By Tobias Hinzmann
With friendly support of Dr. Franz-Josef Schmitt

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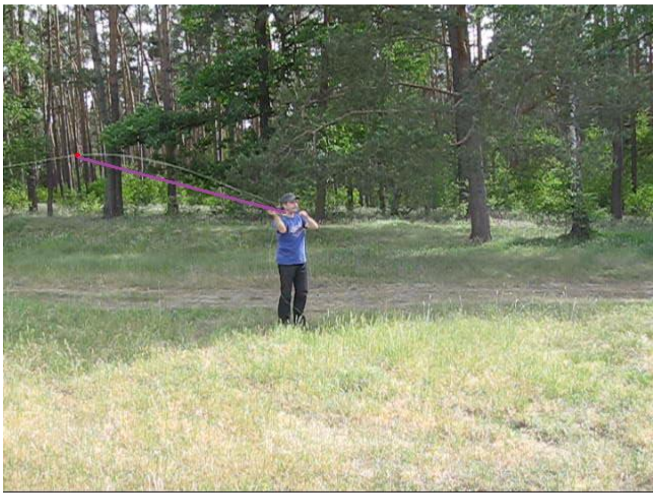
When the “whip” joins the “pirouette”

Since the publication of my investigations[1] a longer time has passed and meanwhile there have been some discussions (especially on the sexyloops.com forum) about the concept Franz- Josef and I have choosen to clarify the redistribution of angular momentum (we call it “redistribution effect”). The preface Franz- Josef wrote for my investigations expresses the concept well how we both tried to clarify the physical relations and we are more convinced than ever that this concept enables much more people to follow the content than too theoretical approaches using differential equations[2].

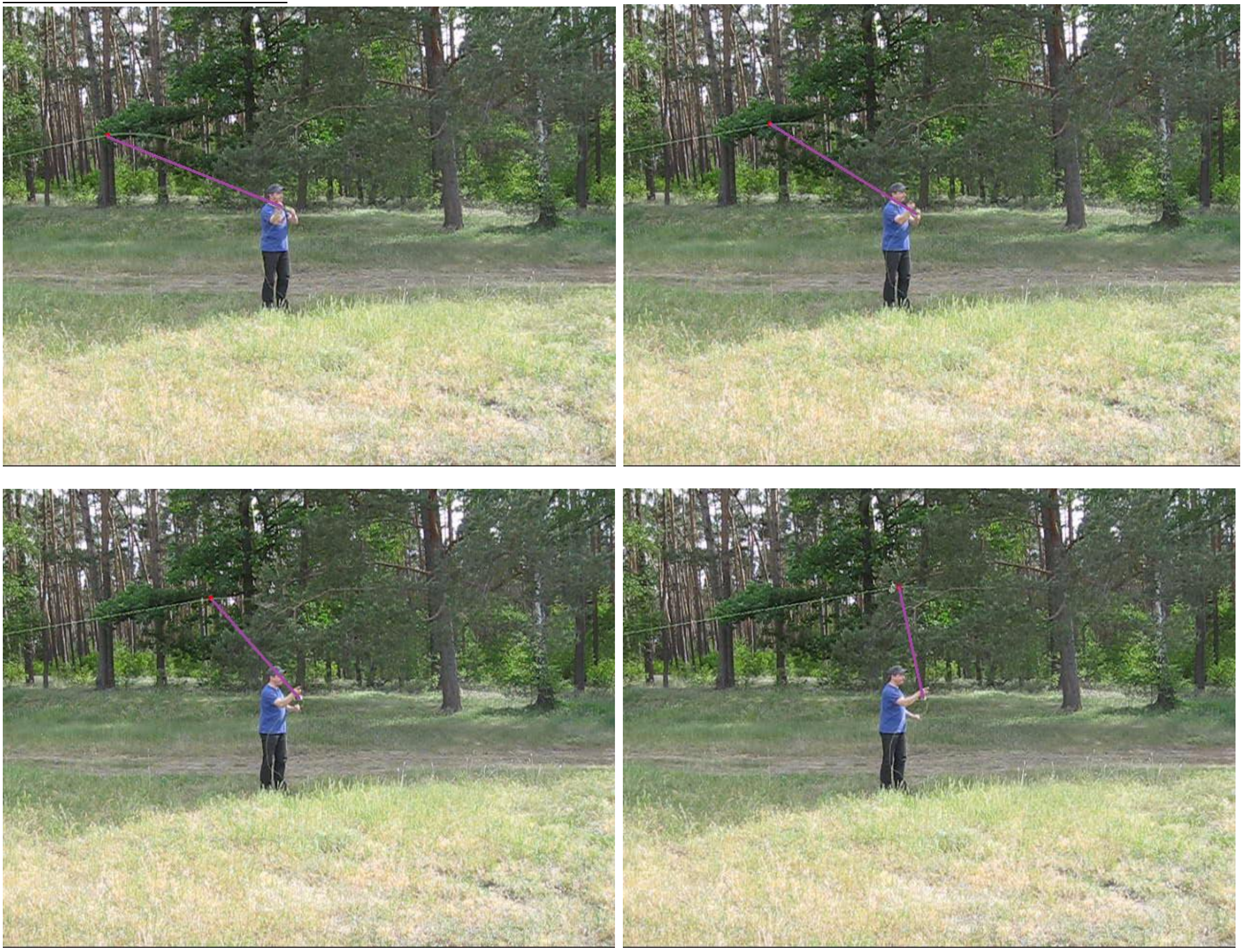
In section F1 as well as in annex 2 and 3 of my investigations Franz- Josef and I are mainly talking about the “pirouette” and the “whip” effect in order to explain the redistribution of angular momentum. This essay is going to look with fresh eyes on the interrelation between the “pirouette” and the “whip” effect and how both effects redistribute of angular momentum.

The “pirouette” effect

The pirouette effect is visualized by the shortening and the elongation of the chord between the tip and the grip of the fly rod (see violet chord on the following pictures).



[1] In this paper I just use the term “investigations” to refer to my “Experimental investigations on the fly rod deflection”, revision 2.0, published in November 2014.
[2] From the preface Franz- Josef wrote for my “Experimental investigations on the fly rod deflection” (11/2014) I quote: *“[…] An open communication of the physical studies is often lacking – because it seems to be “too complicated”. Myself and Tobias believe that this must not necessarily be the case. It is moreover a question of communication to describe the physical properties of a system in an understandable way. The attribution of dynamic parameters to experimental data, an understandable description of each performed step, clear graphical representations of the trajectories and finally a mathematical approach to an estimation of the experimental data with mathematic expressions that are known from school instead of a complicated differential and integral calculus can do it.[…] In such way we believe that the study presented here might be more precious from a socio-scientific point of view than exact calculations based on theoretical physics that often cannot even be described by the theoretical physicist itself who often refers to the calculation process like a black box when asked what the result really means.[…]”*



The 6 pictures above are showing the shortening of the chord between the tip and the grip of the fly rod which leads to an additional tip speed due to the "pirouette" effect.

This effect can be observed by watching a figure skater who runs a pirouette. By attracting his arms he modifies (reduces) the moment of inertia of his body, which consequently leads to an additional rotation speed as the angular momentum redistributes.

<u>In annex 2 of my investigations I estimated, that the shortening of the chord reduces the moment of inertia of the fly rod by about 20%. This clearly indicates that for the deflected fly rod something similar to the pirouette must happen.</u>

On the following 2 pictures the chord elongates again whereby the butt section, the lower mass elements respectively of the fly rod starts to decelerate. This self deceleration process is similar to the figure skater who is finishing the pirouette by straightening his arms. Thereby he modifies (enlarges) the moment of inertia again causing the angular momentum to redistribute as well.

This self deceleration process is already explained in the work "Physics of fly casting" by Dr. Server Sadik from 2009 for example.

The 2 pictures above are showing the elongation of the chord between the tip and the grip of the fly rod which leads to the described self deceleration process of the fly rod (finishing the "pirouette").

The whip effect

The whip effect is an additional component which appears independently of the pirouette effect. It is coupled to the variation of the angular velocities that the lower and upper mass elements of the fly rod are passing through during the entire casting stroke.

The 2 pictures above are showing the distribution of both the angular velocity and the angular momentum as they depend on each other. The size of the arrows visualizes the amount in a simplified form. During the earlier phase of the fly cast the angular velocity is significant higher distributed along the lower mass elements of the fly rod than along the upper ones (watch the biggest arrow). During the later phase of the fly cast it is the other way round. This upward shifting distribution of the angular velocity towards the tip takes up some angular momentum too, which leads to a concentration of energy into the tip of the fly rod as described in section F1 and annex 2 of my investigations. There are other pictures visualizing this effect better, e.g. my paper "Angular velocities of the mass elements on the fly rod shaft (06/2017)" as well as some videos I will refer to later. Because I like to keep the pictures of this paper uniform, I decided to use only the same pictures as I did in my investigations.

During the earlier phase of the fly cast the angular velocity of the flexible fly rod is significant higher distributed along the lower mass elements than along the upper ones (visualized by the bigger arrow on the 1st picture above). <u>This distribution of the angular velocity leads to an angular momentum, which is stronger distributed along the lower mass elements in</u>

comparison to a rigid fly rod. Since this strong along the lower mass elements distributed angular momentum just can't disappear due to the energy conservation theorem, it must be transferred towards the smaller upper mass elements during the later phase of the fly cast (energy transfer from the butt towards the tip of the fly rod). This energy transfer is indicated by the higher angular velocity of the upper mass elements during the later phase of the fly cast (visualized by the bigger arrow on the 2nd picture above)[3].

Looking on the shape of the deflection the idea arose, that the redistribution of angular momentum caused by the whip effect is coupled somehow on the course of the biggest deflection, which moves up towards the tip like a "wave" taking up some angular momentum, kinetic energy respectively. This was the birth of the "wave" concept in order to show this energy transfer along the fly rod shaft.

First Franz- Josef and I inserted a dot into the biggest deflection in order to make the upward moving "wave" visible (see figure XIII of my investigations). A little later we thought that a circle which is adapted into the curvation of the deflection is a good visualization too. In fact the deflection forms a circular wave which rotates towards the tip during its size decreases and finally accelerates smaller mass elements to high velocities like happening in the tip of a whip.

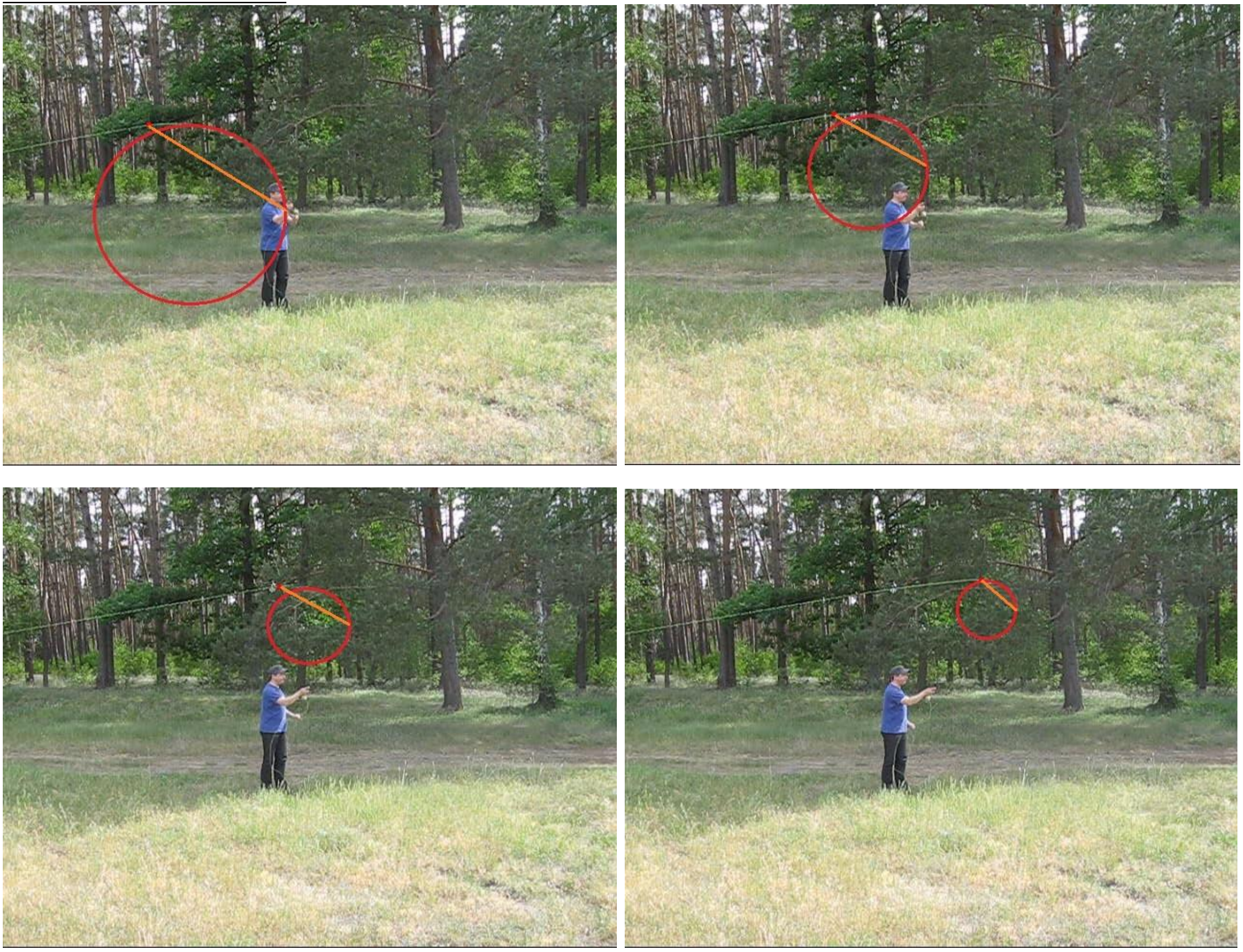
By adapting a circle into the curvation of the deflection this circular wave could be detected well. Thanks to this visualization it becomes obvious, that all mass elements of the fly rod, which touches the adapted circle, are contributing to the rotary motion and therefore to the angular momentum most[4]. The more the adapted circle visualizing the circular wave moves upward, the more the upper mass elements and the less the lower ones contribute[5]. Nothing else is described by the upward moving "center of the rotating mass" in section F1 of my investigations. This upward moving circular wave or "center of the rotating mass" is shortening the radius between the mass elements and the center they rotate around due to their contribution to the rotary motion and therefore to the angular momentum. Hence the redistribution of angular momentum due to the whip effect could also be clarified by an additional / further shortening of the radius or chord between the tip and the "center of the rotating mass", which is rawly estimated at the biggest deflection of the fly rod (see the orange chord / radius on the following pictures)[6].

[3] See the video "Varying angular velocities of the mass elements on the fly rod shaft" for example (http://vimeo.com/226547073). Vince Brandon explains this effect accurately with his own words (on Facebook - 02/2019): "Initially, the whole rod moves and as shown in the picture sequence [of Tobias] you can see that as time elapses the initial momentum is concentrated on a smaller and smaller section of the rod, whilst the rest of the rod is nearly static. By momentum conservation, the reduced moving mass will accelerate just like a whip."

[4] The angular momentum is a energetic description of the rotary motion. See also my paper "Why the center of the rotating mass of a flexible fly rod cold escape the rotation point at the grip" from 11/2015.

[5] The circular wave visualizes the whip effect and will appear from around the vertical position of the grip as it depends on a stronger amount of dynamic. Since during the beginning of the fly cast the whip effect is absent due to a weaker amount of dynamic, it doesn't make sense to adapt a circle earlier. Hence the fact that the course of the biggest deflection could move downwards from the tip to the grip during the beginning of the fly cast doesn't contradict the concept of visualization at all as this course mainly shows the increasing of both the load and the pirouette effect, which could be visualized by other depictions much better.

[6] The video „Center of the rotating mass in fly casting" (http://vimeo.com/148550108) gives further informations about this phenomenon. Also this video from 2014 already tried to visualize the whip effect starting from 1 min 10 sec up to the end http://www.youtube.com/watch?v=2JHo86zDbEE. Since the flexible fly rod has intrinsic "inner" degrees of freedom it is not possible to assign all rotating mass elements to only one conjointly center (see also annex 2 of my investigations, page 53).



The 4 pictures above are showing the circle which is adapted into the curvation of the deflected fly rod as well as the additional / further shortening of the chord (radius) between the tip of the fly rod and the "center of the rotating mass", which is rawly estimated at the biggest deflection of the fly rod. Thanks to this visualization it becomes obvious, that all mass elements of the fly rod, which touches the adapted circle, are contributing to the rotary motion and therefore to the angular momentum most. This upward moving "circle" visualizes, that the contribution of the mass elements regarding the rotary motion, angular momentum respectively is clearly shifting upwards.

By the way, even it is very difficult it should be possible to determine the "center of the rotating mass" indeed[7].

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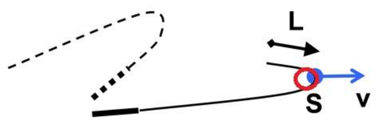
[7] From the exchange of ideas Franz- Josef and I have had with the chair of mechanics of the Technical University of Berlin around the year 2015 we were told that for a higher deflected fly rod the "center of the rotating mass" could really be determined by setting up and solve coupled differential equations. But as this level of difficulty goes beyond that of a master thesis, unfortunately this approach was not followed up. Incidentally, for the whip it is not questioned that a "center of the rotating mass" exists as it is too obvious (see the following picture of a lashed whip). Since the towards the tip shifting red circle can be adapted into both the vertex 'S' of the whip as well as the curvation of a higher deflected fly rod, a "center of the rotating mass" must be able to develop for the fly rod too.



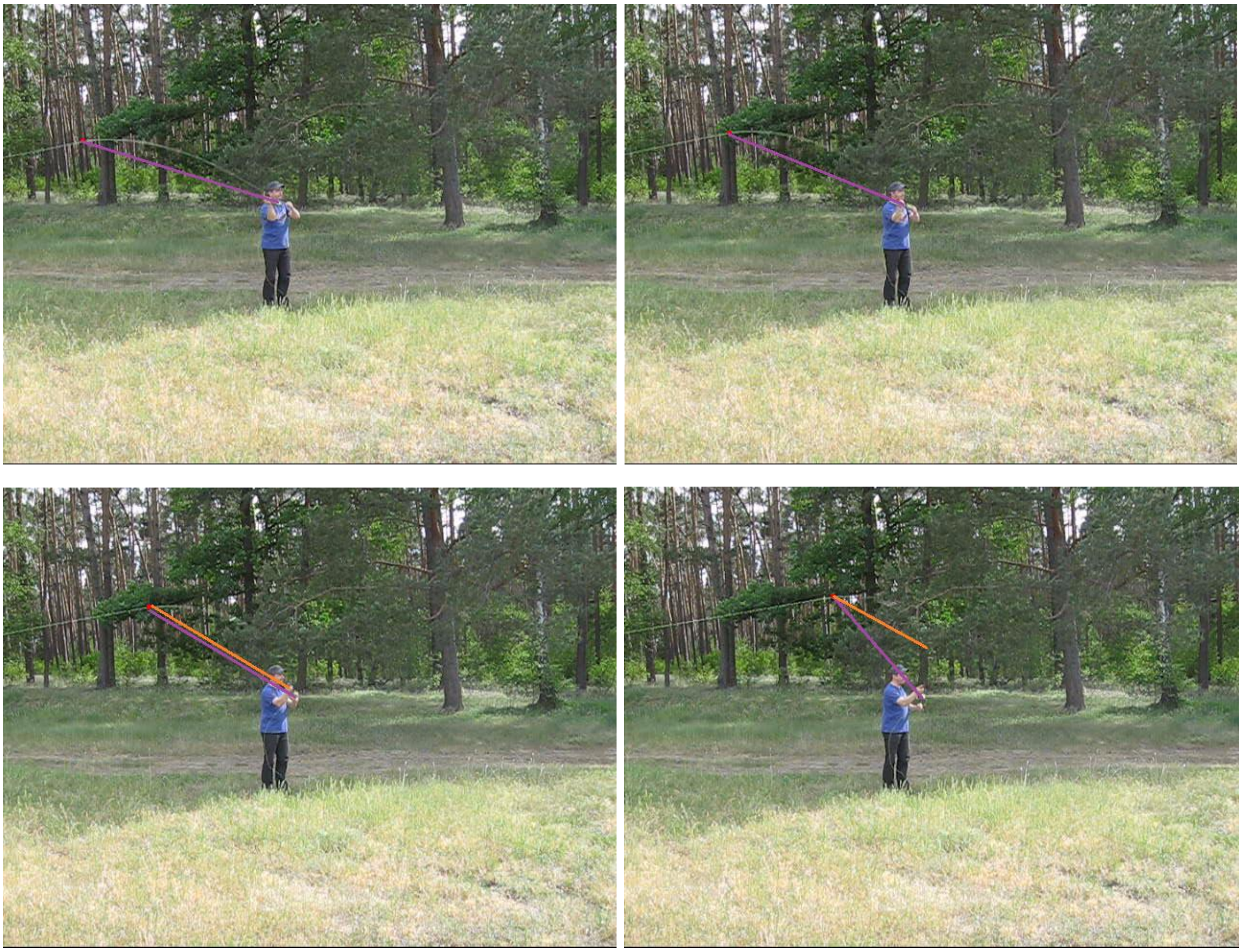
$E \sim m \cdot v^2 = const$
$L \sim m \rightarrow 0$
$v \rightarrow \infty$

Picture was taken out of http://de.wikipedia.org/wiki/peitsche

Both the adapted circle and the additional / further shortening of the chord (radius) should be suitable to clarify the whip effect. In the following the whip effect is visualized by the orange chord only.

The whip joins the pirouette

Looking on all previous pictures above showing both the pirouette and the whip effect it turns out, that the pirouette effect (violet chord) appears first and the whip effect (orange chord) joins around the vertical position of the grip. Once the whip effect has joined, both effects are “working together” concentrating some kinetic energy towards the tip of the fly rod. This is indicated by the ongoing shortening of both chords (the violet as well as the orange one). Watching the further course of the chords both effects tend to split up somehow as soon as the retraction of the fly rod starts, since the violet chord representing the pirouette effect elongates meanwhile the orange chord representing the whip effect shortens further.




On the first 2 pictures above the pirouette effect is supposed to work alone (see the violet chord). Starting from the 3rd picture the curvation of the deflection is developed enough for the whip effect to be able to join (see the orange chord). The last picture visualizes, that meanwhile the pirouette effect decelerates the butt section of the fly rod due to the elongating violet chord, the whip effect still concentrates ("pumps") some angular momentum, kinetic energy (KE) respectively into the tip due to the ongoing shortening of the orange chord.

This indicates that meanwhile the whip effect still concentrates some angular momentum, kinetic energy (KE) respectively into the tip (visualized by the ongoing shortening of the orange chord), the pirouette effect starts to decelerate the butt section of the fly rod (visualized by the elongation of the violet chord – see the last picture of the pictures above).

Since the size of the circle is limited due to the material properties of the fly rod the circular wave doesn't move completely into the tip (as well as the orange chord) but disappears at the end of the cast and a more or less little rest of the tip section turns over creating the counterflex[8].

The concept of visualization seen with fresh eyes

In my investigations Franz- Josef and I tried to face both the "pirouette" and the "whip" effect by talking about the "redistribution of angular momentum" (also "conservation" of angular momentum since the energy conservation theorem must be applied on both effects too). In fact both effects redistribute the angular momentum, but as pointed out before the way they act is a bit different.

Figure XIII of my investigations is visualizing the "redistribution of angular momentum". Based on the previous pictures we would draw this figure from 2014 a bit differently today in order to point out the pirouette and the whip effect more clearly. In the following I copied the figure XIII of my investigations again and I identify the elements on this figure, which visualizes rather the pirouette or rather the whip effect. The same colors as before are choosen in order to identify both effects better.

[8] In contrast to a whip the circular wave along the fly rod shaft can't shift completely into the tip of the fly rod as explained in annex 3 of my investigations. Since the counterflex wastes energy, the caster should try to keep the overturning tip section as small as possible.

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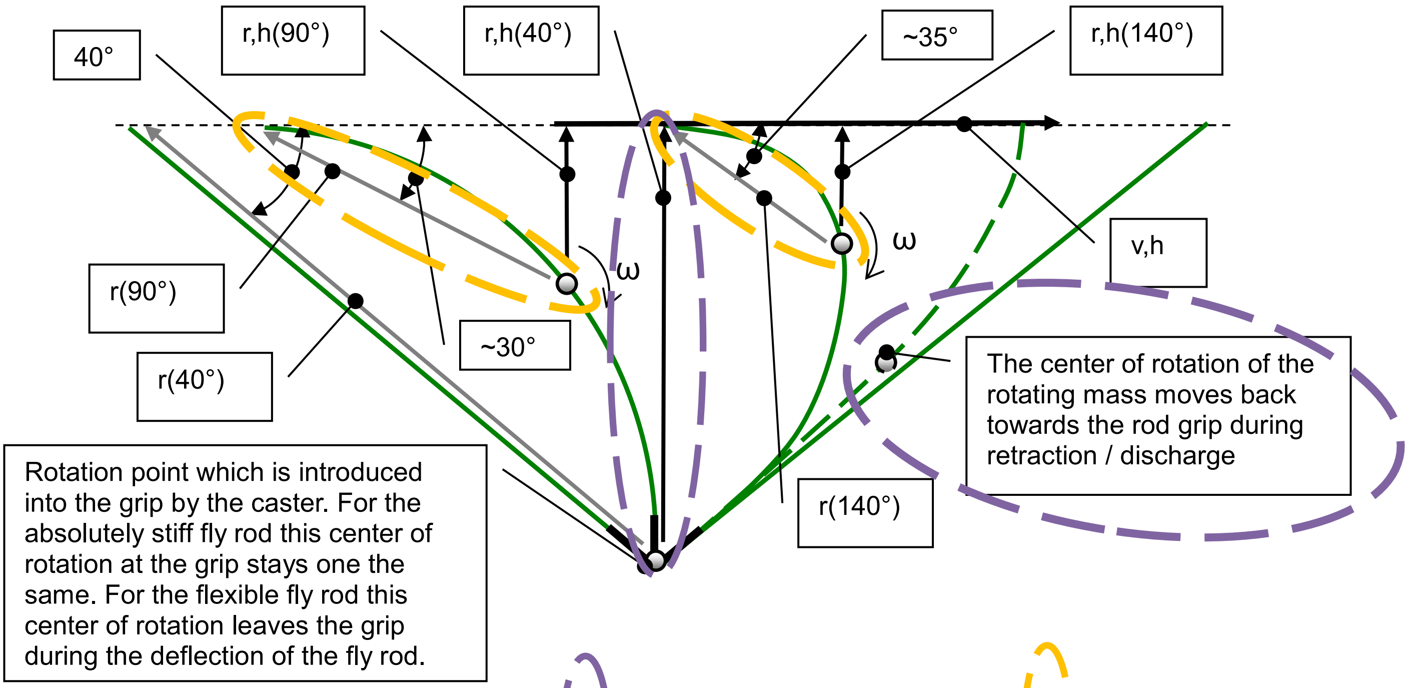
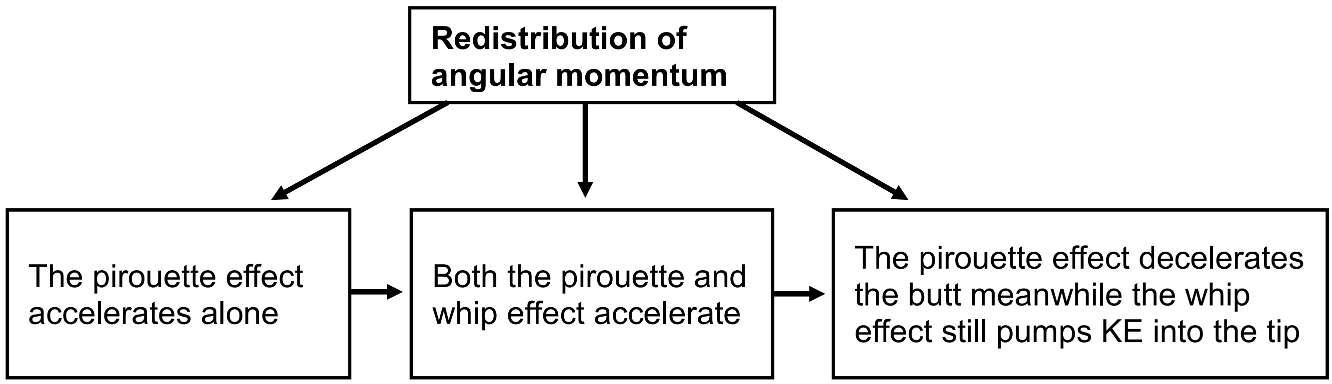


<u>Figure XIII</u>
from the "Experimental investigations on the fly rod deflection" (rev. 2.0 - 11/2014)



As this paper is about the redistribution of angular momentum, the scheme above doesn't consider the spring effect, which acts additional.

Due to the complexity of the fly cast all my explanations could only be an approximation and are furthermore showing a tendency. However, I would enjoy if my investigations could be a kind of a "door" into the complex world of the fly cast.

Potsdam, in February 2019

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