Paragraph No.

Some Physics of Golf Balls adapted freely from articles published online at www.titleist.com by the famous golf ball manufacturers.

This all started when Scottish physicist Peter Guthrie Tait began publishing a series of scientific papers in 1890. These papers were pioneering in their recognition that air had a lot to do with a 1
golf ball's amazing trajectory.

No doubt it is counterintuitive that the overall effect of air on the flight of the golf ball is, in fact, very positive. After all, wouldn't wind resistance slow the ball down and make it drop, rocklike, to mother earth? Believe it or not, a shot that flies 230 yards in the normal atmosphere would only fly about 160 yards in a vacuum. How can this be? Strangely enough, golf balls are 2
brethren to wings, and wings don't work if there's no air. By the magic of aerodynamics, the spinning ball makes lift, suspending itself against gravity. So it flies further even though wind resistance (or drag, as aerodynamicists call it) is slowing it down. If the air were to disappear, then the drag would disappear, but so would the lift. The net result? The ball goes further when there's air around.

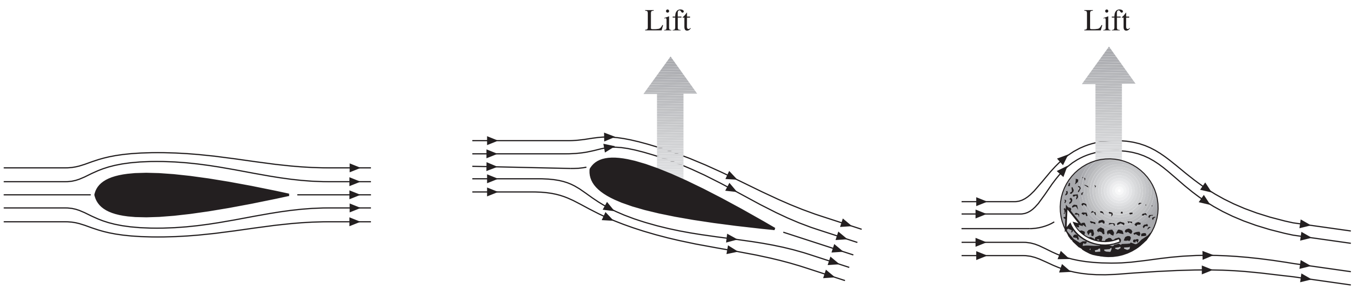
Lift and Drag

Every time we stick a hand out the car window at 50 mph we're reminded that air exerts a force on any object moving through it. Scientists like to break this force down into two basic 3
components: drag, which acts directly opposite the motion to slow the object down; and lift, which acts at right angles to the drag and generally upward.

The Origins of Lift

To the uninitiated, watching a golf ball fly is an amazing experience. It hangs in the air for an astonishing length of time, as if supported by a force field. And it flies twice the length of a 4
football pitch. All of this goodness is possible because of the aerodynamic lift force. But where does it come from?

While a person wouldn't confuse a golf ball with a 747 wing, a wind tunnel might. To the air, they look very much the same. When a simple wing is placed in an air stream and aligned with the flow direction, it simply slices through the air with minimal fuss and generates no lift. 5
However, if it is inclined to create an angle of attack, then interesting things start to happen. It deflects the airflow downward, creating an upward reaction force (Newton's Third Law: "To every action there is always opposed an equal reaction") - which we know as the lift.



Simple Wing Aligned with Airflow | Simple Wing at Angle of Attack | Golf Ball with Spin and Dimples

A golf ball may look portly next to a streamlined wing, but it manages to do similar things to the airflow. When a golf ball is placed in an air stream, it pushes through the air creating a considerable disturbance (that's the portly part), but generates no lift. Here's the good part: 6
given some backspin, it warps the airflow very much like the angled wing, deflecting the air downward and creating lift.

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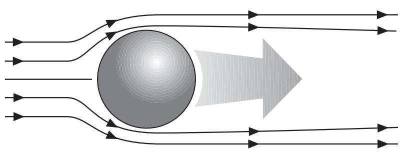
No.

The Origins of Drag

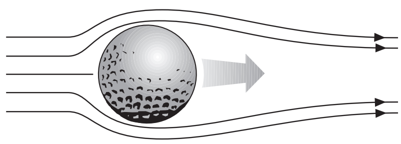
Move any object through the air, and you’ll get some drag. Most flying bodies have a
streamlined profile by design or by nature, so that they cut through the air cleanly with minimal 7
drag. But a golf ball has to be (guess what . . .) a ball, so it is destined to be an air punch rather
than an air knife. This makes for a large drag force.

The air hits the front of the ball, creating a high pressure area, and splits around to the sides. But
it’s going too fast to make the turn to the back of the ball. It separates from the surface, leaving
a low pressure wake like the one a boat leaves in the water. This combination of high pressure 8
on the front of the ball with low pressure on the back is the main source of a ball’s drag.

The solution to drag? Dimples. When the surface of the ball is covered with dimples, a thin
layer of air next to the ball (aerodynamicists call it the boundary layer) becomes turbulent.
Rather than flowing in smooth, continuous layers (a laminar boundary layer), it has a 9
microscopic pattern of fluctuations and randomized flow. Here’s the good part: a turbulent
boundary layer can follow the curvature of the ball’s profile better. It travels further around the
ball before separating, which creates a much smaller wake, and much less drag. In fact, a
dimpled golf ball has only about half the drag of a smooth one.



Ball Punching
Through the Air



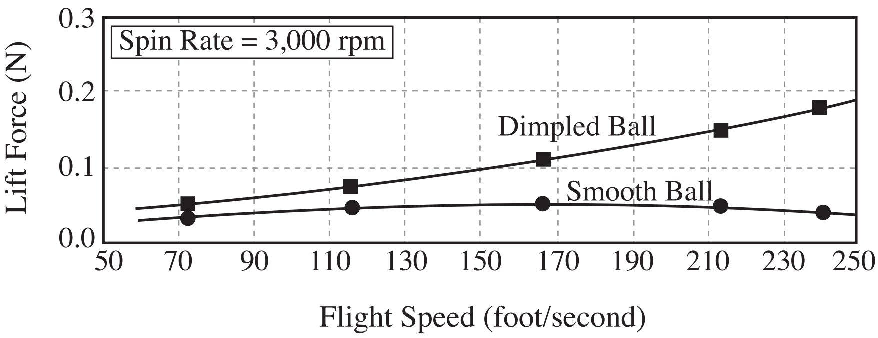
Dimpled Ball Punching
Through the Air

Origins of Measurement and some Modern Results

Many a golf ball guru would explain (wrongly) that a ball without dimples creates no lift. But
more than 250 years ago, Benjamin Robins was able to demonstrate the lift force on a spinning
musket ball without dimples. And any serious table tennis match will provide example after
example of wildly curving, floating, or diving shots produced by lift forces acting on spinning 10
smooth balls. The common factor here is spin, not dimples. As we saw above, it’s the spinning
action of the ball which warps the airflow and makes the ball act like a wing. This is not to say
that dimples have no effect on lift. To the contrary, they can affect both the amount and the
direction of the lift, especially at low speeds.

Paragraph No.

Graph of Lift Force against Flight Speed

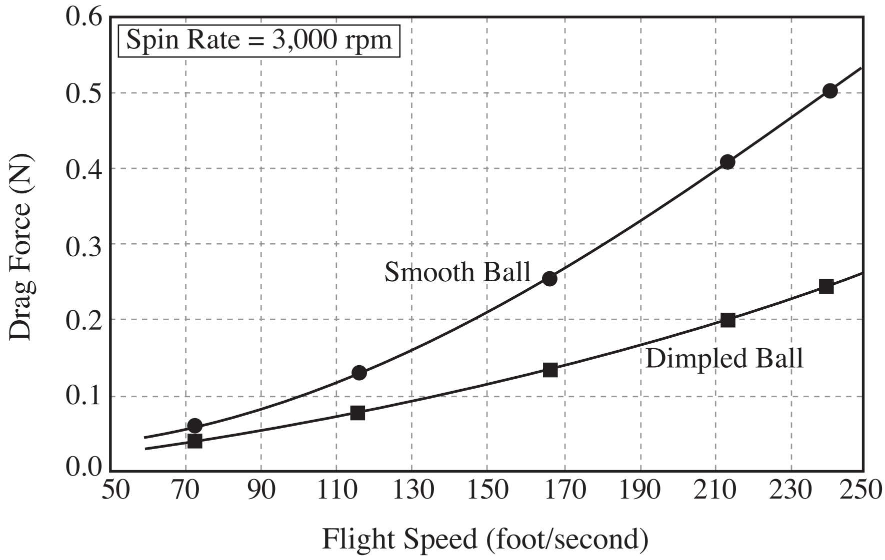


Graph 1

The graph shows the lift forces measured in a wind tunnel on both a smooth golf ball and a dimpled one at identical spin rates of 3,000 revolutions per minute (a typical value for the first part of a drive). While the smooth ball doesn't generate as much lift as the dimpled one, it does create a substantial amount - equivalent to about 1/3 to 1/2 of its own weight for much of the speed range. So in reality, it's the spin that creates the lift. The dimples just tailor the lift to be more useful for a golf ball. 11

It is often said (wrongly) that dimples increase the drag on the ball, but since they are necessary to create the lift, the tradeoff is worth it. Your average Joe Golfer would accept this at face value because it agrees with (guess what?) our common sense. A smooth ball would slide through the air with less friction, right? So a dimpled ball would have more air friction, and thus more drag. Makes sense. Unfortunately, it's completely wrong. 12

Graph of Drag Force against Flight Speed



Graph 2

First, as we have discovered, the dimples don't create the lift, they only improve it. And second, the dimples substantially reduce the drag by creating a turbulent boundary layer which reduces the wake. Wind tunnel tests verify this, as shown in the graph above. Measured drag forces for a smooth and a dimpled golf ball are compared throughout the full speed range. Clearly, the dimpled ball generates much less drag, only about half as much as the smooth one. This drag reduction is the most important contribution of the dimples. 13