David Alciatore, PhD ("Dr. Dave") **ILLUSTRATED PRINCIPLES**

"Return of the Squirt Robot"

***Note**: Supporting narrated video (NV) demonstrations, high-speed video (HSV) clips, technical proofs (TP), and all of my past articles, can be accessed and viewed online at **billiards.colostate.edu**. The reference numbers used in the article help you locate the resources on the website. If you have a slow or inconvenient Internet connection, you might want to view the resources from a CD-ROM or DVD. See the website for details.*

This is a follow-up to my February '08 article, where I presented experimental results from a squirt-testing robot some mechanical engineering students and I designed and built last year at Colorado State University. In my February article, I showed results for how squirt is relatively constant for all speeds, how a laminated shaft can be very radially consistent at different cue twist angles (i.e., the squirt is relatively constant for all laminate orientations), and how squirt varies when mass is added at different distances from the tip. In this article, I present results of some additional tests we did recently for hard and soft tips and stiffness variations.

My August '06 through April '08 articles cover squirt, swerve, and throw in detail, but here's a quick review: **squirt**, also called cue ball (CB) **deflection**, refers to the angular change in the initial CB direction due to an off-center hit. In other words, when you use English, the CB doesn't go where you are aiming because of squirt (see **NV 4.13** and **NV A.17**). When using English, it is also important to be aware of the effects of **swerve** (see **NV 4.14** and **NV 7.12**) and **throw** (see **NV 4.15**, **NV 4.16**, **NV A.21**). Sometimes, the phrase "**effective squirt**" or the term "**squerve**" is used to refer to the net effect of both squirt and swerve on the shift in the CB position at object ball (OB) impact (see my August '07 article for more information). A concise summary of all important squirt, swerve, and throw effects can be found in the FAQ section of my website under "aiming" (see "aim compensation for squirt, swerve, and throw").

As described in my February '08 article, our squirt robot was designed to measure only squirt. In other words, swerve and throw, which vary with speed and ball and cloth conditions, have no effect on our results. When playing pool, swerve and throw do come into play because the cue is always elevated some to provide clearance, either for your grip hand or over the rails (see my March '08 article for more info). If you want to refer back to any of my past articles, they are all available on my website (***billiards.colostate.edu***).


normal video

NV 4.13 – Squirt due to high speed English
NV 4.14 – English curve due to an elevated cue
NV 4.15 – Using throw to make a partially blocked shot
NV 4.16 – Over-cutting a cut shot to compensate for throw
NV 7.12 – Small-curve massé shot
NV A.17 – Effective squirt vs. speed
NV A.21 – Bank shot using throw and spin transfer

Diagram 1 shows the results of a classic experiment to show how end-mass affects a cue's squirt. In the experiment, a mass is added to the cue at different positions. When the added mass is close to the tip, the effect on the squirt is the largest; and when the added mass is more than a certain distance from the tip, the added mass has no effect on the amount of squirt. Diagram 1 shows the results for two identical Action cues, one with a soft tip and one with a hard tip. The tests were done with two different added masses: 8 grams (0.28 ounces) and 34 grams (1.23 ounces). The four curves show the following trends:

1. More added mass creates more squirt.

2. The closer the added mass is to the tip, the more squirt you get.

3. When mass is added beyond 6-8 inches, it has no effect on squirt. The curves don't show data beyond 8 inches, but we did test this.

4. A soft tip seems to create slightly more squirt than a hard tip.

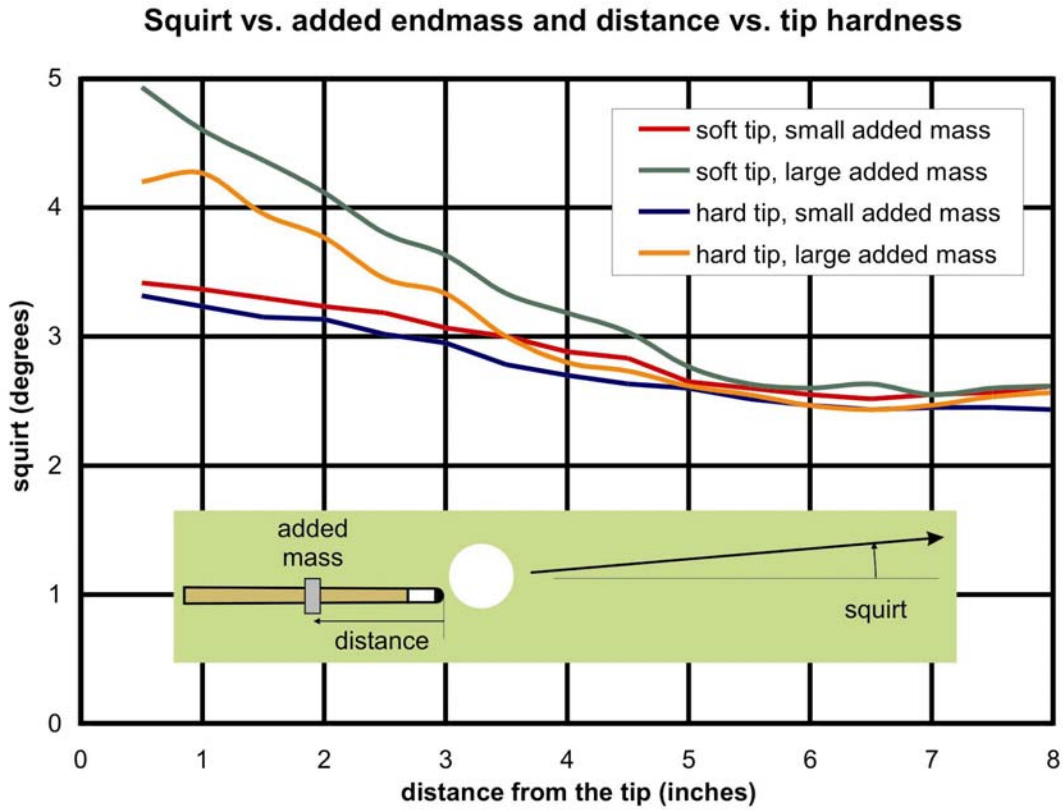

Diagram 1 Squirt vs. added endmass amount and distance for soft and hard tips

Items 1 through 3 above are the same results seen in previous experiments reported in my February '08 article. Item 4 is the new result here. It makes sense because a soft tip has a slightly longer contact time than a hard tip (we used a high-speed camera to measure contact times of a little more than 2/3000 of a second for the soft tip and a little less than 2/3000 of a second for the hard tip). A slightly longer contact time results in slightly more effective endmass (see **TP A.31** for more info). This results in slightly more squirt, which also results in slightly less English for the same tip offset (see Diagram 3 in my December '07 article). If you are curious, you can read a lot more about tip hardness and its effects from me and others under "cue tip" in the FAQ section of my website. I should mention one more thing about item 4. I included the phrase "seems to" because I didn't use the exact same shaft for each set of tests. The two shafts (one with the hard tip and one with the soft tip) were the same model and from the same batch, but there could be differences. A better test would be to replace the soft tip on one shaft with an identical weight hard tip and repeat the same tests with the exact same shaft ... maybe next time. For example, it is possible (but not likely, IMO) the difference between the soft and hard tip results above are just due to tip weight or shaft density differences. Isn't science hard?

technical proof

TP A.31 – The physics of squirt

The results of the added-mass experiment explain why manufacturers have been able to create “low-squirt” cues by using a smaller diameter shaft, drilling out the end of the shaft, and/or using a lighter ferrule. All of these modifications reduce the end-mass of the cue (see my December ’07 article for more information). If you want to see an exaggerated example of the effect of end-mass on squirt, see **NV B.1**. At the 6:00 point in the video, Mike Page uses a pair of metal vise grips to add significant mass and squirt to a cue. The effect is dramatic ... check it out ... the CB squirts more than two feet over the length of the table! I don’t recommend using vise grips at home, because you might damage your cue, but if you have some clothespins lying around, give them a try (see **NV B.32**). Clothespins won’t add as much mass as a vise grip, but the effect is still quite noticeable ... and your shaft won’t get damaged. Give it a try.

normal video

NV B.1 – Mike Page's squirt and swerve video
NV B.32 – Squirt and the effects of endmass

In my February ’08 article, I presented results for how squirt varied (or didn’t vary) with cue twist angle for a Meucci Black Dot laminated cue. At different twist angles, the wood layers are oriented at different angles relative to the table, and one might expect the shaft to have different properties (e.g., stiffness) at different twist angles (i.e., cue orientations), but the squirt angles were very consistent (i.e., the shaft had good “radial consistency”). The radial consistency might be related to the fact that the wood laminates are glued together. The glue might help make the density and stiffness more uniform throughout the shaft, but I’m not sure.

Diagram 2 shows experimental data for squirt measurements taken for an inexpensive Action cue (the same cue used for the soft-tip tests in Diagram 1). Twist angle refers to how much the shaft is rotated, before the shot, to change the grain orientation (see the end view of the shaft in the diagram figure). One might expect the “end-mass” to vary slightly with cue twist angle due to slight density and stiffness variations due to grain orientation (see **TP A.31**); but, apparently, the effect is not very significant, at least with the cues we tested (e.g., the inexpensive Action cue made from a single piece of wood).

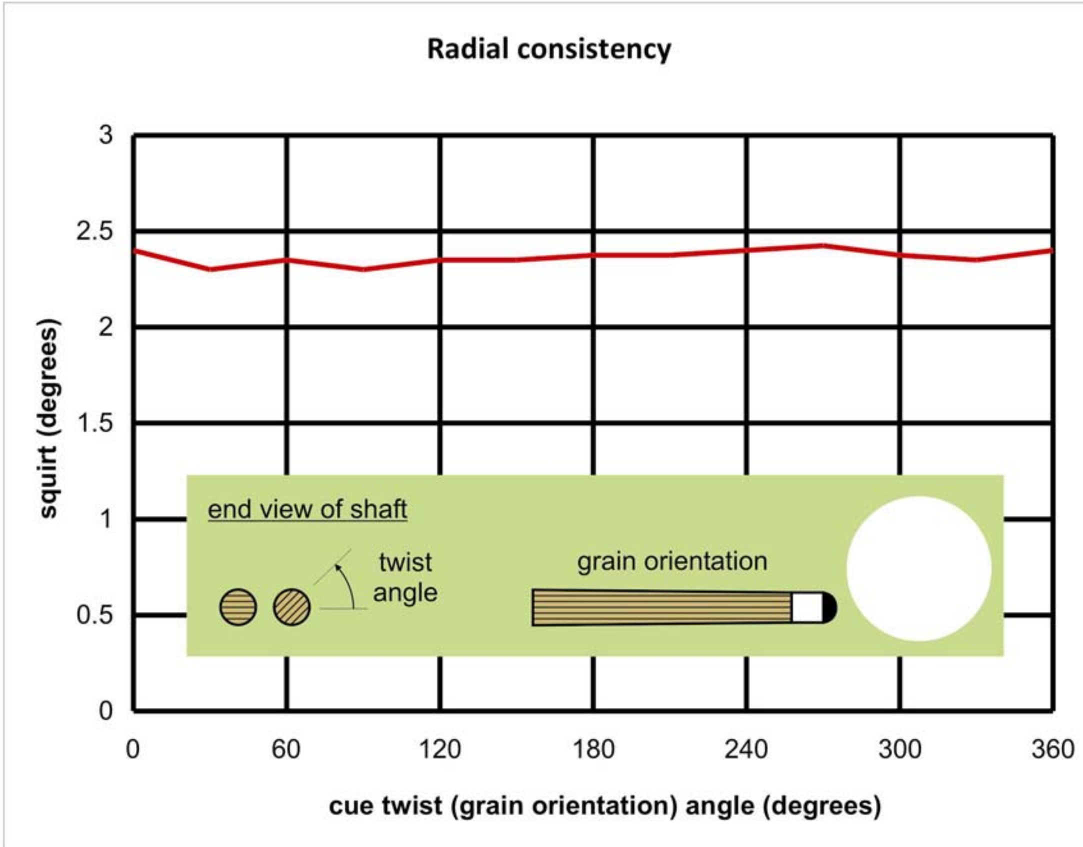

Diagram 2 Radial consistency for an inexpensive Action cue

Diagram 3 shows results for what I call the "Beaver Cue" experiment. We took a Meucci Red-Dot cue (made from a single piece of wood, not laminated like the Black-Dot tested for my February '08 article) and cut away wood from both sides of the shaft, leaving a narrow section of wood, as illustrated in the inset figure in Diagram 3. The goal was to test the effects of shaft-end stiffness on endmass and squirt. One would expect the 0º orientation of the cue, where the narrow section of the cut is vertical, to be the least stiff, and the 90º orientation, where the section is horizontal, to be the most stiff. The data does show radial inconsistency (the squirt is about 20% smaller at 90º and about 20% larger at 180º), but I think many people would have expected to see a much larger variation in squirt with the beaver cue. Squirt does change with cue twist angle for this grossly malformed, asymmetric cue, but it doesn't seem to change much with unmodified cues (for the ones we have tested to date, anyway). This makes sense because the mass of the end of the shaft doesn't change with orientation. However, the effective endmass does depend on the stiffness of the end of the shaft (see TP A.31), and stiffness can vary with cue orientation. Stiffness variation is what I think explains the trend in Diagram 3.

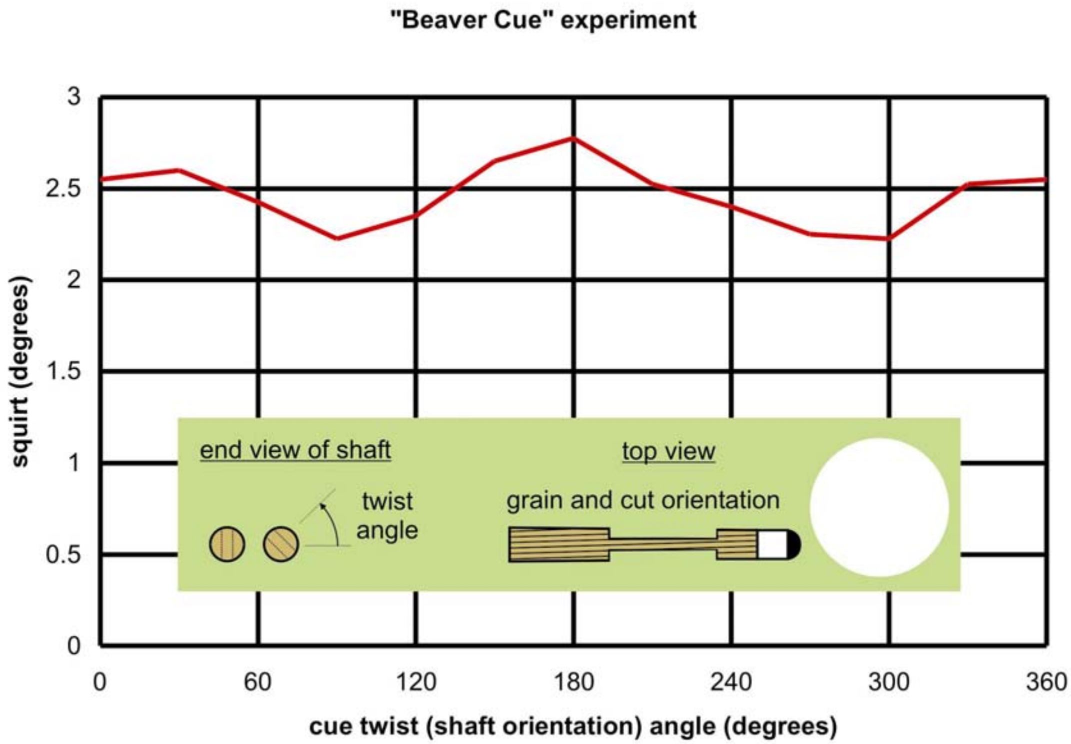

Diagram 3 "Beaver Cue" radial consistency experiment

Before doing the "beaver cue" experiment, I thought the largest squirt would occur at 90º (and 270º), where the narrow section of the cut provides the greatest sideways stiffness, but this wasn't the case. Maybe the wood grain orientation has something to do with it. As illustrated with the grain orientation lines in the Diagram 3 figure, the grain in the shaft we tested had about a 30º twist over the first foot of the shaft. Unfortunately, one thing we failed to do was test the shaft before we made the cuts. I know this sounds ridiculous and incredibly stupid ... I guess our "beavers" were a little too eager. I'll try to repeat the experiment in the future with other cues, being more careful to run the tests both before and after removing material.

Mike Page has also done some "beaver cue" experiments where he made big cuts closer to the joint of the cue. He removed a large amount of mass, but because it was well outside of the endmass zone, it had no affect on squirt at all. The experiment also showed how overall cue stiffness (the cue was very whippy after the cuts) has no effect on squirt.

I hope you have learned from the data provided by our squirt-testing robot. Next year, we plan to build a better machine and perform many more studies for a larger collection of cues. So expect more "Return of the Squirt Machine" articles in the future.

Good luck with your game,
Dr. Dave

PS: I know other authors and I tend to use lots of terminology (e.g., squirt, throw, cling, stun, tangent line, 30º rule, etc.), and I know not all readers are totally familiar with these terms. If you ever come across a word or phrase you don't fully understand, please refer to the online glossary in the "Instructor and Student Resources" section of my website.

PS: I just released a new DVD called "*High-speed Video Magic*." It features billiards, but it also includes stupid human and animal tricks, balloons popping and bouncing, things breaking, engineering stuff, toy physics, and fluids and foods in super slow motion. For more information and video excerpts, see the website (*billiards.colostate.edu*).

Dr. Dave is a mechanical engineering professor at Colorado State University in Fort Collins, CO. He is also author of the book, DVD, and CD-ROM: "The Illustrated Principles of Pool and Billiards," and the DVD: "High-speed Video Magic."