Why does a golf ball have dimples?

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A golf ball can be driven great distances down the fairway. How is this possible? Is the drive only dependent on the strength of the golfer or are other factors at play? As we will see, the aerodynamic forces play a key role in the flight of the golf ball. We will start by looking at the history of the golf ball, show why a golf ball has dimples, then explain how lift is formed by the spin imposed on the golf ball. We will also look at how experimental tests can be performed using a spinning ball in a wind tunnel.

History of the Golf Ball

The early golf ball, known as a featherie, was simply a leather pouch filled with goose feathers. In order to obtain a hard ball, the pouch was filled while wet with wet goose feathers. Since people believed a smooth sphere would result in less drag (and thus fly farther), the pouch was stitched inside out. Once the pouch was filled, it was stitched shut. Therefore there were a few stitches on the outside of the ball. The ball was then dried, oiled, and painted white. The typical drive with this type of ball was about 150 to 175 yards. Once this ball became wet, it was totally useless.

In 1845, the gutta-percha ball was introduced. This ball was made from the gum of the Malaysian Sapodilla tree. This gum was heated and molded into a sphere. This resulted in a very smooth surface. The typical drive with the gutta-percha ball was shorter than that obtained with the featherie. However, according to golf legend a professor at Saint Andrews University in Scotland soon discovered that the ball flew farther if the surface was scored or marked.

This lead to a variety of surface designs which were chosen more or less by intuition. By 1930, the current golf ball with dimples was accepted as the standard design. The modern golf ball consists of rubber thread wound around a rubber core and coated with dimpled enamel. The dimples are arranged in rows. The number of dimples is either 336 for an American ball or 330 for a British ball. The typical drive with a modern golf ball is about 180 to 250 yards.

The Dimples

Why, then, does a golf ball have dimples? The answer to this question can be found by looking at the aerodynamic drag on a sphere. There are two types of drag experienced by a sphere. The first is the obvious drag due to friction. This only accounts for a small part of the drag experienced by a ball. The majority of the drag comes from the separation of the flow behind the ball and is known as pressure drag due to separation. For laminar flow past a sphere, the flow separates very early as shown in Figure 1. However, for a turbulent flow, separation is delayed as can be seen in Figure 2. Notice the difference in the size of the separation region behind the spheres. The separation region in the turbulent case is much smaller than in the laminar case. The larger separation region of the laminar case implies a larger pressure drag on the sphere. This is why the professor experienced a longer drive with the marked ball. The surface roughness caused the flow to transition from laminar to turbulent. The turbulent flow has more energy than the laminar flow and thus, the flow stays attached longer.

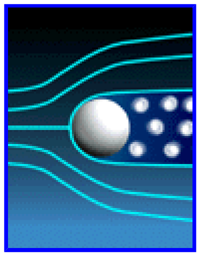


Figure 1: Laminar Flow Over a Sphere.

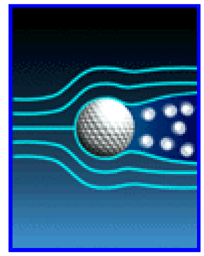


Figure 2: Turbulent Flow Over a Sphere.

So, why dimples? Why not use another method to achieve the same affect? The critical Reynolds number, Re_{cr}, holds the answer to this question. As you recall, Re_{cr} is the Reynolds number at which the flow transitions from a laminar to a turbulent state. For a smooth sphere, Re_{cr} is much larger than the average Reynolds number experienced by a golf ball. For a sand roughened golf ball, the reduction in drag at Re_{cr} is greater than that of the dimpled golf ball. However, as the Reyn olds number continues to increase, the drag increases. The dimpled ball, on the other hand, has a lower Re_{cr}, and the drag is fairly constant for Reynolds numbers greater than Re_{cr}.

Therefore, the dimples cause Re_{cr} to decrease which implies that the flow becomes turbulent at a lower velocity than on a smooth sphere. This in turn causes the flow to remain attached longer on a dimpled golf ball which implies a reduction in drag. As the speed of the dimpled golf ball is increased, the drag doesn't change much. This is a good property in a sport like golf.

Although round dimples were accepted as the standard, a variety of other shapes were experimented with as well. Among these were squares, rectangles, and hexagons. The hexagons actually result in a lower drag than the round dimples. Perhaps in the future we will see golf balls with hexagonal dimples.

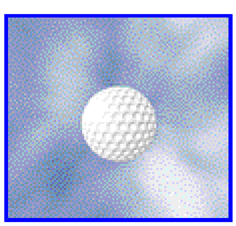


Figure 3: Golf Ball

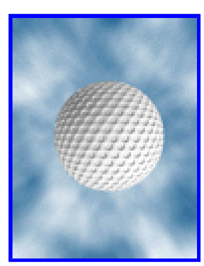


Figure 4: Turbulent Flow

with Round Dimples. with Hexagonal Dimples.

How a Golf Ball Produces Lift

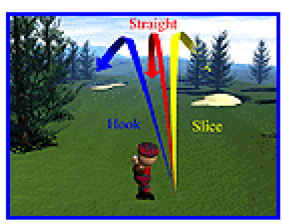
Lift is another aerodynamic force which affects the flight of a golf ball. This idea might sound a little odd, but given the proper spin a golf ball can produce lift. Originally, golfers thought that all spin was detrimental. However, in 1877, British scientist P.G. Tait learned that a ball, driven with a spin about a horizontal axis with the top of the ball coming toward the golfer produces a lifting force. This type of spin is know as a backspin.

The backspin increases the speed on the upper surface of the ball while decreasing the speed on the lower surface. From the Bernoulli principle, when the velocity increases the pressure decreases. Therefore, the pressure on the upper surface is less than the pressure on the lower surface of the ball. This pressure differential results in a finite lift being applied to the ball.

Figure 5: Smoke Flow Patterns
Over a Spinning Sphere.

The dimples also help in the generation of lift. By keeping the flow attached, the dimples help promote an asymmetry of the flow in the wake. This asymmetry can be seen in Figure 5. In this figure, the smoke shows the flow pattern about a spinning golf ball. The flow is moving from left to right and the ball is spinning in the counter-clockwise direction. The wake is being deflected downwards. This downward deflection of the wake implies that a lifting force is being applied to the golf ball.

Hook and Slice



A hook or a slice can be explained in the same way. If the golf ball is given a spin about it's vertical axis, the ball will be deflected to the right for a clockwise rotation and to the left for a counter-clockwise rotation. The generation of an aerodynamic force by a spin about the axis perpendicular to the flight path is known as the Magnus effect. The Magnus effect is important in most ball games.

Happy Nonhooker

In order to eliminate the hook or slice from a golfers game, modifications were made to the dimpled golf ball. Since we know how the dimples aid in producing lift, what if we removed the dimples from two sides of the ball and leave a strip of dimples around the equator. Then if we line up the ball on the tee such that the dimpled band is in the vertical plane, we can minimize the side force imparted by a spin about the vertical axis while still receive the benefits of the backspin. This ball was known as the Polara or the happy nonhooker. However, the United States Golfing Association soon became concerned that this ball would "reduce the skill required to play golf and threaten the integrity of the game." So they amended the rules to require that a "golf ball be designed to have equal aerodynamic properties and equal moments of inertia about any axis through its center." This new rule effectively made the happy nonhooker illegal.

Effect of gravity

During the last part of a golf balls flight, the gravitational forces become dominant. As the balls velocity decreases due to the drag imposed upon it, the lift decreases. At some point, the lift will no longer be greater than the weight and the ball will begin falling to the ground.

Experiments

The effects of the dimples on a spinning golf ball were measured experimentally. This was done by placing a model of the golf ball in a wind tunnel. Several problems occur whenever wind tunnel experiments are made. The most obvious is how do we keep the model in the center of the test section? For the spinning golf ball, another basic question must be answered - How do we make the ball spin? Scientist always seam to have answers for questions like these. Wires were used to suspend the model in the tunnel. The diameter of the wire had to be much smaller than the golf ball in order to minimize any possible interference effects. Also, to stabilize the ball, two wires had to be used. The first suspends the ball from the top of the tunnel, while the s econd stabilizes the ball from the bottom.

Applying the spin to the ball is a harder problem. To solve this, a hollow golf ball is used. A small motor and bearing assembly on which the ball revolves is placed inside the ball. The wires also serve to supply a voltage to the motor assembly.

Not only do the wires provide support and the necessary voltage for the motor, they also help in analyzing the forces acting on the ball. The upper wire is mounted to a strain-gauged arm which measures the lift force on the ball. It should be noted that since the ball is spinning about the vertical axis, this force is actually a side force.

The strain gauge is in turn mounted to a rigid support attached to a wind-tunnel three-component balance. The wind-tunnel balance is used to measure the drag on the golf ball.

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