PHYSICS LAWS AND ANALYSIS OF THE SOCCER BALL

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Abstract

The physics of sports has broad applications, and is useful for boosting performance in a variety of athletic disciplines. A lot of the time, good athletic performance is based on proper control and coordination of movement. Other times, it helps to have a good understanding of the physics taking place, and then using this knowledge to the soccer players advantage.

Key words: Reynolds number, Bernoullis Principle, Fevernova, Inflation of soccer ball, Shin guards

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INTRODUCTION

How and where you kick the ball is the most important aspect within the game of soccer. If you kick the ball perfectly giving it no rotation (or spin), this means that you have given the ball a velocity (v) and an initial angular speed zero. When the ball comes into contact with the ground it will begin to spin because the ground is not frictionless. The soccer ball will eventually begin to roll without slipping, which is when the balls center of mass is equal to its angular speed.

Friction

Friction is a huge factor when considering the game of soccer. When a soccer ball is moving along the field there is constantly a frictional force working in the opposite direction of the balls movement. There is an equation that can be used to find the friction force working against the ball and it is [14,18] f=mN. This is where f is the frictional force, m is the coefficient of friction, and N is the normal force pointing upward. The coefficient of friction is dependant upon the surface type and ball being used, it is not a constant. This tells us that the coefficient of friction will cause the ball to roll slower. when it is large and not as slow when it is small. This also shows that the more friction there is between the ball and the field the slower the ball will roll.

Airflow

In many situations throughout a soccer game it is necessary to make a ball curve around someone and due to airflow against the ball this is possible to do. To get a ball to curve you must first put it into a rotating motion. To do this you need to initially kick the ball off-center so that a side spin iscreated. A low-drag and high-turbulant airflow is then working agains the ball causing the spin. But, the speed that the ball is kicked at can also directly effect the curve you get from the ball. If the ball is kicked too hard it will enter a smooth-airflow, or laminar, phase. This can create a large amount of drag and in turn brings in Bernoulli's principle and a large sideways force. This force causes the ball to curve in a direction that is hopefully the one you desired. Bernoulli's principle shows that the ball in motion will have an effect due to the airspeed above and below it. The balls movement will also be effected because of the spin put on it. Bernoulli's principle [16-17] shows that there is a lift pushing out to the side because of the rotation due to air pressure giving it a lift. The most important number used to describe phenomena associated with soccer balls moving through air is the dimensionless Reynolds number, Re, defined as

Re =vD/ή

where v is the air speed far from the ball in the ball's rest frame, which is the speed of the ball in the stationary air's frame. Also D is the ball's diameter, and ή is the kinematic viscosity, defined as the ratio of the viscosity to the density of air . The game of soccer is played mostly for 10 mph<v< 70 mph and hence the range of Reynolds numbers relevant for a soccer game is approximately 70 000_Re_490 000.

As the Reynolds number is increased through a critical value, air flow in the ball's boundary layer changes from laminar to turbulent flow. The boundary layer separates farther back on the ball, and the resistive drag coefficient drops. Panel connections, like stitches on a baseball and dimples on a golf ball, induce turbulence at a Reynolds number lower than that of a smooth ball.

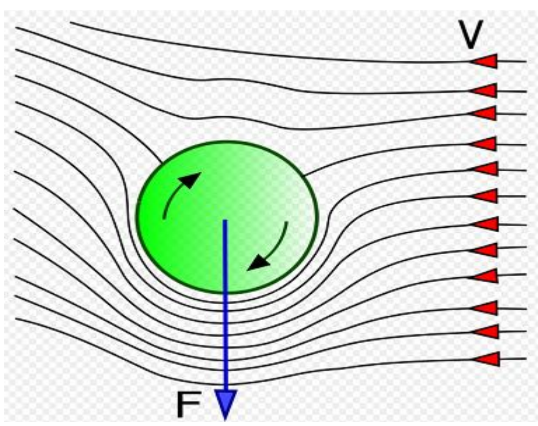

Fig 1

If a player imparts spin to the soccer ball, as might happen for a free kick or a corner kick, the ball may curve more than it would if it were not spinning. Forces associated with the spinning ball are usually parametrized by the Reynolds number and by the dimensionless spin parameter, Sp, which is the ratio of the rotating ball's [3-8] tangential speed at the equator to its center-of-mass speed with respect to the air 25 For a ball of radius r, angular speed w, and center-of-mass speed v, Sp is given by

$$Sp = rw/v$$

The Ball

To an amature soccer player all soccer balls being used probably feel about the same when playing, but the professionals can easily tell the difference between a poorly constructed ball and a nice one. In fact, there is a lot of science involved in the creation of a nice ball and, of course, the physics of the game are taken into consideration throughout this creation process. The ball above is their latest creation called the **Fevernova** ball. It has recieved a lot of hype due to the components it is made out of. These components include Syntactic Foam with gas-filled micro balloons, transparent PU coat, high solid PU, natural latex, 3 ply raschel knitting, and underglass print.

The revolutionary component involved in this ball is the new Sytactic foam that causes the ball to rebound quicker, meaning that the ball should not spin or hook unless the player spins or hooks it and that the ball should whistle when kicked at high velocities.

This ball was chosen to be used in the 2002 World Cup for the main reason that with the foam the ball will allow faster and harder shots to impress the crowds around the world. When the ball is spinning, the air tends to follow a longer path around one side than the other, because it's dragged along by the ball's turning surface." Air following the longer path bends more sharply, resulting in a dramatic drop in air pressure on that side of the ball. The ball is pushed toward the low-pressure side.

A similar drop in pressure over an airplane's wing is the source of lift that supports the plane. "Although a plane's lift is upward, Bloomfield points out, "for a ball lift can be in any direction, depending on the direction [9,10] the ball is spinning."

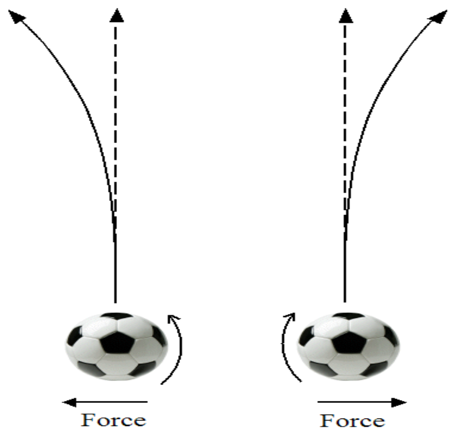

Fig 2

Boots

It is not until recently that the soccer boot or cleat has been researched. In fact, soccer has received much less attention when compared with other sports in the research department. This is now being done is to help reduce injuries and enhance performance. In an experiment, five different shoe designs were tested for ball speed, shoe deformation, and tibial shock. The results of this experiment showed the importance of biomechanical analysis for the improvement of soccer cleats. When considering energy return, it can be expected that larger ball speeds would cause more deformation. It was found that there was one shoe model that had the opposite reaction. Due to this finding it is shown that cleat design is a very important aspect of the game and it is important to continue research in this area.

Shin Gaurd

Shin gaurds are very important to the game of soccer because they are the only protection a player has against other people's legs and the ball. There are many different forms of shin gaurds out there, but the newest shin gaurds out are made of gel to take the impact of objects. Most shin gaurds are made with plastic, but this is not as protective as gel due to the fact that the gel absorbs some of the impact of the collision as the plastic blocks the collision, but doesn't absorb much of it. The gel absorbs some of the energy being pushed into the player's leg reducing pain. They are continuing research in this area to make the game safer for players.

Passing the Ball

Out on the soccer field, you need to work as a team to be successful. Let's face it, one player can't do everything. Passing is the simplest, most accurate way to send the ball to your teammates. Passing also demonstrates some interesting physics properties. When passing the ball, it is best to kick the ball so it stays on the ground. This allows the receiver of the pass to quickly get control of it.

Newton's Second Law

Newton's Second Law which can be rewritten as $F = ma$ can be used to describe the motion of the pass. When force is applied to the ball, it is accelerated into motion. However, force is only one part of the equation. We also have to consider the mass of the ball. A soccer ball's mass is around 400 to 450 grams. This is a relatively small mass. Newton's Second Law shows that an object that has a small mass has a great acceleration. The bigger the mass, the slower something will accelerate. There are factors other than force and mass that affect a pass, as well. When the ball is put into motion, it is rolling over the grass. This creates friction, which is a force created by two surfaces or fluids coming in contact with each other. Friction always opposes motion. The equation $F = \mu Fa$ describes all aspects of the ball's motion, including friction. μ is the symbol for the coefficient of friction and the higher this number is, the slower and shorter the ball will travel. This is because the coefficient of friction is defined as the force of friction divided by the normal force. The normal force is the same as an object's weight, which is defined as the product of an object's mass and acceleration due to gravity (9.8 m/s squared). Since the force of friction cannot be directly measured, we have to substitute the force applied. Force applied is simply the force you apply to the system. Let's take a look at what happens when the acceleration of our soccer ball is 0 m/s squared

$F = m \times 0$ m/s $=0$ we can see, no matter what the mass of the ball is, the force will equal zero. This gives us a net force of zero whenever the acceleration is zero. This is because although we have applied to force to the ball, the force of friction is the same strength, only in the opposite direction.

Inflation of the Ball

As is the case with any game or sport that uses an air-filled ball, a soccer ball must be inflated in order to play soccer . Most of you know how to inflate a ball, but how many of you know what's actually going on inside the ball? Let's take a look. When air is pumped into a ball, the amount of air molecules being crammed into the same about of space is increasing. This leads to a rise in air pressure within the ball. Air pressure is measured in Pascals. One Pascal equals 1 Newton per square meter. For example, in a square measures 1m x 1m x 1m x 1m, or 1 meter squared. Let each red dot represent the amount of air equivalent to 1 Newton of force. As you can see, the total air pressure within the square is 4N/1m squared, or 4 Pascals. What does this have to do with a soccer ball staying inflated? Well, not only does the air inside the ball have air pressure, but the air around the ball also does. This is known as atmospheric pressure. Figure 3 demonstrates a square with greater air pressure within it than the atmospheric pressure outside of it.

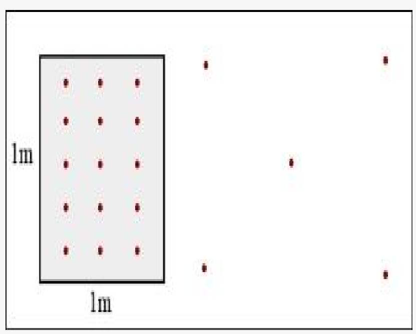

Fig 3

From the example, you can easily determine that the air pressure inside the square is much greater than the atmospheric pressure surrounding it. It is widely accepted that one of the fundamental tendencies of fluids is to move from areas of high pressure to those of low pressure. Figure 4 takes a look at what this does to our system.

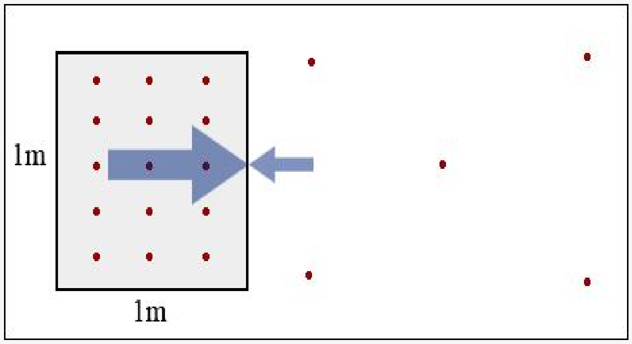

Fig 4

Air pressure applies forces on the objects around them. The blue arrows above represent force vectors (although they are only present on the right side of the square, Pascal's Law states that the pressure applied by the air would be the same no matter where on the square it was measured). However, in our system above, these force vectors aren't equal. Newton's Second Law states that the force applied on an object divided by its mass equals its acceleration. This is often simplified to F = ma, where F is the net force on the system, m is the mass, and a is the acceleration. This concept can be applied to a soccer ball, although it helps clarify if the ball expanding is substituted for the ball accelerating.

When the ball is inflated and the force vectors of the air pressure within the ball and the atmospheric pressure surrounding the ball are equal, the system is in a state of equilibrium, and the ball doesn't expand or contract. However, the rubber/latex bladders used within most soccer balls hold air very well, but not perfectly. Microscopic pores allow air to slowly seep out. As this happens, the pressure within the ball goes down, but the atmospheric pressure does not. This causes the force applied on the outside of the ball to increase, and the ball deflates until equilibrium is achieved once again. The exact opposite is true when you pump air into the ball. More air is put into the ball, and the pressure goes up. The air within the ball exerts a larger force than the air outside the ball, and the ball expands. This whole process is demonstrated in fig5 below.

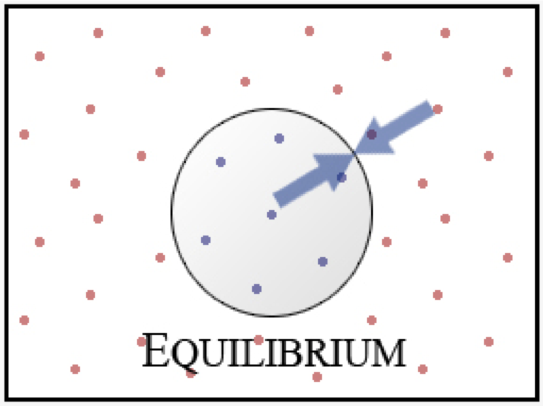

Fig 5

Trapping the Ball

When receiving a pass in soccer, we want to control the ball close to our feet, as this will allow us to keep possession of it much easier. This controlling of the ball is called trapping. There are three basic types of traps in soccer: foot traps, chest traps, and thigh traps. The purpose of a foot trap is to get the ball to stop right at your foot when receiving a pass. However, if we simply hold out our foot and wait for the ball, it will not stop. Rather, it will bounce off your foot and stop in front of us. This is due to uneven force vectors. To understand this, fig 6 below demonstrates the scenario.

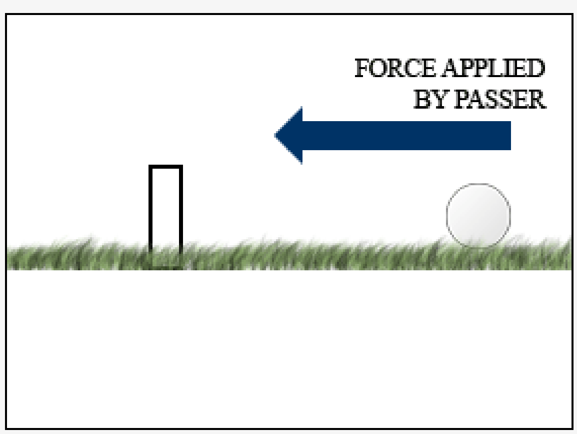

Fig 6

We can see, the force applied by our foot is greater than the force of the pass. To compensate for this, soccer players will pull their foot back when the ball comes in contact with them. This will increase the amount of time the ball is in contact with the foot, but the force and the impulse will remain constant. Impulse is defined as the product of force involved and the time interval of the collision. More force equals less time, and more time equals less force. By pulling your foot back, the time of the collision is extended, and the force involved is decreased. However, according to the Law of Conservation of Energy, energy cannot be created or destroyed. Notwithstanding, it can be changed into a different form. Where does that energy go then if it decreases as time increases? Well, the answer has to do with momentum. Momentum is the product of an object's mass and velocity. When the ball is moving toward your foot, it has mass and velocity; therefore it has momentum.

The Law of Conservation of Momentum states the same as the Law of Conservation of Energy, except with momentum in place of energy. When the ball comes in contact with your foot, and you bring your foot back, both the energy and the momentum of the ball are transferred to your foot. This is how the force can be absorbed by your foot without it being destroyed. Fig 7 gives us a complete picture of a foot trap.

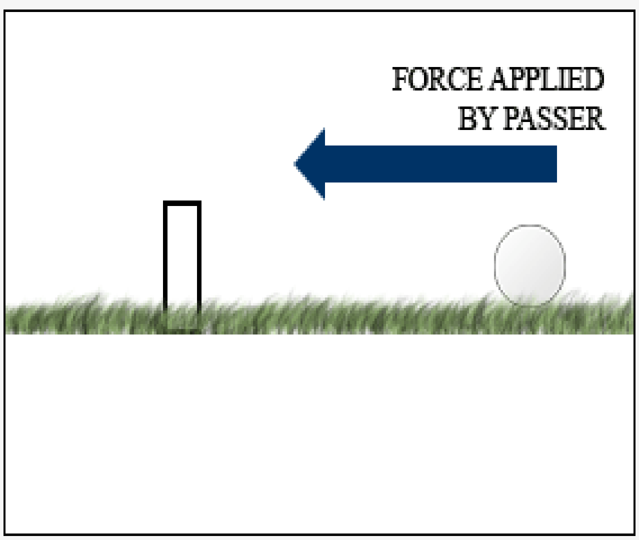

Fig 7

Conclusion

Soccer deals with physics in many more ways than meet the eye at a first glance. As a matter of fact, all sports deal heavily with physics. Physics is only confusing, overwhelming, and boring if we let it be. If we enjoy it for what it is and recognize the applications of it, studying it can be a very enlightening experience. By understanding physics, we gain a much better understanding of the world around us. Chances are we won't be taking this knowledge onto the "pitch" with us, as it will serve us little purpose in a game. However, it will help us enjoy the game more, as we will see it in a whole new light

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