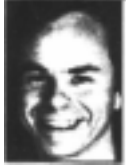


Bob Jewett



# Complete Breakdown

Cue sports simulators allow us to analyze the fleeting moments of pool.

Computer simulations of physical systems are increasingly parts of our lives. The movie *Titanic*, video-arcade basketball games, and automobile design all benefit from this sort of virtual reality. (Automobile manufacturers doing crash testing of new designs use the most powerful supercomputers available to run cars into brick walls; it's cheaper in the CPU than on the test track.) Cue sports simulators such as Virtual Pool and Carom Simulator are now accurate enough that techniques and strategies useful on a real table can be learned from them.

This column describes a computer program that simulates a stick shooting a center-ball shot. We'll see that even such a simple case has interesting phenomena that the simulator, with its greatly expanded time scale, lets us examine in detail.

A fairly simple model is used for the stick itself, as shown in **Diagram 1**. (All diagrams are approximate.) The stick is divided into several hundred sections, and each is thought of as a small lump of mass connected to its two neighbors by springs. At first glance, this seems nothing like a real stick: the weights would sag down. To prevent this in the simulation program, the force of gravity is ignored, so the only force acting on each part of the stick is from its neighbors, and all the parts stay in line.

Each spring works very simply: in the resting position it does nothing, but if the

two adjacent parts move closer, the spring pushes back with a force directly proportional to that compression. Similarly, if the two neighbors move apart, the spring will tend to pull them back together. The "stiffness" of the spring — how much push for how much compression — is set from the known properties of maple wood.

The taper of the stick is included by making the masses larger away from the tip. At the same time, the springs get stiffer because the larger cross section of wood is more resistant to compression.

The tip — or rather, the tip-to-ball interaction — is a little more complicated to simulate. While the parts of the stick are connected, the ball and tip only interact when the tip has moved into the space occupied by the ball; the tip doesn't grab the ball as it moves away. Also, the "spring" in this case is not the classical spring governed by Hooke's law, but instead increases in stiffness as the penetration increases.

The ball is treated as a single six-ounce lump that is stationary at the start of the shot. While there may be some distortion or "ringing" of the ball due to the hit, modelling this would require dividing the ball into many small parts linked by springs — too complicated for this first look.

Now that we've reduced the ball and stick to masses and springs which interact by simple rules, how does the action pro-

ceed? The stick is positioned a short distance from the ball, and all its parts are given some initial speed. The "clock" is stepped forward by a tiny increment — typically one-millionth of a second — and the new positions of all the parts are calculated from the known velocities. If any of the springs is compressed or expanded, the velocity of neighboring parts will change a little. After the position and velocity of each part of the stick and the cue ball have been updated, the clock is advanced by another microsecond, and another cycle of calculation starts.

The following plots show what happens when a 20-ounce virtual stick travelling at one meter per second hits a cue ball. In **Diagram 2**, the tip compression is shown. Tip first meets ball at one millisecond on the time axis. The compression builds to three quarters of a millimeter, and then falls to zero as the ball is pushed away from the tip.

**Diagram 3** shows the force between the tip and the ball. The units are newtons — the calculation is all done in metric units — which are each about four and a half pounds of force, so the peak force for this moderate-speed shot is about 900 pounds. The shape of the force is a little different from that of the compression because the tip is a variable-rate spring, as mentioned above.

The ball velocity is shown in the next

Diagram 1

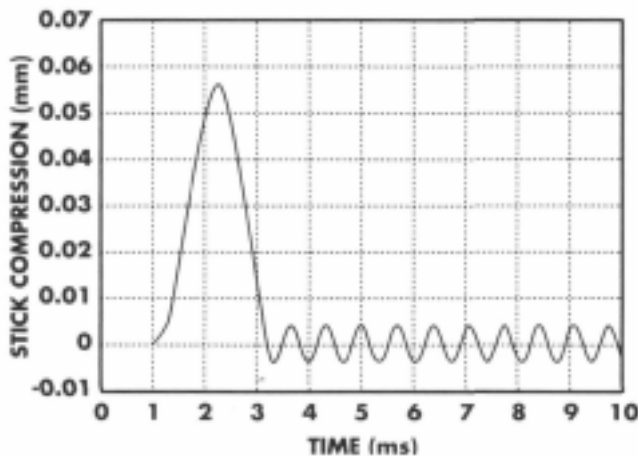
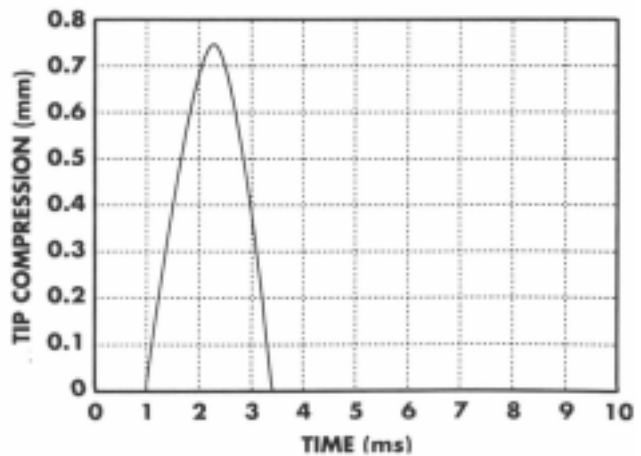


Diagram 2



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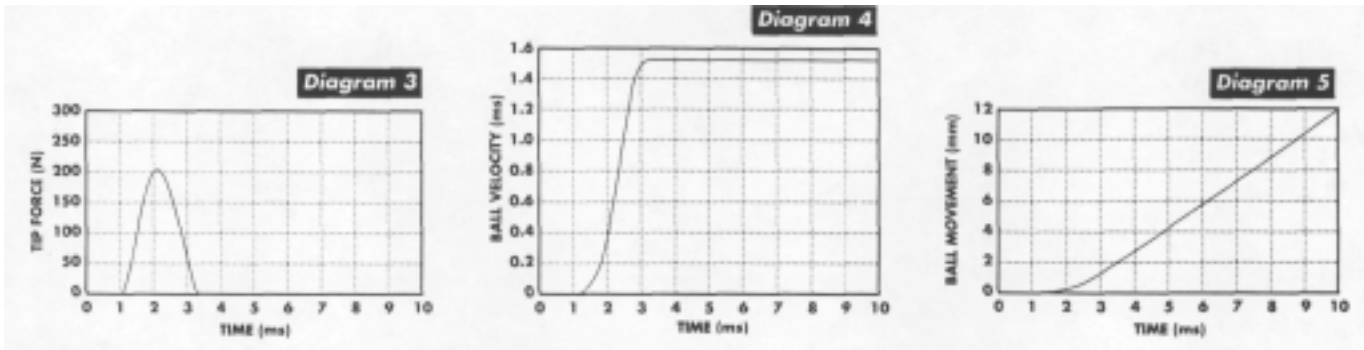


Diagram 4. Note how it builds up during the tip contact. An interesting point is that the final ball velocity — about 1.5 meters per second — is greater than the initial stick speed of one meter per second. This is expected from the simple physics of collisions between mismatched masses, and the value shown by the simulator is very close to the theoretical prediction.

Shown in Diagram 5 is how much the ball has moved versus time. The major point to notice here is how far the ball has gone when it leaves the tip, which happens 3.3 milliseconds into the simulation: about two millimeters.

Very simple physics predicts a "tip departure" after a travel of pi times the amount of tip compression, so this is

another indication that the program is giving reasonable answers.

As with most beginning simulations, the above leads to many new questions: How do different tapers react? If there is a lump of metal in the middle of the stick — AKA, a joint — does it change the hit? A harder tip is likely to cause more ringing. How hard is too hard? The answers to these questions, and others that you might send to me at [jewett@billiardsdigest.com](mailto:jewett@billiardsdigest.com), will have to wait for a future column.

This simulation program does not include side spin. That is a much more complicated problem, because in order to simulate the resulting bending of the cue stick, it must be chopped up into small parts in at least two dimensions and prefer-

ably three, as opposed to a single dimension for the present program. Getting the details right — how bendable is typical joint and ferrule material? — is a large job. A study of squirt, which is perhaps the most interesting cue stick problem that is susceptible to simulation, will have to wait for a more complete program. While the information explained here doesn't have an immediate application on the table, it should help you understand what is really happening when you hit the ball. And, since you can't control time of contact, it should be one less thing to worry about while you shoot.

*Bob Jewett is a partner in the San Francisco Billiard Academy, a BCA Master Academy. You can e-mail Bob at [jewett@billiardsdigest.com](mailto:jewett@billiardsdigest.com).*