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THE JACKSONVILLE EXPERIMENT

UNLOCKING CUE MYSTERIES THE HIGH-TECH WAY

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Historically, billiard physics has been long on talk and short on data. Not any longer.

Special Cue Report: The Jacksonville Experiments

UNCOVERING THE CUE MYSTERIES

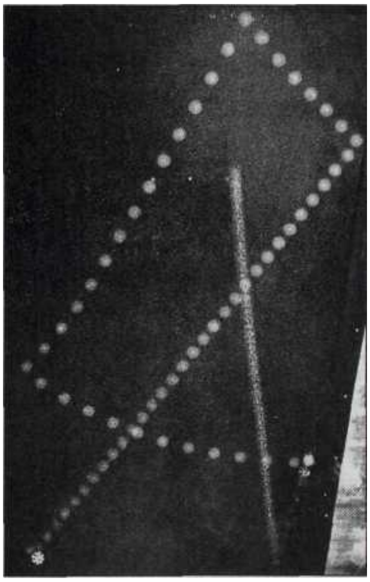
BY **MIKE SHAMOS**

What happens when a cue stick hits a ball? Does the tip flatten? Does it mushroom? Does the shaft bend? How long does the contact last? Does it matter how fast the stick is traveling? Since the game has been played for over 500 years, you would think that someone might have worried enough about these issues to try some experiments. I figure that if scientists can get us to the moon they ought to be able to tell us why some cues squirt more than others. But they can't. The reason is that billiard physics is long on talk and short on actual data. After five centuries we don't even really know what hits what on a miscue. And that's because no one, even the physicists, has ever done any careful experiments.

One reason there are few experimental results is that all the interesting action when a tip hits a ball takes place in a few thousandths of a second, far too fast to be seen and way under human reaction time. Since the 1940s there have been cameras capable of filming rapid events but they are extremely expensive, shoot vast quantities of film and need special lighting equipment. Then once the film is exposed, you have to wait until it's developed to see whether the experiment worked. No one in history had been willing to bear the expense in the case of billiards, except for a few stroboscopic photos taken of Willie Hoppe taken over 50 years ago by photographer Gjon Mili (see picture, right).

Technology has advanced quite a bit since then. Computers and digital cameras have eliminated the need for photographic film, so you can understand my excitement when Bob Jewett told me last summer he was part of a group that was renting a high-speed camera to find out what really happens on a table. What's high speed? 12,000 frames per second. At that rate, it takes over 6 minutes to watch one second of action. He calculated that the cue tip and the cue ball ought to be in contact for only 1-2 milliseconds, which means we should see them touching for about 12-24 frames, enough to get a good idea of their behavior.

The idea for the experiments began in early 1998 with a correspondence between Jewett and Jim Buss, President of the American Cuemakers Association (ACA). The cuemakers are very interested in squirt, what causes it, which cues have less of it and how it can be eliminated. There had been endless debate about these issues and Buss felt it was time to get the facts. Through a great deal of e-mail, the two of them developed an agenda of questions.



A Willie Hoppe masse shot taken by Gjon Mili circa 1941. The first evidence of high-speed photography used for billiards.

Photos courtesy of MIKE SHAMOS

Jewett sent messages to a list of people known to be interested in such things, asking whether anyone wanted to participate and soliciting their ideas. I sent in about 40 questions that have bothered me since birth, such as, "Does the cue ball back up (even slightly) before it starts rolling forward on a full-hit follow shot?" and "Does the ferrule strike the cue ball during a miscue? If not, what makes that funny sound?" For a game that's so old, I was always amazed that no one knew the answers. So the chance to find out had me completely hooked.

Jewett found out that Kodak manufactures the perfect machine for billiard studies, the Model 1012 Ektapro High Gain Imager with Hi-Spec processor that can record directly to SVHS tape. Fortunately, we didn't have to buy one for $65,000. It rents for $2000 a week, for a minimum of two weeks.

There was still the question where the experiments would be done, who would bear the costs and who would run the show. Sometimes political questions like these can doom the best-intentioned project. But not this time. Alan McCarty, President of Clawson Cues (makers of the Predator) stepped up to the plate with a persuasive offer. He would pay half the cost of the equipment if Clawson could use it for a week. The other experimenters could use it for another week at Clawson's factory in Jacksonville, subject to no restrictions whatsoever. Whatever we learned, whether it was favorable to the Predator or not, we were free to publicize. He asked only that we not comment on anything we might learn about Clawson's operations or future product plans. Our agenda was separate from Clawson's. (Clawson's staff did not influence these experiments in any way.)

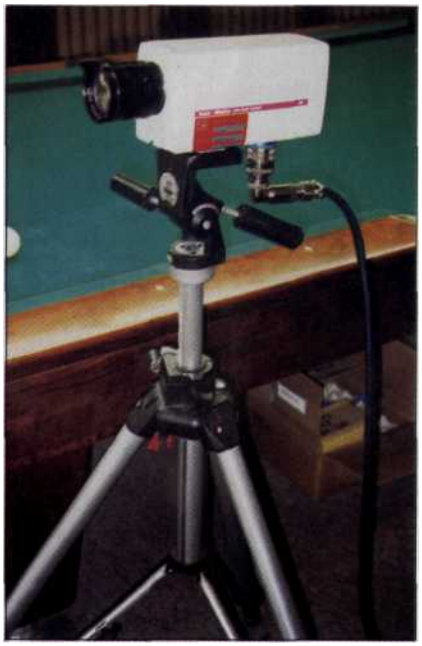
The team consisted of me, Jewett, Buss, Hans De Jager, and Walt Harris. De Jager is in charge of tournaments for the Billiard Worldcup Association, which runs the world three-cushion championship tour. He also gives courses in Artistic Billiards (of which Jewett and I are alumni) and was scheduled to be in Florida to teach at Bill Maloney's room in Ft. Lauderdale. When he found out about the experiments, he rearranged his schedule to visit Jacksonville. Walt Harris is the author of the *Billiard Atlas of Systems and Techniques* series.

We all met in Jacksonville for the start date of November 2, 1998. The camera had been sent on ahead by Kodak. I knew that everyone would be bringing his favorite cues, but when we collected Jim Buss at the airport, he had the largest cue case I've ever seen. It was big enough for 26 butts and 52 shafts. The thing is so heavy that it has to be wheeled around, but if you need a different shaft every week of the year then nothing else will do!

For a whole week we had run of the Clawson facility, and they even gave us the key to the plant so we could work late into the night.

Monday morning we got together to construct an agreed list of experiments. The camera is so expensive that we felt like mission planners for the space shuttle, not wanting to waste any time in orbit.

That afternoon, Bill Spinelli, a technician from Kodak, arrived to set up the equipment and give us a crash course in its operation. Being digital, the Kodak machines were fairly robust, but he gave us one heart-stopping warning: "The only way you can damage this camera is to drop it or unplug it while the power is on." In addition to the camera, we needed an SVHS recorder, various lenses (for different degrees of closeup), and a selection of graph papers to provide measurement capability on the videotape. The small gray box on the table at the left of the video monitor (below) is the hand-held control panel. The thick cable in the center runs to the camera.



Top and below: The Kodak model 1012 Ektapro High Gain Imager with Hi-Spec processor, capable of capturing up to 12,000 frames per second.

What made the experiments feasible is the design of the camera. It operates at variable speeds up to 12,000 frames per second (fps) in a continuous time loop until the stop button is pressed. Enough frames are stored in the camera's electronic memory to play back about a second worth of action at 12,000 fps or 4 seconds at 1,000 fps. (There's a good reason the ratios are different, too minor to go into here.) So when you press stop at 12,000 fps, the last second of action is sitting in the camera. It can be viewed directly on a video monitor at various playback speeds and/or copied onto videotape. So not only is there no film processing, but instantaneous review is possible. This enabled us to do several hundred tests per day.

Lighting is something of a problem. At 12,000 fps you need a lot of light to illuminate the balls. This required two floodlights of several thousand watts, which generate a great deal of heat, enough to deliver a severe burn to anyone who touches one and quickly causing the camera to overheat. To counteract this effect, we had to fashion a heat shield for the camera housing. The properties of the camera's electronic retina require very even lighting over the whole scene, so placing the floods properly was an issue for every camera setup. With the kind of close-up work we were doing, holding the camera by hand was out of the question, and a heavy tripod had to be used, and we often had to put it right on top of the table to shoot from above. Since the camera registers black and white only, and is highly sensitive to red, it's almost impossible to tell the difference between balls. The cue, three and seven balls look identical on the videotape (unless the numbers are visible).

One of the first things we wanted to photograph was the cue stick hitting balls with varying degrees of English to learn exactly what happens.

To do reproducible experiments we frequently used "Iron Willie", a pool-shooting robot. It's a very heavy metal frame in the vague shape of a human being that has an adjustable spring-loaded mechanical arm and a simulated bridge hand that can hold the stick with different degrees of tightness. The results are so consistent that we were able to set up trick shots in which the cue ball caroms off three balls sitting near pockets and sinks all of them every time. Because Willie is not a per-

Bob Jewett sets up the high-speed camera to determine whether a *fouette* — a rare stroke used when the cue ball and object ball are just millimeters apart — is legal.

fect simulation of a person (he holds the cue too tightly and has trouble with masse and other special shots), we only used him for about 10 percent of the experiments.

Getting the team coordinated required some practice. One person controlled the lights, another was responsible for shooting the balls and I usually operated the camera. The ritual we developed was that the shooter would call "ready" when he was prepared to shoot. The camera operator would reply, "ready" and then wait for the sound of the shot. At the sound of the shot, the operator would hit the stop button and then we would gather to view the results, deciding whether and at what playback speed to put them on videotape. With only a second of recording if you hit the stop button too late you lose all the action.

The first experiment made it clear that there were going to be lots of surprises. We quickly learned that the shaft does not buckle noticeably at the ferrule, but for any off-center hit it bounces substantially away from the cue ball. It then immediately starts to return toward the cue ball at a speed that depends on the characteristics of the shaft and the tightness of the bridge hand. We started with a center-ball hit and then moved the stick successively to the right in 2-millimeter increments using a calibrated V-block supplied by Clawson.

The objective of our experiments was not to measure squirt, but to understand why it occurs. It is very difficult with a high-speed camera having a narrow field of view to perform any precision squirt measurements, which are best done by observing how far the cue ball deviates from its path over the distance of a table-length. We observed more by studying cue stick-cue ball interaction. A typical equipment configuration is shown above, which has Jewett placing the camera to record an unusual stroke called a *fouette,* in which the cue ball and object ball are only a few millimeters apart. One of the questions we had was whether it is possible to make a legal hit in this position or whether the shot has to be a foul. Amazingly, it's legal if done properly with the correct English and a very fast stroke. The cue stick bounces away from the cue ball. By the time it returns, the cue ball is gone and no double hit occurs. This is a shot in which seeing isn't believing — without a high-speed camera. Lots of people who see the shot with the naked eye swear it's a foul.

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We discovered that most miscues are actually fouls, and if they happen in a game like 9-hall, they should result in hall-in-hand.

The intrepid experimenters, from left: DeJager, Jewett, Shamos and Buss.

On Monday evening, Buss and I continued with the camera, mostly exploring masse and kiss shots. If the object ball is frozen to a rail and you hit the cue ball directly into it at a 90-degree angle to the cushion, exactly how many ball-to-ball contacts are there? From listening to the sound the shot makes, you might guess six or eight. The answer is: exactly two. The cue ball hits the object ball (that's one). The cue ball stops dead because of the direct hit. The object ball sinks into the cushion by an amazing amount, more than the size of the numeral on the ball. The object ball rebounds out and hits the stopped cue ball (that's two). Then the object ball continues to creep away from the contact point because of cloth-induced spin.

De Jager arrived from Holland on Tuesday. He always travels with a large collection of cues for Artistic Billiards, which requires butts of different weights and shafts having different degrees of flex. (The reasons for this were always suspected but not proven until we did the experiments.) The U.S. Customs Service is not a billiard fan, however. On his arrival at Dulles Airport in Washington, he declared the cues as business articles. Customs immediately impounded them pending payment of duty or proof that De Jager wasn't going to sell them in the U.S. So he had to fly on to Jacksonville without them, beginning a soap opera that would last a week. Part of every day was spent calling Washington, Miami, the airport and the airlines. We were told the cues had gone to Detroit and a host of other stories that changed every day. De Jager took it well, but I could tell he was frantic.

When Walt Harris arrived we got to work for the second day. What happens when the cue ball is shot full at an object ball with follow? Does the cue ball "back up" even slightly, before rolling forward? It's theoretically possible because the friction between the object ball and the cloth increases the effective mass of the object ball. But it never occurs. In fact, with a level cue the cue ball always begins moving forward past the point of contact, even if it is shot with draw. This is because the collision between balls is slightly inelastic and a perfect rebound is not possible. With Centennial balls and a hard stroke, the cue ball moves forward 1-2 mm before drawing back. With ivory balls, the cue ball advances beyond the contact point by almost a third of a diameter. It's unbelievable to see on the video.

De Jager had a theory that the most English can be imparted if the cue tip is actually accelerating at the moment of contact. Jewett doubted that a human being can accomplish that. Years of debate ended in about an hour when we tried the experiment. No matter how anyone stroked, the best we could do was to have the cue stick move at constant speed for the last few inches before it hits the ball. In fact, unless a very good stroke is used, the stick actually decelerates on the way in. (The cue must slow down immediately upon hitting the ball because of conservation of momentum, but that's a different phenomenon.) We spent the rest of the day studying miscues and fancy strokes. I'm an expert at the former and De Jager is exceptional with masses and other wild shots. We learned that the cue ball jumps slightly on essentially every shot, even if the cue stick is level. If you hit a ball with draw, then squirt tends to make it rise. If you hit it with follow, squirt drives it slightly into the cloth and it rebounds up. This was not only apparent from the video, but you can easily prove it to yourself by placing a dime about six inches in front of the cue ball and stroking hard with follow.

Miscues are quite a story. It is possible for the cue stick to hit the cue ball four times on a miscue, two or three times with the cue tip and once or twice with the ferrule. In fact, the slapping sound you hear on a miscue is exactly that — the ferrule hitting the cue ball. This means that most miscues (not all — it doesn't always happen) are fouls and if they happen in 9-ball, it should technically result in ball-in-hand. This will require a change to the rules someday, since it's probably not a good idea to make the referee use a high-speed camera to tell when a foul has occurred. Since two of the experimenters are on the BCA Rules Committee (Jewett and I) we will recommend that no penalty be assessed on a miscue unless the player makes a deliberate effort to hit the ball twice. The embarrassment and loss of cue ball control on a miscue are punishment enough.

Reeling from the miscue discovery, we moved onto other potentially revealing trials. Our next question: what happens when a level cue stick held with a closed bridge hits a ball with right follow. Here's how it unfolds: (1) the tip begins to flatten out slightly, increasing the area of contact; (2) the cue ball immediately begins to rotate, and the tip remains in contact with it as it does; (3) the cue stick begins to bounce away from the cue ball up and to the right; (4) a ring of chalk begins to fly off the cue tip in all directions from the contact point; (5) because of Newton's Third Law of action-reaction, the cue ball must travel to the left of the line of aim (this is squirt); (6) the cue tip breaks contact with the cue ball; and (7) the cue stick remains vibrating in the air as the cue ball moves away (the vibration is caused by the restoring force of the bridge hand and the rigidity of the shaft. What is surprising is the amount of rotation the cue ball can make during the contact (about 20 degrees), the distance the shaft bounces away and the magnitude of the shaft vibration.

> **What is surprising is the amount of rotation the cue ball can make during contact.**

Hans De Jager finally got his cues back from U.S. Customs — after all the experiments were over. We went home having produced over two solid hours of tape, quite a bit when you consider that each experiment only lasted a few seconds, even considering slow playback speed. Jewett even transferred all of the recorded experiments to ordinary VHS tape. Nothing was cut out. It answers some age-old questions, but it's not the kind of thing you would invite friends over to watch with popcorn. The images are black and white, there is no narration, and the balls move very slowly. On the other hand, if you've ever wondered what the cue stick does when it hits a ball, this is the tape for you.

Mike Shamos is a contributing editor of Billiards Digest.

Starting on page 72, Bob Jewett will explain the technical significance of these experiments aided by visual documentation captured at the test site.

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Special Cue Report: The Jacksonville Experiments

Some surprising discoveries about cue/cue hall interaction emerged from the Jacksonville Experiments.

FREEZE FRAME

BY **BOB JEWETT**

While the entire series of the experiment with the Kodak Ektapro Hi-Spec Motion Analyzer Model 1012 to witness cue/ball interaction is well-documented in the previous article, we now have some visual evidence of this quasi-historic event. As I have stated before, these results were compiled in the witness by five billiard enthusiasts; you must understand that the conclusions are purely our own, and not necessarily the opinion of *Billiards Digest.* That some of us write for *BD* is purely coincidental.

With that said, let's take a look at what a 12,000-frames-per-second camera could see that the naked eye cannot.

In **Figure 1,** you can see some of the features of the camera and video system that we used to record these findings. They can be found on the black border surrounding the image. (The camera itself was similar to a standard handy-cam, but it had a thick cable going over to a large box of electronics that stored the sequence of images in digital memory, or RAM. The camera was fitted with several different lenses to allow close-ups and normal views.)

The time and date (upper left-hand corner) are obvious. The ID number, 10 (right), shows which scene is being shown. Over the week-long period, we taped more than 250 different scenes.

The REC 3000 (r.) shows that the images were captured at 3,000 frames per second, which is about 100 times faster than standard video. The frame number, which gives the count from the trigger, is -606 (lower left), which means that the trigger will occur in 606 more frames. For all of the runs, the trigger — a button on the remote control —was pressed just after the action, and the camera was set to stop recording on the trigger. This is also reflected in the ET, or, elapsed time indicator (lower r.), which says there are 0.202 seconds until the trigger.

The X and Y numbers on the left show where the cross-hairs are located, and these can be moved around when viewing the video after the recording. This allows exact measurement of distances and provides a good reference.

Now that the numbers don't seem so foreign anymore, let's look at the interesting stuff: the images.

The image in Figure 1 represents one of the first tests we ran. The camera is looking down from above the table. The stick, which is moving towards the cue ball, has been caught at maximum tip compression.

The main test here was to look for bulging of the tip during the shot. In the image shown, the vertical white line or, marker, was positioned so any bulge in the right side of the tip would be highlighted. It isn't possible to see the "before" from this still picture, but the sliver to the right of the marker was only half as wide before impact.

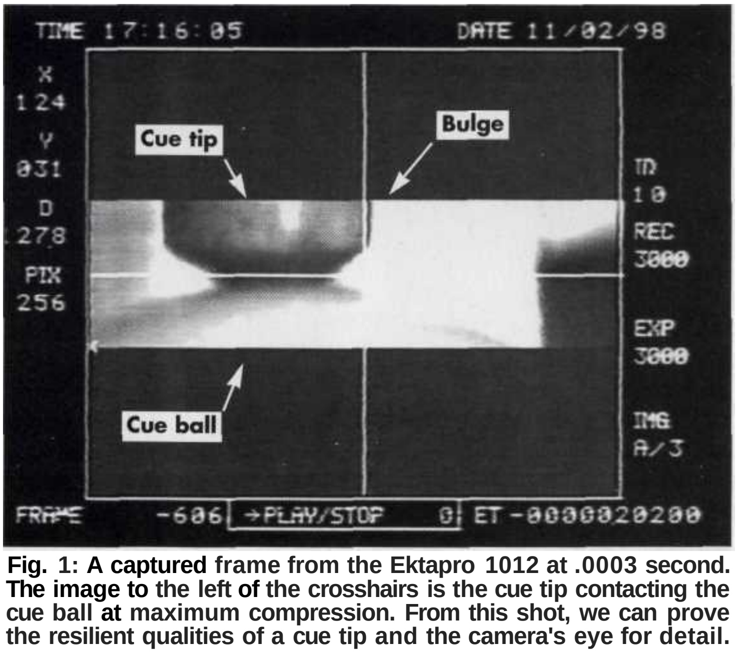

Fig. 1: A captured frame from the Ektapro 1012 at .0003 second. The image to the left of the crosshairs is the cue tip contacting the cue ball at maximum compression. From this shot, we can prove the resilient qualities of a cue tip and the camera's eye for detail.

Figure 2 is a typical view of a side-spin shot, again seen from above. The ball began with the line between the light and dark areas placed perpendicular to the stick, so it has started to rotate a little. The cue stick, which started out several millimeters closer to the center of the ball than in the image, has been moved to the side by the ball's rotation. The dark cloud which is just visible between the tip and the ball is the chalk dust that flies in all directions on spin shots. Below the ball is a grid with minor divisions every 2 millimeters and major divisions each

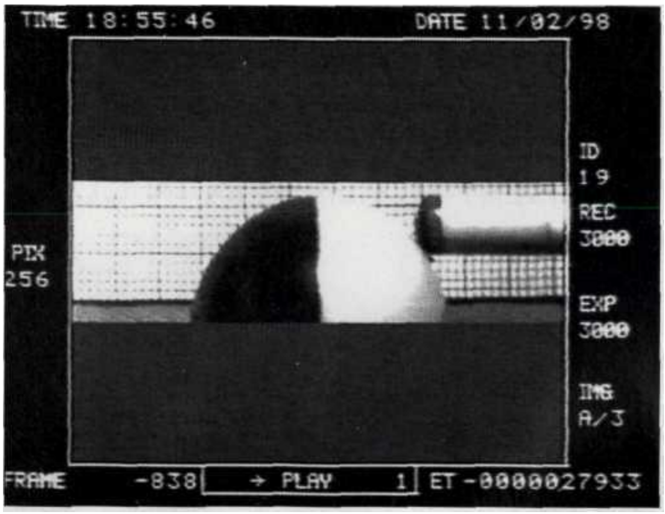

Fig. 2: This model demonstrates how the ball's rotation can throw the cue tip off-center when English is applied.

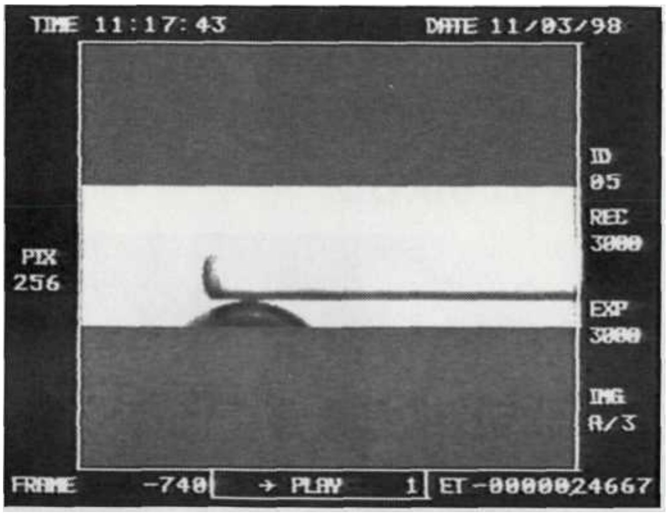

Fig. 3: The most surprising result: On just one miscue, the tip, the ferrule and even the shaft can all contact the cue ball.

centimeter, which allowed accurate measurements of speed and deflection. As we tried more and more English, it wasn't long before we started miscuing.

Figure 3 is the surprising result. In many but not all miscues, the ferrule — or in extreme cases, the shaft — slaps the cue ball several times during the motion.

In **Figure** 4, the speed of the camera has been set to its maximum: 12,000 frames per second. At this rate, each image is a short horizontal slice, and the display stacks twelve of them vertically, reading from top to bottom, giving the history of one-thousandth of a second. This is a close-up of a graphite cue hitting a ball. You can roughly estimate the speed of the stick by noting that in the first 12 frames (.001 second) the stick moves about 3 millimeters, or about 3 meters per second. A grid would have helped, but there was no room in this picture for one. The main point of this test was to see whether the stick hit the ball multiple times. It is pretty clear that the tip makes only one contact. By counting the number of slices in which the tip is touching the ball, you can get the total contact time. It appears that the tip is touching in twelve consecutive frames, which would give a time of .001 seconds. In the last few frames, it's hard to say whether the tip is still touching the ball or not, because the chalk cloud obscures things. Other tests which didn't require side-spin were done without chalk for a clearer view.

Conclusions: How can the above ideas or insights be applied to a game? Here's one example: As predicted by physics, the ball moves off the tip at a speed faster than the incoming stick. What is not directly predicted is that this speed-up, which is caused by the springiness of the tip, is not as large as the simple calculation says.

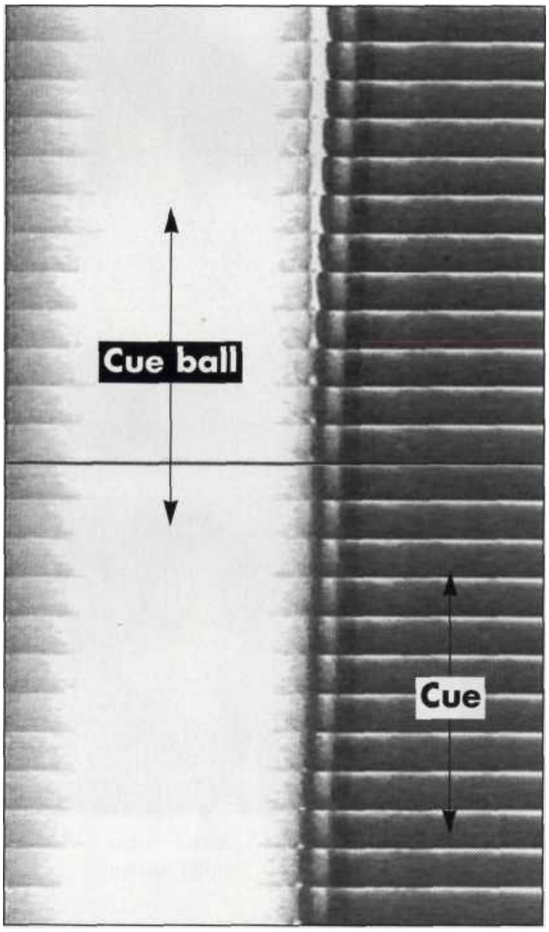

Fig. 4 proves that the cue makes only one contact with the cue ball. Total contact time: .001 seconds.

Presumably, significant energy is lost in the tip, perhaps as much as 30 percent. For a break stick, you want to lose as little energy as possible. The suggestion from the video is that work on the tip is more likely to improve a break stick than anything else.

Another major contribution of the tape is an improved understanding of how squirt develops. It is clear now that all sticks must have squirt or deflection on spin shots, because movement of the front part of the stick to the side as the tip rotates sideways with the spinning ball must have an equal and opposite motion to the other side by the cue ball.

However, there is no way to control how much sideways speed the stick gets — that's determined by the amount of spin used — but it is certainly possible to reduce the effect by reducing the weight of the front part of the stick. This result bears out what a lot of people have been saying for some time: balance, length and weight aside, all of the payability of a stick is in the shaft. ^

To obtain your own copy of the Jacksonville Experiment tapes, along with a copy of the notes that were made during the experiments, send $30 ($35 for S-VHS) to Bob Jewett at 962 Stony Hill Road, Redwood City, CA 94061.

Bob Jewett

Don't Grip It and Rip It

The Jacksonville Experiment also revealed the significance of cue speed.

The video tapes made during the Jacksonville Experiment *(BD,* April) provided the first quantitative information on cue speed throughout a shot. We did this by attaching a graph-paper scale to the cue that would be used for the measurement. The high-speed video camera was focused on the scale, and set to its fastest recording rate. Each of three players took shots at various speeds and with several cue weights.

To convert this raw video data into cue velocity, the sequence was examined frame by frame, and the time for each movement of one centimeter (about four-tenths of an inch) is noted. This gives the time the cue took to move one centimeter. The number could then be turned into speed by simple division. When the resulting speeds were plotted versus cue positions, a graph like Diagram 1 is produced. Along the horizontal axis is how far the tip traveled from the bridge hand. On the vertical axis is the speed of the stick, with negative speed on the backstroke and positive speed on the forward stroke.

The backstroke begins with the tip almost at the ball — about 22 centimeters, or 8.5 inches from the bridge hand. As the stick is brought back, a peak negative speed of 0.6 meters/second is reached. The stick comes to a stop (speed = 0) with the tip just a centimeter from the bridge. As the forward power takes over, the stick is accelerated to 1.9 meters/second. When the tip contacts the ball, the stick speed suddenly drops to about half its value. This takes only a millisecond (one-thousandth of a second), which is about one-fifth of the time between the measured points, and was determined from separate close-ups of the tip/ball contact. The follow-through takes the stick forward another 12 centimeters as it slows to a stop.

A major point to note on this stroke is, the ball was struck when the stick was at, or very near, the peak of its speed. As mentioned in a previous column, this is theoretically the best time to hit the ball for efficiency and consistency. Just at the peak, the stick is coasting at maximum velocity.

A very interesting and unexpected feature in the plot is that the cue speeds back up after the ball has left. This turns out to be from the hand and arm, which don't slow down much during the very brief tip-ball contact. After the ball has left, the cue, hand and arm gradually go to their average speed, which is about halfway between the peak speed and the reduced cue speed after contact. From the time it takes for equilibrium to be reached, it is possible to estimate how tightly the hand is gripping the stick, compared to how hard the tip is. It turns out that the hand is about 100 times softer than the tip. That is, to push the tip one millimeter into the ball required 100 times the force needed to move the cue one millimeter against the grip.

What does all of this mean for practical purposes? In essence: Let the cue do the work and don't worry about the details. A very major point is that your hand — unless your grip is much, much firmer than mine — cannot have any significant influence on the ball during the brief tip-ball contact. Another point is that a good time to hit the ball is at the peak speed. Notice that if the ball had been an inch (2.5 centimeters) closer, the cue speed at impact would have been nearly the same. This means small errors in stroke timing should have little influence on the outcome.

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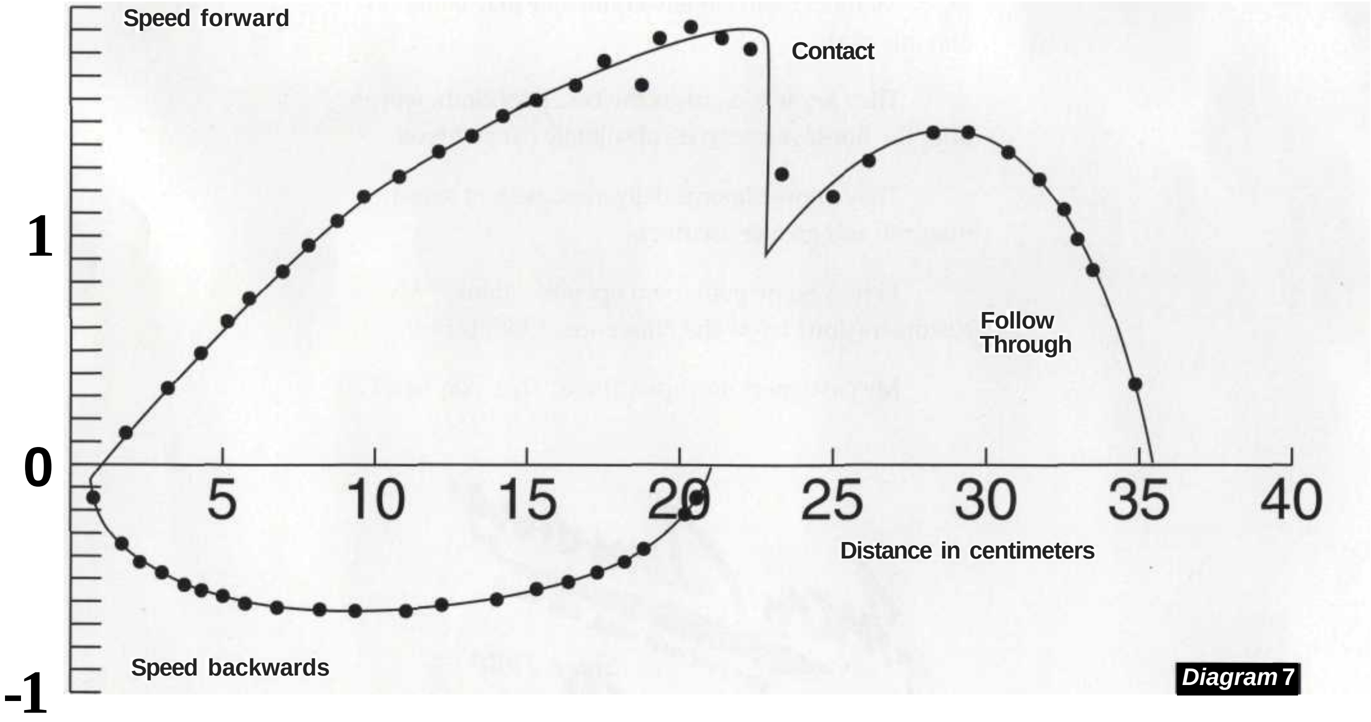

Diagram 7