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

"Coriolis was brilliant ... but he didn't have a high-speed camera – *Part IV: maximum cue tip offset*"

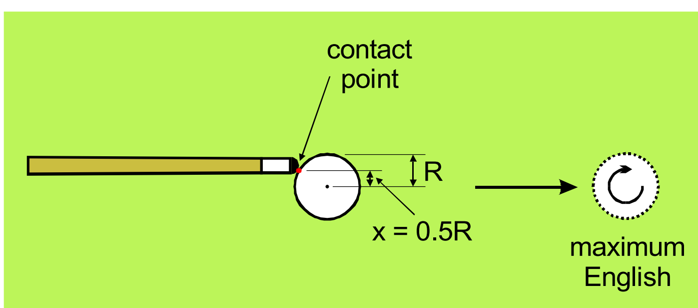
***Note**: Supporting narrated video (NV) demonstrations, high-speed video (HSV) clips, and technical proofs (TP) can be accessed and viewed online at billiards.colostate.edu. The reference numbers used in the article (e.g., **HSV A.16**) help you locate the resources on the website.*

This is the fourth article in a series I am writing about the pool physics book written in 1835 by the famous mathematician and physicists Coriolis. Two months ago, I described some high-speed camera work I've done and showed some examples that relate to some of Coriolis' conclusions. Last month's article dealt with the shape of the cue ball's path after hitting an object ball, and the effect of spin and speed on the shape of the path. FYI, all of my past articles can be viewed on my website in the instructional articles section.

The topic of this article is Coriolis' conclusion summarized in **Principle 24**. He claims that to achieve maximum English, the cue tip should not contact the cue ball more than half a ball radius off center, as shown in **Diagram 1**. For a pool ball, with a diameter of 2 1/4 inches and a radius of 1 1/8 inches, the corresponding contact point would be off center by 9/16 of an inch. It just so happens that the radius of the red circle on an Elephant Practice cue ball (this is the cue ball used in many of the NV and HSV video clips on my website) happens to be exactly 9/16 of an inch. The reason for this is that hitting the cue ball with offsets much larger than this creates a high risk of miscuing. In the remainder of the article, I will refer to the amount of tip **offset** as "x" (see **Diagram 1**) and the ratio of offset to ball radius (x/R) as the **offset factor**.

<u>Principle 24</u> Cue tip offset for maximum English

To achieve maximum English, the point of contact of the cue tip with the cue ball should be half a ball radius off center (see Diagram 1).



<u>Diagram 1</u> Contact point offset for maximum English

In Coriolis' book, there are actually several different analyses involving tip offset. In one analysis, he shows that for offset factors greater than 0.6, the amount of English will be reduced because the cue tip will not slow down enough after initial impact and it will stay in contact with the cue ball for a while. The claimed result is that the cue tip will rub on the spinning cue ball creating friction, which would reduce the amount of spin. In Coriolis' summarizing conclusions, he states that an offset factor of 0.5 results in the maximum English, but after reading his 0.6 analysis, it seems that he is claiming offset factors up to 0.6 will result in more English. To be honest, I wasn't able to resolve the apparent discrepancy after careful study of his document. But, as I'll show later, experimental evidence seems to back up the 0.6 number. Although, 0.5 is the typical recommended limit beyond which miscues are too risky.

In **TP A.12**, I present an analysis that relates the offset factor to what I call the **spin rate factor (SRF)**, which is a measure of how much spin (rotational speed) the cue ball acquires compared (as a ratio) to the amount of linear (translational) speed of the ball's center. A SRF of 0 implies the cue ball has no spin (e.g., a stun shot), a SRF of 1 implies the amount of spin is the same as the natural roll rate for the cue ball (e.g., a natural roll follow shot), and a SRF greater than 1 implies a spin rate greater than the natural roll rate (e.g., a follow shot with excess spin). It turns out that for the maximum recommended offset factor (0.5), the spin rate factor is 1.25, which means the cue ball has 25% more spin than the natural roll rate. The examples I cite above are for follow shots, but the spin rate factor can also be used to quantify English sidespin (although the amount of spin is still compared to the natural roll rate).

technical proof

TP A.12 – The relationship between cue ball spin and cue tip offset

Recently, I performed a high-speed video study to try to observe a potential effect of decreased spin rate factor at larger offsets. The super slow motion video footage can be viewed in clips **HSV A.98-A.109**. The experiment involved using various cue sticks with various hardness tips from soft to super hard (phenolic). Three stroke speeds were tested for each tip. For each speed, the tip offset was increased gradually on successive shots until there was a miscue. Each HSV clip shows a single hardness tip at a single speed but for several increasing offsets leading up to a miscue. I was fortunate to have Dave Gross help me with the filming. He is a great player with excellent technique, helping to ensure a consistent and accurate stroke for the experiment. Thanks Dave!

high-speed video

HSV A.98-A.109 – English and squirt for various hardness tips at various speeds and increasing offsets.

The largest non-miscue offset and resulting spin rate factor was from the fourth shot in **HSV A.106**. **Diagram 2** shows some stills from the clip. The cue tip hits the cue ball in still "a," deflects away from the cue ball as the cue ball moves in stills "b" and "c," and gets close to contacting the cue ball again in still "d" (but doesn't). By stills "e" and "f," the cue sticks starts slowing and the cue ball starts separating more from the cue tip. **Diagram 3** (from **HSV A.16**) shows a close-up of cue tip contact and the resulting cue stick deflection away from the cue ball immediately after impact for a typical hard shot with lots of English. **HSV A.5** and **HSV A.25** show larger scale views so you can see typical cue tip deflection and resulting cue stick vibration. The sequence in **Diagram 3** corresponds to the action between stills "a" and "b" of **Diagram 2** (although the video clips are of different shots). Notice, in **Diagram 3**, that the cue tip deflects away from the cue ball significantly immediately after impact between stills "b" and "c." Only three ten-thousandths of a second (0.0003 sec) have elapsed between stills "b" and "c!" Also notice the cloud of chalk forming in still "c" and growing in still "d." Don't forget to brush and vacuum your table cloth periodically!

high-speed video

HSV A.106 – English and squirt for a Predator 314 shaft at slow speed and increasing offsets
HSV A.16 – Side-English cue-tip reaction for a very large offset, very fast speed, non-miscue shot
HSV A.5 - Cue stick deflection during a hard shot with English
HSV A. 25 - Cue stick deflection and vibration due to firm stroke with English

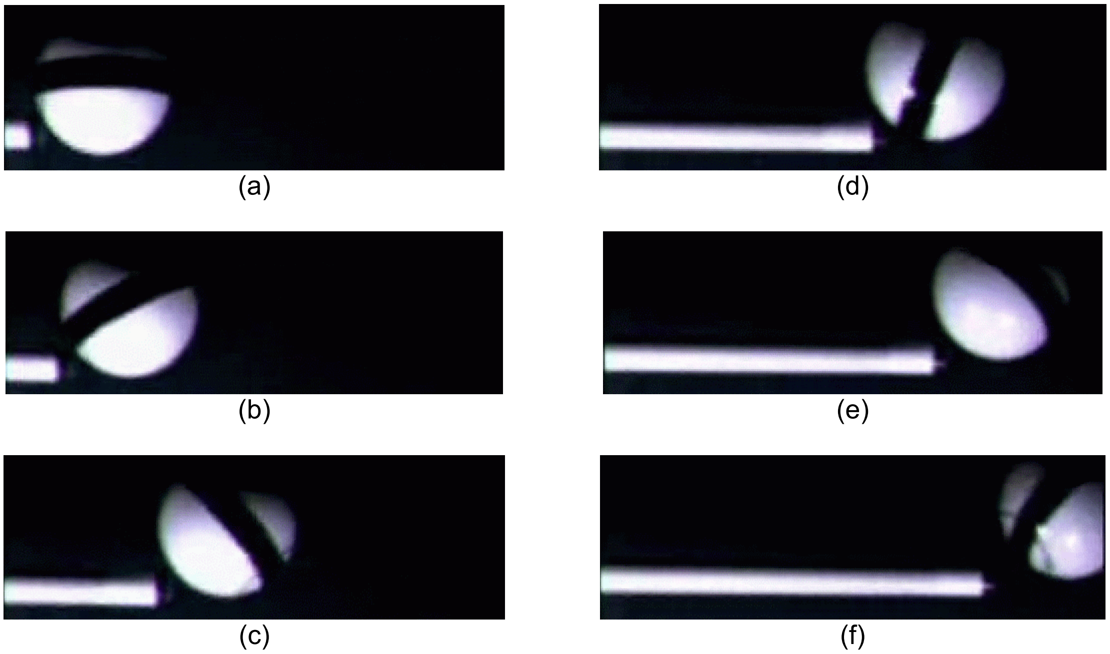


Diagram 2 Stills from HSV A.106

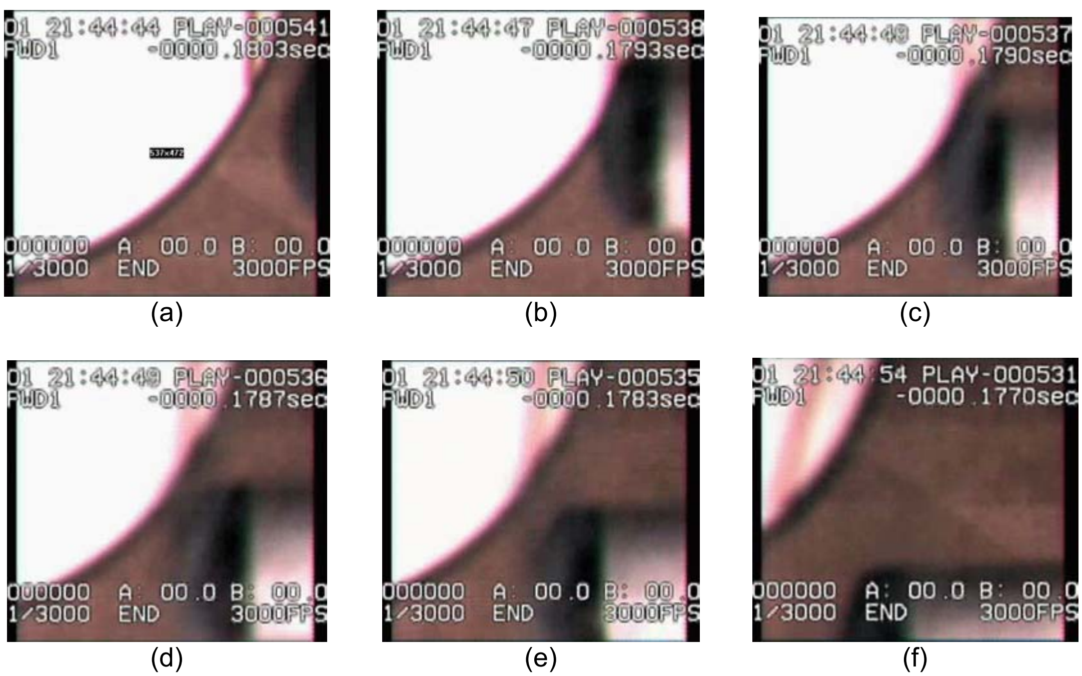


Diagram 3 Stills from HSV A.16

The spin rate factor measured for the fourth shot in **HSV A.106** was 1.37, which means the cue ball had 37% more spin than the natural roll rate. As shown in **TP A.12**, this spin rate factor corresponds to an offset factor of 0.55, so my experimental results show that the cue ball can be struck, without miscue, further off center than 0.5R, but not by much.

The results of the high-speed video analysis show that the larger the offset, the larger the spin rate factor (i.e., the cue ball gets more spin). At large offsets, the cue tip deflects away from the cue ball and does not remain in contact. Even at the largest offsets, on the verge of a miscue, the cue tip did not contact the cue ball again after the initial contact, although it came close a few times. In other words, post-impact rubbing of the cue tip as described by Coriolis was not observed for any of the shots. Although, I wouldn't rule it out as a possibility just because I haven't observed it yet. Secondary contact (and rubbing) was close to happening in HSV A.106, and Coriolis' analysis is valid (although, he assumes a rigid cue stick with no deflection and straight-line cue ball motion with no squirt).

So the bottom line of this article is: to apply maximum English, you can hit the cue ball as far off center as you want as long as you are confident you won't miscue. The 0.5R offset is still probably a good limit to stay within. Maybe that's why Coriolis listed it this way in his conclusion summary.

I hope you are enjoying my series of articles about high-speed video and the work of Coriolis. Next month I'll conclude the series by taking a closer look at Coriolis' method for aiming massé shots.

Good luck with your game, and practice hard,
Dr. Dave

PS:

- If you want to refer back to any of my previous articles and resources, you can access them online at ***billiards.colostate.edu***.
- If you are interested in the physics of pool, you might be interested in the new "Pool/Billiards Physics Resources" section of my website. It lists and provides links to many general interest and technical books and articles that explore the world of pool physics.

Dr. Dave is a mechanical engineering professor at Colorado State University in Fort Collins, CO. He is also author of the book: "The Illustrated Principles of Pool and Billiards" (2004, Sterling Publishing).