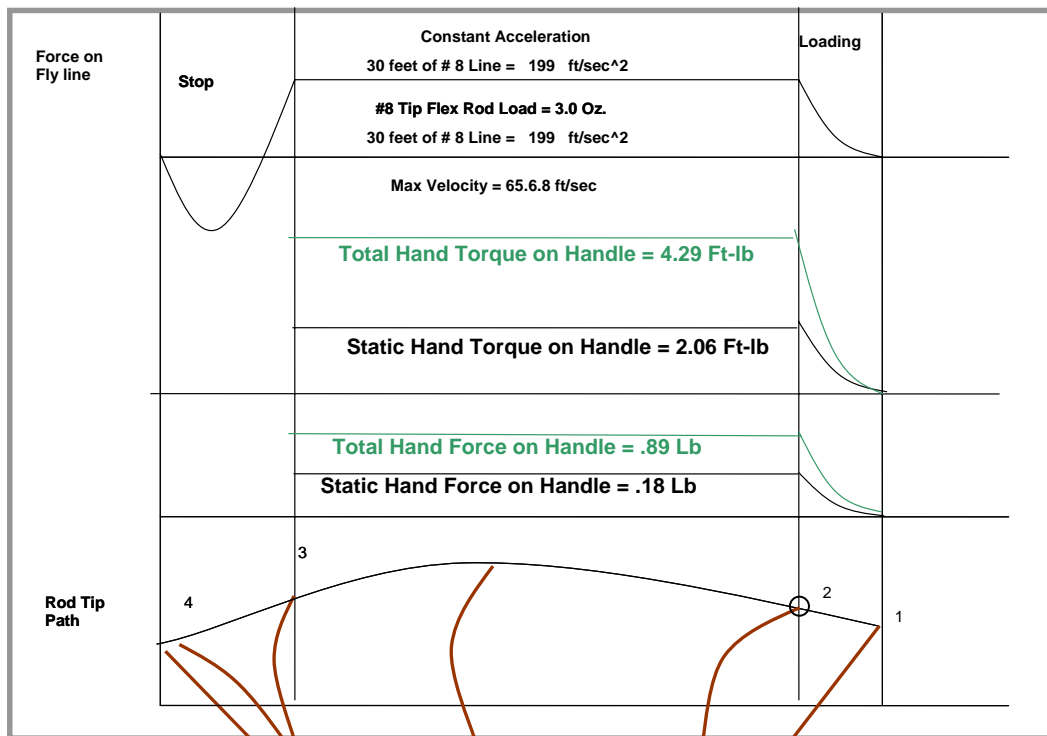


Figure V. Dynamic and Static Loading

weighing each section, we can get the component force on the system. Same goes for the reel. Then by summing all these forces and moments, we can get the handle metrics – what the caster feels.

Now all these forces are dynamic. The forces depend on the mass of each element which means they are dependant on things like density, diameters, wall thickness, rod taper, etc. To get data to perform these calculations, I cut up an Orvis tip flex 10 foot 8 weight rod that had a broken tip from some other monkey shines. I then built a mathematical piece wise linear beam model and compared masses and deflection to the real rod. This model will allow me to build rods with different tapers later in the paper without having to cut up a bunch of

rods. I will give details on the model further down. After calculating the dynamic loading, I plotted it in Figure V. It can be seen that the dynamics of the rod and reel contribute substantially to the felt loading at the handle. It is this loading that we have to understand in order to rate rods both dynamically and statically.

Figure V. shows the rod handle moments and forces. It is represented by the area between the black static force line and the green total force line. The rod is the 10 foot Orvis 8 weight Tip Flex. The cast is for an eight weight line in the 35 - 45 foot category. It can be seen that the rod and reel exceed the force of the line in felt load. A breakdown looks like Figure VI below. The top 5 feet of

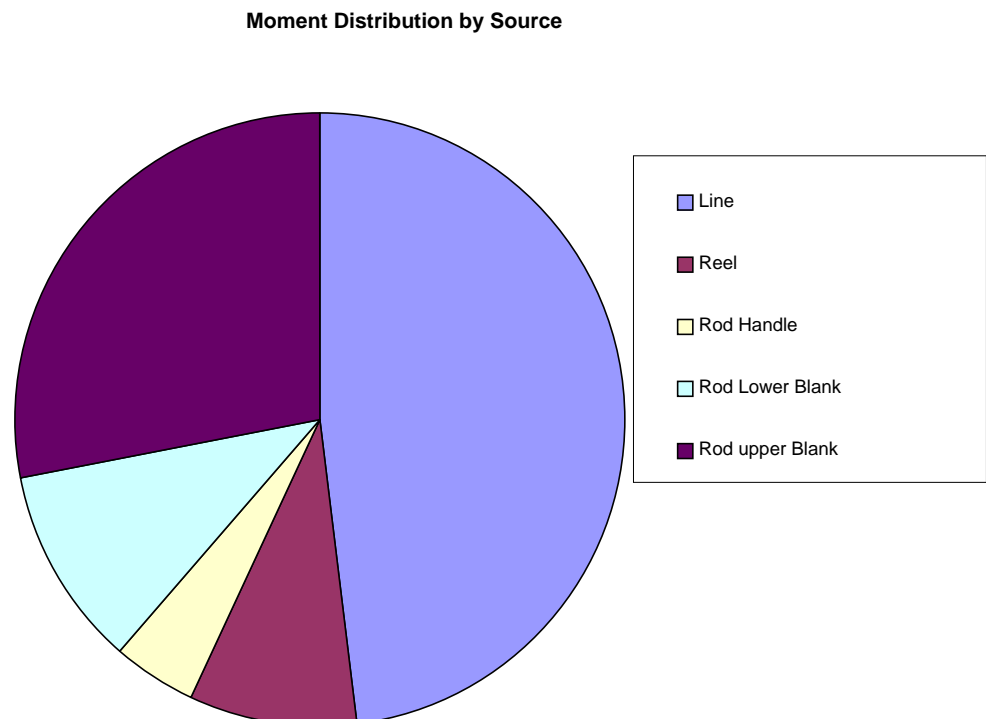


Figure VI. Moment Distribution

rod are summed. This is basically the top section of a two piece rod. This mass distribution is influenced markedly by things like section modulus, material modulus, tapered, density, and diameters. And the mix of these is very important in how the answer will come out. For instance, the higher the material modulus, the smaller section modulus and steeper the taper can be and still not exceed limiting stresses. In fact, higher material modulus will actually withstand higher stresses. The end result will be a lighter rod and consequently lower dynamic forces. You will “feel” this during the cast.

The Rod Model

The mathematical rod model used for this simulation, as stated before, was based on a

10 foot Orvis rod. The model consists of 1 foot beam sections anchored end to end and treated as individual cantilever beams. The deflection total is simply the sum of the deflections of the individual beams. Some attempt was made to correct for cosine error as the sections deflected. The sections were as in the chart below.

Distance	OD	ID
9	0.401	0.321
8	0.361	0.281
7	0.318	0.238
6	0.275	0.195
5	0.305	0.227
4.75	0.289	0.217
4.5	0.238	0.186
4	0.206	0.147
3	0.169	0.107
2	0.138	0.082
1	0.106	0.057
0	0.073	0.013

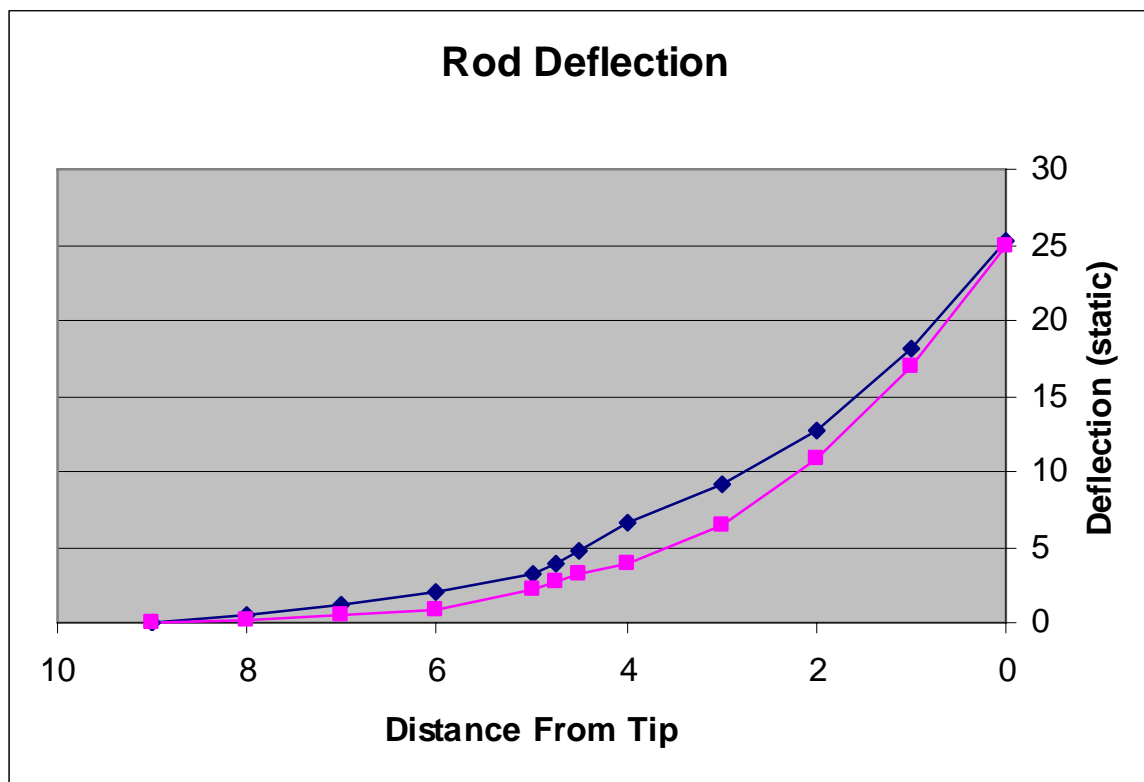


Figure VII. Rod Deflection (model in blue)

The comparison of the rod model with the actual rod can be seen In Figure VII. Where the model is shown in blue and the deflection of the actual rod is seen in magenta. The reason to convert to a mathematical model is that things like wall thickness, material modulus, and taper can be readily changed without trying to find an actual rod and cutting it up. The simulation, although not nearly as good as a finite element model, will suffice in accuracy for what this article is attempting.

Material Modulus

So for starts, let's start off by changing the material modulus only on a rod and see what happens. If we reduce the modulus by 23% the curve looks like Figure VIII. The rod

in blue in this case has the lower material modulus. It is easily seen that the major change in stiffness would be evidenced by a lower ERN. In fact, the ERN is 26% lower because of nonlinearities in the deflection curve. Now looking at Figure V. again, the rod loaded point would not change because it is derived from the energy required to deliver the flyline. If the fly line was the same and mass distribution was the same, the curve from rod loading to rod stop would have to be the same. So what changes?

If we look at the portion of the curve to the right of the loaded rod position and plot both rods, the curves would have to look like Figure IX. Below.

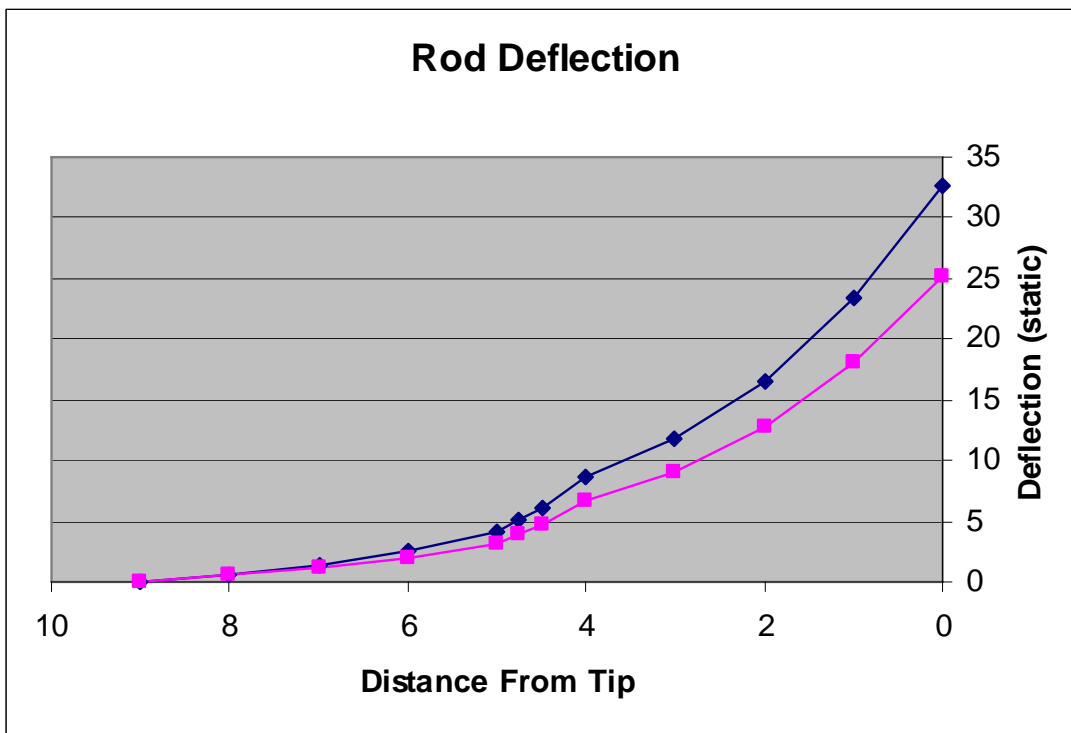


Figure VIII. 23% Material Modulus Reduction

The logic behind this plot is that if the deflection of the rod will be greater to deliver the same cast, the length of the stroke in the beginning of the cast must increase proportionally to provide that load. The beginning of the cast in Figure IX is shown in red for the lower modulus (and lower ERN) rod. Although the handle metrics will not change during the dynamic part of the cast, the timing and length of loading movement will definitely be “felt” by the caster. The rod will feel “softer” by the caster and he may be tempted to call it a “slower” rod. Note that ERN does not care what mix of material modulus, section modulus, or taper the rod has. Whether the rod is a wooden dowel or a metal rod doesn’t matter so long as the total load at the

required deflection is met. So if a caster defines a rod as slow or stiff or whatever judged by how it loads the line in this quasi-static position, he (or she) is really “feeling” the ERN and that is the only number they need be concerned with. But we all know this is not all that is going on. Then why else do we concern ourselves with high modulus materials and fancy rod tapers?

To examine this, let’s build a different rod with the model that has the same ERN and material modulus, but has a different taper and section modulus in each segment. This rod should “load pretty much the same as the original except that the mass distribution will vary significantly. Now for Figure X.

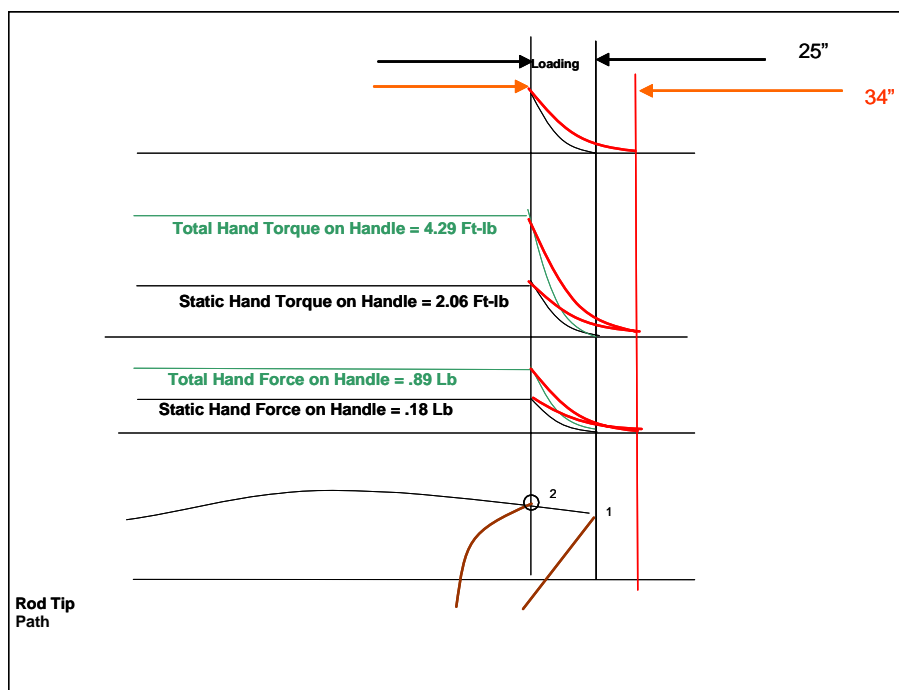


Figure IX. 23% Material Modulus Reduction Rod Loading

Rod Dynamics

If we accept the premise that rods of equal ERN will load similarly and build a new rod with equal ERN but markedly different taper (some might define as full flex vs tip flex), we can run the same handle metrics analysis as we did on the original test. The taper

compositions below yield the rods shown in Figure X. Now it is important to note that these tapers are radically different. They are so to prove a point. The point being that rods with the same material modulus and ERN can feel significantly different in the dynamic part of the curve.

Position		Rod A			Rod B		
Start	End	OD (in)	ID (in)	Mass (g)	OD (in)	ID (in)	Mass (g)
8	9	0.401	0.321	9.78970312	0.31	0.23	7.321938624
7	8	0.361	0.281	8.70497148	0.28	0.2	6.508389888
6	7	0.318	0.238	7.53888495	0.26	0.18	5.966024064
5	6	0.275	0.195	6.37279843	0.25	0.17	5.694841152
4.75	5	0.305	0.227	1.75828221	0.3	0.22	1.762688928
4.5	4.75	0.289	0.217	1.54370873	0.27	0.2	1.394049657
4	4.5	0.238	0.186	1.86845026	0.25	0.15	3.3897864
3	4	0.206	0.147	3.52995407	0.21	0.11	5.42365824
2	3	0.169	0.107	2.90030124	0.18	0.08	4.40672232
1	2	0.138	0.082	2.08810842	0.15	0.05	3.3897864
0	1	0.106	0.057	1.3537112	0.12	0.02	2.37285048
	Tip	0.073	0.013	0.05	0.073	0.013	0.05

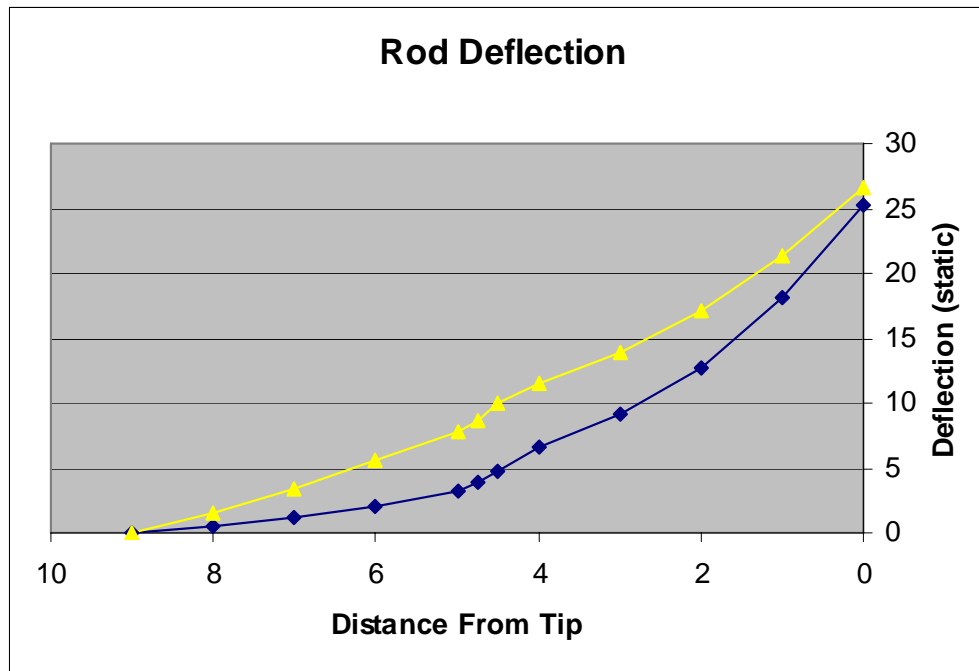


Figure X. Rod Taper Comparison (new rod (B) in yellow)

Shown in Figure XI. in red is a comparison of our previous subject rod (in green) and the new taper (in red). During the dynamic part of the cast the handle metrics are heavily influenced by the section modulus and taper. This comes about primarily (as advanced by the work of Magnus Argus) because of mass and more specifically, the mass distribution of the rod. Most important is the mass of the upper section of the rod. So anything that influences this mass distribution will contribute heavily to the dynamic “feel” of the rod. So high modulus highly tapered rods are going to “feel” faster in this part of the cast.

Static vs Dynamic

So where do we go from here. If we assume that ERN of ERN time rod length is going to give a good indication of the static part of the cast, what then for the dynamic part? We really can't go around cutting up and weighing sections of all the rods in the data base. And even if we did the data would mean little in such a cumbersome data base. What then about action angle (AA) that is already in the data base? It does give a picture of rod taper. But is it all inclusive? If a rod was built to such dimensions out of a high modulus and another of a lower modulus that yielded the same action angle and ERN, are they the same? Or is it even possible to build such a rod?

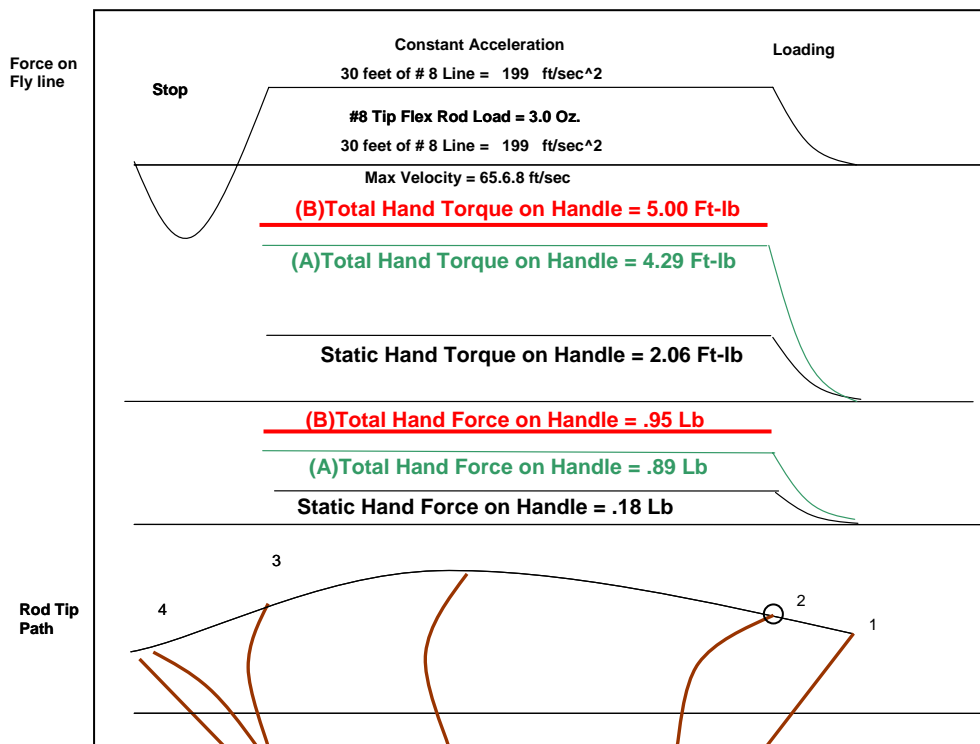


Figure XI. Rod Taper Comparison (new rod (B) in yellow)

If we take the Sexyloops data base and plot ERN vs AA it would look like Figure XII. below. The chart doesn't seem to show a lot of correlation but maybe there isn't any. It also doesn't appear to be very usable. But maybe there is another characteristic that shows a better story. I might suggest, as others have, that the dynamic part of the curve could be represented by rod fundamental frequency. The formula for fundamental frequency of a simple beam is proportional to the square root of the section modulus times the material modulus divided by the mass per unit length times the length to the fourth power. All the right stuff is in there and with increases in both the section and material modulus serving to increase frequency and length and weight lowering it.

mass serving to lower it. It should be a good indicator of all that is dynamic should track construction related to mass and mass distribution fairly well. I would suggest that rod frequency data be added to the data base so we can plot ERN vs natural frequency. The plot would look like Figure XIII.

That's about as far as I can take this analysis for now but when more frequency data is available I will continue.

There is another area that needs to be examined in the next article. This is the mechanical analysis of the rod behavior after rod stop and through RSP and counterflex. This is important because long distance casting uses counterflex in loop formation

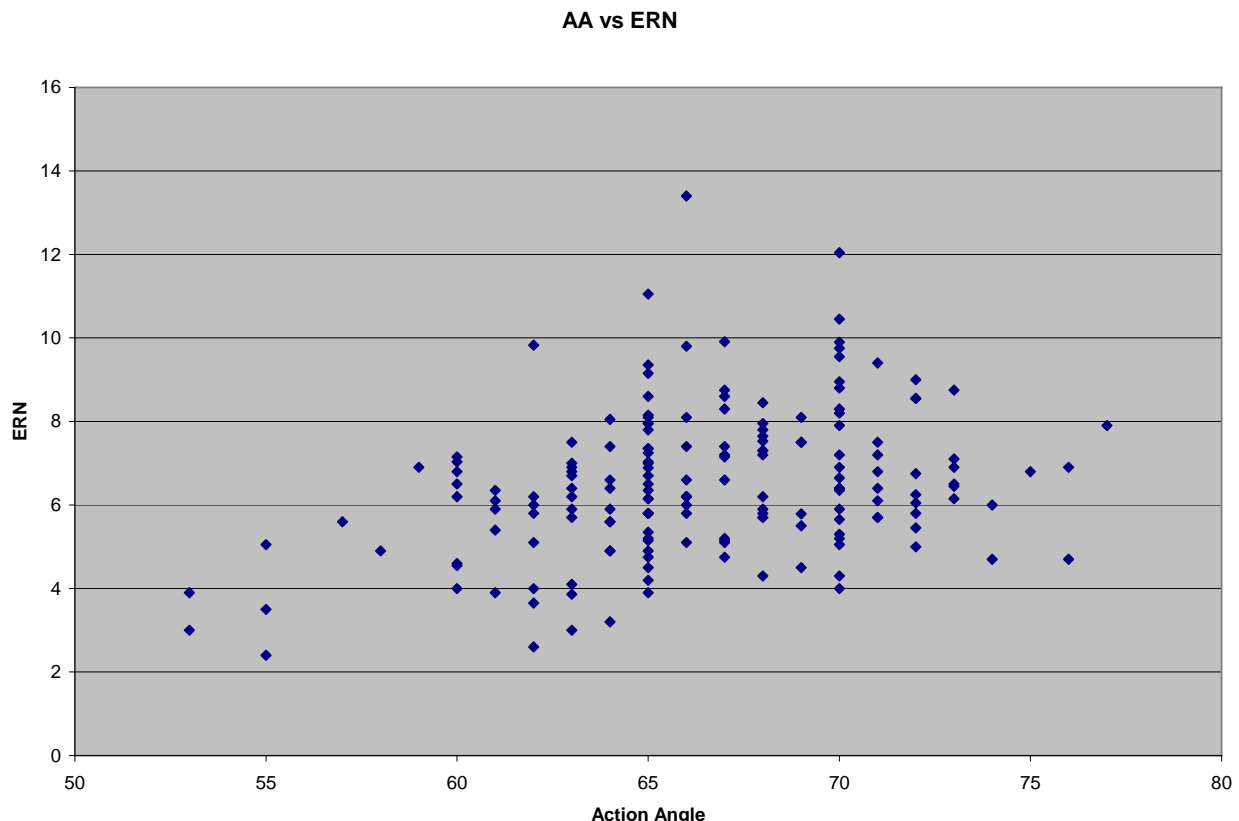


Figure XII. Action Angle vs ERN

Summary

Fly rod “feel” can be mathematically broken down to two different responses that a caster senses at the handle of the fly rod. The first is a quasi static phenomenon that is perceived during the loading part of the cast when the fly line is at near zero velocity at the end of the back cast and the rod is flexed against it in preparation for the forward cast. The loading is a function of the rod taper, material modulus, length, and section modulus combined in most any fashion and can be well represented by the rod ERN value calculated from the CCS system (or some other static technique).

The second characteristic is a dynamic quantity which is heavily dependant on rod

mass distribution (thanks again Magnus) which is, in turn, influenced by the rod taper, material modulus, length, and section modulus, but is very sensitive to how these properties are combined. At present, only two methods address this short of cutting up the rod into sections and calculating the loading on the casters hand from a free body diagram. These are AA from CCS or fundamental natural frequency taken from physical non-destructive measurements on individual rods. It is unclear at this juncture, how all this will pan out and further analysis will be necessary when more data is available.

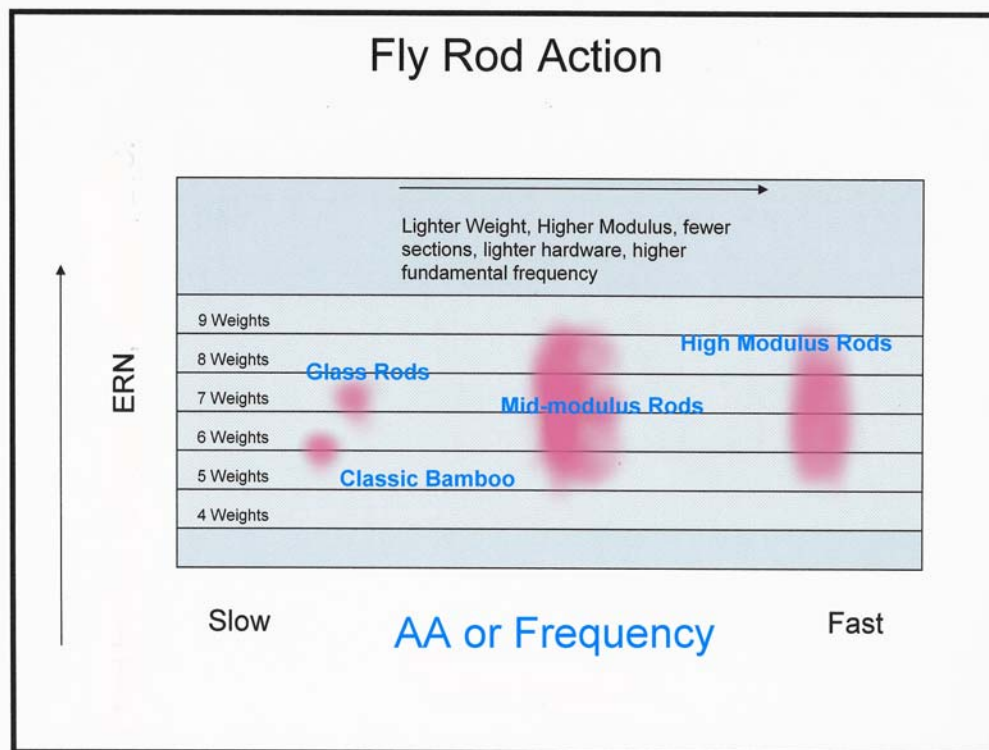
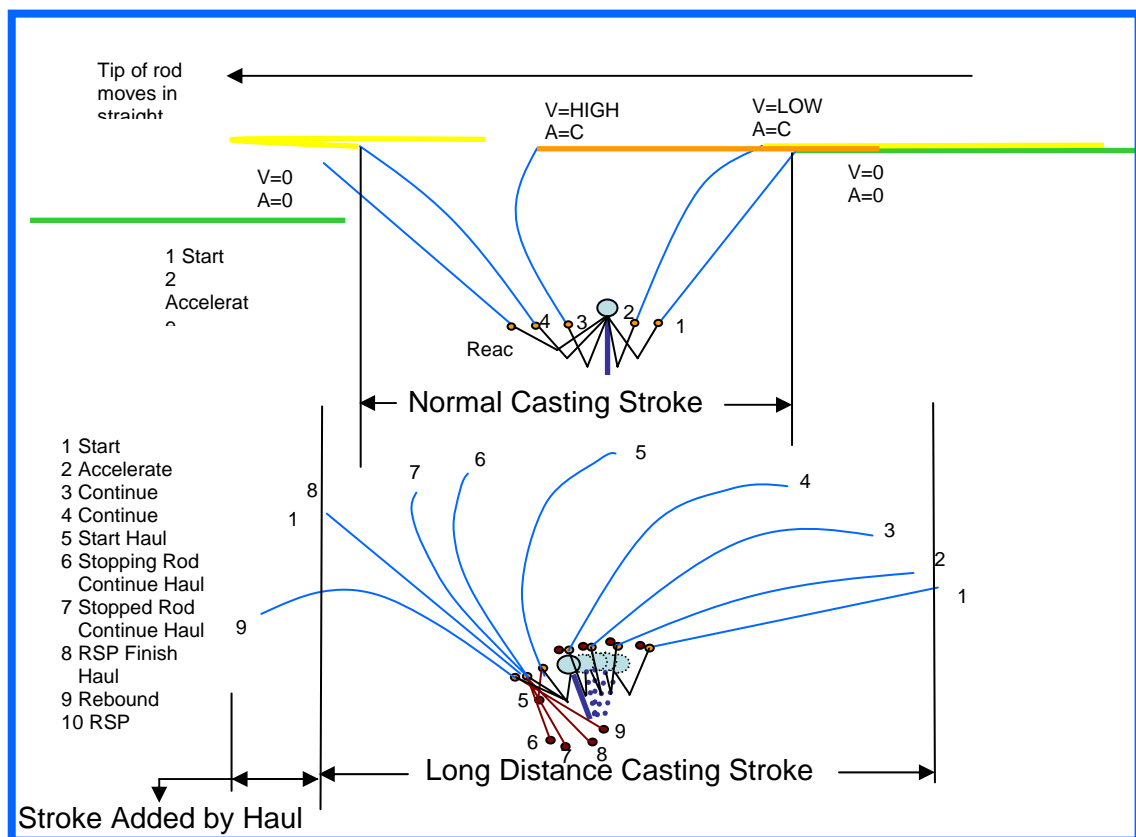


Figure XIII. Suggested Rod Characteristics Plot

A Caveat

Below is a quick explanation of why I choose to treat long distance casting as a separate issue. All of the previous articles are associated with the simple casting stroke shown in the first figure. The second figure shows a representation of the long distance stroke with differences in the back cast and front cast shown. The entire casting stroke depends on a

very significant rod deflection to maintain a straight line path. The finish depends on a significant counter flex in the rod to help with loop formation. There is also energy associated with the haul. None of these issues were addressed here and are of significant importance. I plan on talking about these more in future articles and when I learn enough about them to not sound like an idiot.



*Bob Bolton is a retired mechanical engineer. He spent 35 years designing engines for a major automobile manufacturer and now writes technical design manuals on consignment to his own consulting company. In his spare time he hunts birds, fly fishes fresh and salt water, and works on finding fishing sites for handicapped anglers (www.HATofMichigan.org). He has written one book, *You Can't Make a Living Tying Flies*, in which writes of fishing and hunting in Michigan.*