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November 16, 2004

Crunch! Oof! Well, That's Physics

By HENRY FOUNTAIN

LINCOLN, Neb. - It's third and long midway through the second quarter, and Baylor's quarterback arcs a pass 30 yards down the field into Nebraska territory. The ball is thrown in front of the intended receiver, however, and two Nebraska defenders converge on it from opposite directions. Their eyes on the ball and not on each other, they collide at nearly full tilt and the ball pops away.

To the 77,000 fans at Memorial Stadium on this October Saturday, all but a handful dressed in red in tribute to their beloved Cornhuskers, this is just a typical bruising hit, made slightly more interesting, and alarming, because it involves two players on their team. But Dr. Timothy Gay sees it differently.

"Wow, cool, a three-body collision!" Dr. Gay said from his seat in the stands. The forces in this encounter are enormous, but the players don't appear to be injured. Their pads and helmets and the shortness of the collision help protect them, and the third "body" - the ball - absorbs a little bit of the momentum.

Weekdays, Dr. Gay is an experimental atomic physicist at the university who spends most of his time smashing electrons in a basement laboratory, studying the way they scatter as a means of understanding what might go on in the plasma of a fusion reactor or a star.

On fall weekends, when the Huskers play, he makes the short walk across campus to Memorial Stadium, to pursue his avocation - football physics.

To watch a football game with Dr. Gay is to view the sport through a different lens, one where talk of fly patterns, blitzes and muffed punts is supplemented by discussions of vector analysis, conservation of momentum and strange forces that can affect the flight of the ball. At Dr. Gay's perch a dozen rows back on the 35-yard line, Isaac Newton is cited as often as Vince Lombardi, and the X's and O's of the game are enhanced by delta-V's and delta-T's.

Back at his lab after the game, he does a quick estimate of the forces involved in that defender-on-defender hit. The players, who weigh about 200 pounds each, are running at about 20 feet per second, and after they collide they bounce back at perhaps half that speed. It's easy to calculate the acceleration - change in velocity, delta-V, over change in time, delta-T - and force, which by Newton's second law is proportional to mass times acceleration.

The rough result is that the players encounter a force of about 1,800 pounds and an acceleration of 9 g's, or 9 times the force of gravity. Such forces would be bone-breaking and capillary-draining if applied over time, but in the split-second of this collision the players can withstand them. The third body helps a little too - with its much smaller mass, the football is sent flying toward the sideline by the momentum imparted to it.

Dr. Gay draws a parallel to his work. "The three-body collision - that's the kind of thing I do for a living in the lab," he said. "In atom-molecule collisions, you cannot make a certain chemical reaction go unless you have a third body in there to take up some of the momentum. It's essentially the principle of catalysis."

Dr. Gay is as much a teacher as he is a researcher, and for the past five years has been intent on teaching fans of football something of the science behind it, first with a series of humorous one-minute videos shown on the scoreboard at Nebraska games and now with a book, "Football Physics: The Science of the Game."

"My connection to football is deep because what I do is collisions," he said. "I'm really interested in what happens if I send an electron in, where it's going to scatter to, how much momentum will it transfer."

"You see that all the time in football," he added. "You see guys colliding. Obviously the physics is a bit different. In football we use Newtonian physics, in atomic collisions we use quantum mechanics."

Using Newtonian physics, he explains later in the game why it was so easy for Nebraska to score on a short goal-line plunge.

"It's just the classic advantage of the momentum of the offense," Dr. Gay said. Because the offense knows when the ball is going to be snapped and the defense doesn't, the offensive line has about two-tenths of a second to build up momentum before the defense can react.

In Newtonian terms, momentum is simply mass times speed. The Nebraska linemen are both large (on the order of 300 pounds each) and speedy (they can run a 40-yard dash in about 5 seconds), so in that two-tenths of a second the line has built up a lot of momentum - something like 10,000 pound-mass-feet per second in the sometimes arcane units of physics.

Dr. Gay put it more plainly: "They've got a head of steam so they can just bowl over the defense, which hasn't started moving yet. It's Newton's first law in action."

Dr. Gay traces his interest in football and physics to his years at prep school in Massachusetts. He wasn't good enough to make the squad, but he worked as team manager. At the same time, he took his first serious physics course. The two interests coalesced.

"Plus, this was football in New England in the fall," Dr. Gay said. "It doesn't get any better than that."

Of course, it has gotten better. With degrees from Caltech (where he was good enough, or rather the team was bad enough, that he played on the offensive line) and the University of Chicago, Dr. Gay has for the past 11 years been at Nebraska, home to one of college football's blue-chip programs and some of its most loyal fans, who have sold out every home game since 1962. Lincoln is the state capital and a college town, but every fall it is swept up in football mania. Even the portable toilets are done up in Cornhusker red.

This year, after decades of a "three yards and a cloud of dust" philosophy, in which a strong running game is crucial, Nebraska has a new coach and a new way of doing things. It's called the West Coast offense, and it relies far more on the passing game, with the receivers running quick, precise routes and the quarterback timing his throws.

In physics terms, the team has gone from relying on mass and force to emphasizing kinematics, the science of motion and time. The problem is, most of the players were recruited for the old system. So in football terms, the team has gone from good to mediocre - at least by Nebraska's standards.

In the previous week's game, momentum may have been conserved, but pride was not. "Everybody knew we were going to have a tough year," Dr. Gay said. "But we didn't expect to lose, 70-10, to Texas Tech."

This week, though, Nebraska is having an easier time with Baylor, a perennially weak opponent. After a game in which fans pleaded with the team not to throw the football, Nebraska has resorted to more of a ground attack, led initially by running back Cory Ross, who at 5 feet 6 inches and 195 pounds has a low center of mass and is hard to bring down. The Cornhusker line is also throwing its mass around, and Baylor is getting the worst of most collisions. "They're losing the battle of Newton's first law," Dr. Gay said.

That first law - and the second and third, for that matter - are old hat to physicists. "Many of my colleagues say, 'Tim, why are you doing this? This really isn't a very interesting problem, this football physics,' " Dr. Gay said.

"In a narrow sense, they're right," he added. "It's not like we're discovering new physics."

But while it's often described as a collision sport, football is not just about hitting and getting hit. The flight of the ball, for one thing, presents interesting issues. "In this case, I really think there is something new to be learned," he said.

On a basic level, a ball's trajectory has much to do with how tight the spiral is. A wobbly pass presents more surface to the wind, incurring more drag and failing to travel as far. That's one reason, no doubt, why that second-quarter Baylor pass fell short of its target. A tight spiral generally requires that the ball be thrown faster, for reasons of torque. "The harder you throw it, the more torque you apply as it leaves your hand, so it spins faster," Dr. Gay said. "That means that it's more stabilized, and you get a tighter spiral."

Dr. Gay was particularly interested in something an old prep school colleague, now a coach for the New England Patriots, told him about punts - how they tend to drift to the right or the left, depending on the direction of spin and whether they "turn over," dipping front-end down after they reach the high point of their arc.

Drawing on work by another physicist, Dr. Marianne Breinig of the University of Tennessee, Dr. Gay described the forces at work. As the spinning ball moves through the air, one side is moving in the same direction as the air moving past it, while the other is moving in the opposite direction. This results in different relative velocities, and "you actually get a pileup of air on one side," he said.

"Because the friction and drag force are bigger, you get turbulence and a force that shoves the ball." This is the Magnus force, which is what makes a spinning baseball curve.

The Magnus effect doesn't create problems on kickoffs and field goal attempts, he said, because the ball is rotating on a different axis, end over end. It might cause the ball to move up or down, but not side to side, so accuracy wouldn't be affected.

As physics concepts go, the Magnus force is fairly ethereal. Back on the field, the situation is much more concrete: Nebraska is thumping Baylor. The Huskers go on to win by 59-27, aided by Ross and another back, Brandon Jackson, who have scored three touchdowns between them. Dr. Gay, objective physicist, is also a subjective, and happy, fan, left to wonder what it is that makes players like Ross and Jackson so good.

Science, he finds, offers only a partial explanation. "As biomechanical machines they're so complex," he said. "You can talk about overall patterns and features and stuff like that, but it's difficult to say why one running back is better than another.

"You know, heart, the will to win. Physics isn't going to touch that."

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