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

"Coriolis was brilliant ... but he didn't have a high-speed camera – *Part II: High-speed video*"

***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., **NV A.76**) help you locate the resources on the website.*

This is the second article in a series I am writing about the pool physics book written by the famous mathematician and physicists Coriolis in 1835. In last month's article, I summarized and illustrated some of the main conclusions in the book. In this article, I want to describe some high-speed camera work I've done and show some examples that relate to some of Coriolis' conclusions. Over the next few months, I will look at Coriolis' conclusions in more detail and explain when they do and don't apply.

Before I look at some of my high-speed video results, I want to acknowledge the work others have done. In 1998, Bob Jewett, Mike Shamos, and others did some high-speed filming of various shots. They called their project the "Jacksonville Experiments." They summarized their work in the 1999 April and June issues of Billiards Digest (see the link under the "videos" section in the "Online Threads" area of my website for more information). Some of the conclusions they arrived at in their work include:

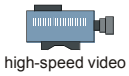
1. During impact, the cue tip is in contact with the cue ball only for about 0.001 second (a thousandth of a second). This is the case for most shots, regardless of the speed, English offset, or type of grip and follow-through.

2. With an off-center hit, the cue stick deflects away from the cue ball substantially.

3. During miscues, the cue stick often hits the cue ball multiple times.

I have verified these and other conclusions with my own high-speed video testing. For the 1st conclusion, see almost any of the HSV clips on my website. For the 2nd conclusion, see HSV 4.4-4.5, A.5-A.7, A.13-A.28, and A.35-A.54. And for the 3rd conclusion, see HSV 2.1, A.1, A.13-A.15, A.17, A.43-A.45, A.54, and A.61. I will summarize other conclusions from my work in a future article.

Another group that has done some very impressive high-speed video work is Robert Leitner and three-cushion champion Andreas Efler out of Austria (see the link under the "videos" section in the "Online Threads" area of my website for more information). Bob Jewett showed some still images from their work in the May, 2005 issue of Billiards Digest. The high frame-rate, high-resolution, full-color images the Austrian group creates with their extremely expensive camera are very impressive. You can check out samples of their video footage at **HSV A.76**.



HSV A.76 - Austrian high-speed and infrared video clips

Diagram 1 shows the equipment I use to film my high-speed video clips. I use a Kodak Motion Corder Analyzer PS-110. I teach a course at Colorado State University dealing with dynamics of machinery, and we normally use the camera to film high-speed machines to visualize and quantify complex motion and vibrations. Fortunately, when the camera is not being used for laboratory classes, I can borrow it to shoot pool stuff in my basement at home. The camera has a

maximum frame rate of 10,000 frames per second! This is much faster than typical consumer video cameras that run at only 30 frames per second. I usually run the camera at 1,000 or 3,000 frames per second because that is fast enough to visualize most pool shots and because the resolution (number of pixels) is better at the slower speeds (i.e., the pictures are more clear). Another critical piece of equipment is a high-intensity lamp (e.g., 1200 Watts). The high frame-rate doesn't give the camera sensors much time to record, so the objects being viewed must be bright. The one downside of such intense lighting is that it can cause "sun" burn, melt the hair on your hand and arm, and periodically cause the finished wood on the rail to smoke. I know these things from experience, but they are small prices to pay for science. For more information on how I edit, store, and post videos online, see the "video" links under the "Online Threads" area of my website.

Diagram 1 Dr. Dave's high-speed video equipment and typical setup

Diagrams 2 and 3 show stills from two example high-speed video clips that relate to Coriolis' conclusions (see last month's article). Here, I just want to show the clips (or stills from the clips) and make some observations. I'll discuss the ramifications in future articles. **Diagram 2** shows a follow shot with large offset and fast speed. The full clip can be viewed online at **HSV A.49**. To see other shots with different speeds and types of English, see HSV 4.4-4.5, A.5-A.7, A.13-A.28, and A.35-A.54. For the shot in Diagram 2, the cue tip is in contact with the ball only between the 2nd and 3rd stills. The "3000FPS" at the bottom-right portion of the still indicates that the clip was filmed at 3000 frames per second. The elapsed time (being counted down) is shown on the 2nd line at the top-right of the still. The time changes only by 0.001 second between the 2nd and 3rd still. The duration from the 1st to the last (6th) still is 0.0127 second (a little more than a hundredth of a second). Note how much the cue stick deflects up as a result of the impact with the ball. This is evidence that there is a vertical force (perpendicular to the impact line) between the cue tip and ball during impact. This force, which causes the cue stick to deflect and vibrate (see **HSV 4.4**), is the same force that causes the object ball to deflect ("squirt") with side English shots. The force is related to how much end mass the cue stick has. Low squirt cues like the Predator have low end-masses to limit squirt. For more information on squirt and end mass, see the "English deflection (squirt)" links in the "Online Discussion" section of my website.

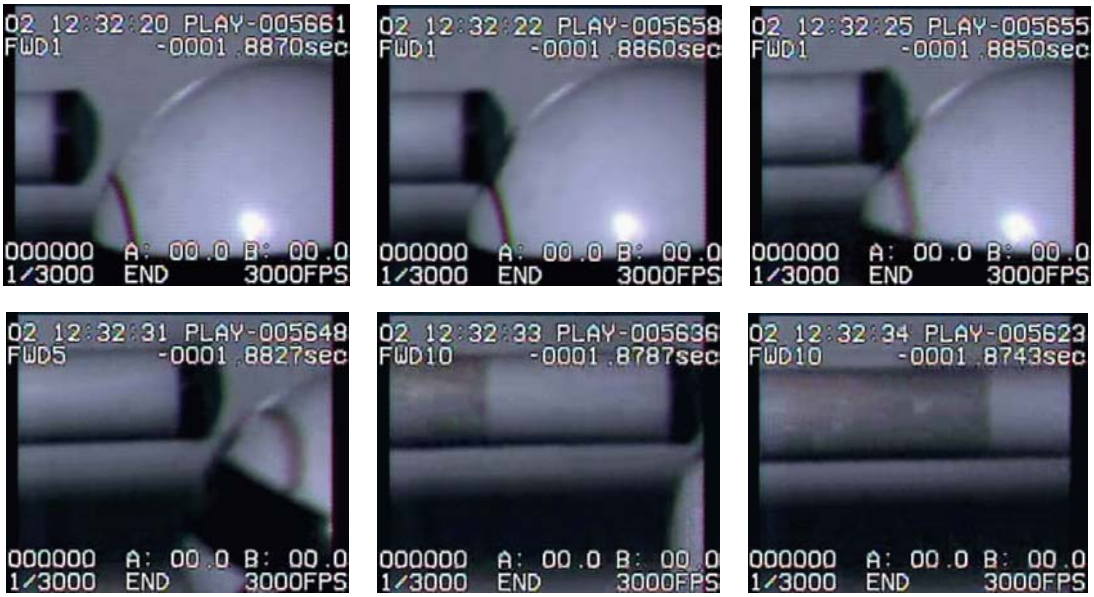


Diagram 2 Close-up of cue tip impact during a large-offset follow shot

HSV A.49 – Follow shot with large offset, light grip, good follow-through, and fast speed
HSV 4.4 - Deflection (squirt) due to high-speed English

Diagram 3 shows stills from a good-action massé shot. You can view the entire clip online at **HSV A.60**. Unlike with most shots, the cue tip stays in contact with the cue ball over a much larger duration because the cue stick is driving the cue ball into the table (and the table pushes back, like any self-respecting table would). For this particular shot, the cue tip is in contact with the cue ball starting in the 2nd still and ending approximately with the 3rd still. This corresponds to about 0.004 second (4 thousands of a second), which is four times longer than with most shots. Also note how much the cue stick deflects laterally (to the left) while it is in contact with the ball. The ball is mostly staying in place, picking up spin, during the cue tip contact. I hope you view the clips online, because looking at the stills really doesn't do the clips justice.

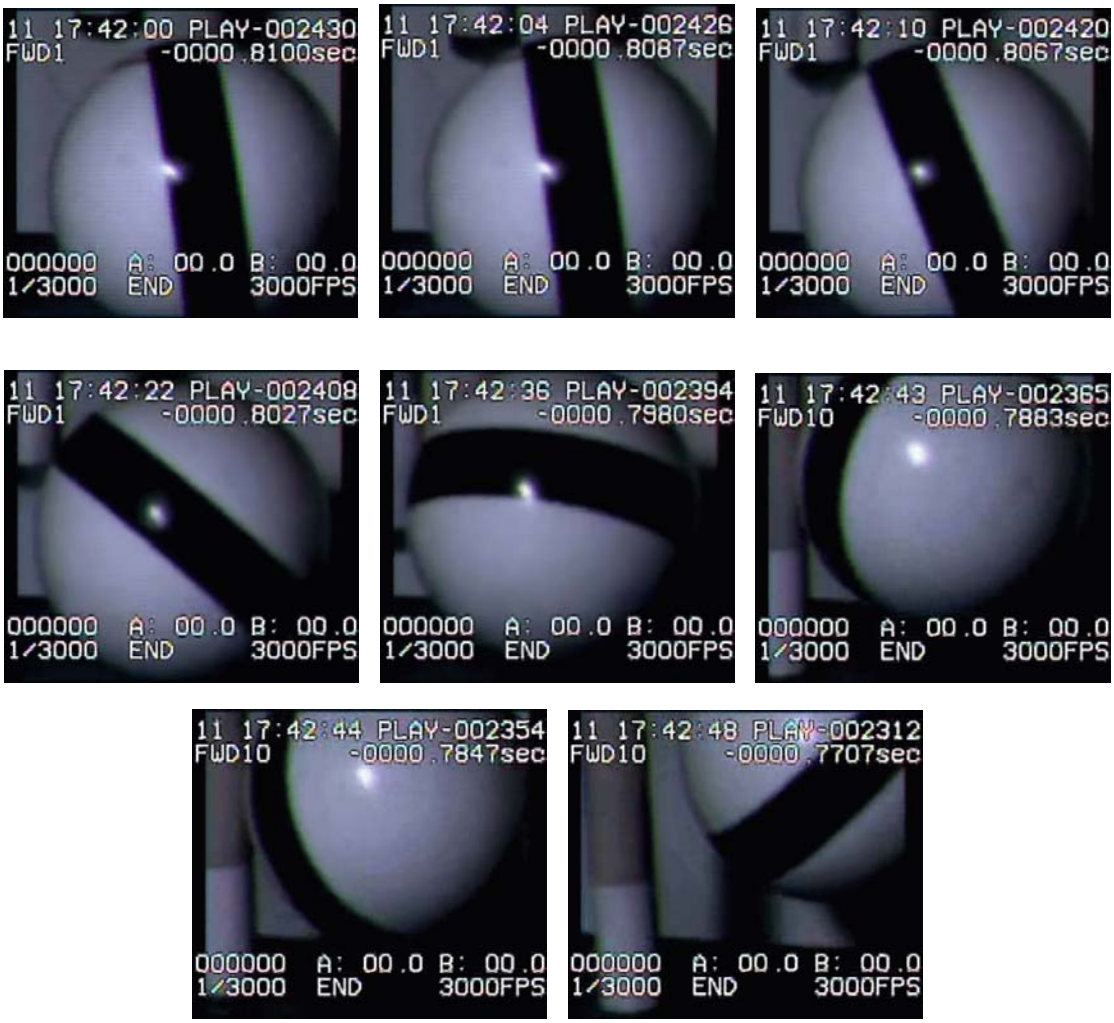
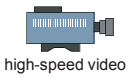


Diagram 3 Massé shot



HSV A.60 – Masse draw shot with firm follow-through and good action

All of my high-speed camera footage to date can be viewed under the HSV section of my website. I also have a huge collection of non pool (and sometimes silly) clips available for viewing at:

www.engr.colostate.edu/~dga/high_speed_video/

There, you can find almost everything imaginable including shooting a shaken pop can with a pellet gun, dropping a cube of Jello, puncturing water balloons, and dropping an egg on a rat trip. You can even see the performance of various stupid human and animal tricks ... all in super slow motion for your viewing pleasure. Enjoy! **Diagram 4** shows one of my favorite clips, which shows my dog “Girl” fetching a bone off her nose. (I know ... I’m not very creative with my pet names. By the way my cat’s name is “Kitty.”) “Girl” was always a willing subject for high-speed video science as long as there were treats involved. I have included this clip here partly in tribute to “Girl” who passed away recently, but also to make a point concerning many sports, including pool. You can view the clip online by clicking on the link at the bottom of the “High-Speed Video”

section of my website. Click on “dog bone catch” in “Dr. Dave’s Hall of Fame.” When Girl performs this trick, she moves so fast that the bone remains almost motionless in midair (because gravity is so slow compared to dog) while she moves her head around to have the bone end up in her mouth. Pretty impressive, don’t you think? In case you still haven’t figured out what point I’m trying to make with this clip concerning pool, here it is: *“Keep you eye on the bone.”* Notice how in the 1st and 2nd stills, her gaze is fixed on the bone. Only after the bone is safely in her mouth in the 3rd still does she relax her gaze. This should serve as inspiration and as an example for athletes in many sports where there is a ball involved. In pool, the message should be: “Keep you eye on the object ball during your final stroke, and don’t move your gaze (or anything else except the cue stick) until after impact (or well after).”

Diagram 4 Dog fetching bone off her nose

I hope you are enjoying my series of articles about high-speed video and the work of Coriolis. In future articles, I will try to use some high-speed video results to help explain how and why some of Coriolis’ conclusions (see last month’s article) may or may not be valid in different situations. I will also show how some of Coriolis’ conclusions might be useful in your game.

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

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).