written by Steve Aoyama (Titleist)

When it comes to sporting projectiles, Golf is King. But what about baseballs? Basketballs? Footballs? Tennis balls? Forget about it. Nothing but concoctions of skin, bark, and hair. Where's the technology? In golf balls, that's where. High technology materials engineered into high precision airframes with high performance flight capabilities.

A golf ball's performance dwarfs that of any other ball in sport: A child can easily hit one out of a Major League ballpark and the average adult can launch one an eighth of a mile. What makes a golf ball fly like that? In a word, AERODYNAMICS. While other sporting projectiles push through the air, golf balls soar through it.

The aerodynamics of the golf ball is a complicated topic. Although scientists and others have scrutinized it for over a century, the topic remained largely a mystery until perhaps the last 20 or 25 years. But even today, some of the details still defy analysis by supercomputer, let alone your 98 pound Pentium 166. It is one aspect of a golf ball's engineering that remains, in part, a technological art.

Tech Art or Cave Art?

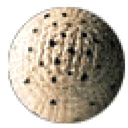
Featherie (c. 1400)

It is tempting to assume that all of the great tech stuff happened after we figured out how to make beach sand into microchips. But with a pastime as ancient as golf, something must have clicked early on or it never would have survived this long. That hook may well have been the Featherie golf ball, perfected by the Dutch around five or six hundred years ago from a basic technique used for game balls in ancient Rome. They would stuff a hatful of wet feathers (and remember, they liked BIG hats in those days) into a wet inch-and-a-half leather pouch, sew it up, and let it dry. The feathers would expand, and the leather would shrink, creating a ball as hard as... well, a golf ball. This made for a very resilient and lively projectile, especially when compared to the wooden(!) balls used previously.

Guttie (c. 1860)

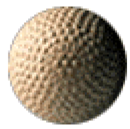
The featherie performed remarkably well on the links, as evidenced by a recorded drive of 361 yards by Samuel Messieux in 1836, at the Old Course in St. Andrews! Sure, it was just skin and bird hair, but it was still a quantum leap by any measure, sort of the transistor of golf balls. For more than 400 years, it was the ball of choice. That is, if you could afford it. These ball's extravagant cost (the best ballmakers could produce only four or five per day) sealed their ultimate fate when the cheap "guttie" ball appeared around 1850.

Blind Genius



Hammered Guttie (c. 1870-80)

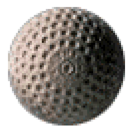
This new ball was made from a solid piece of gutta percha, a natural gum from Malaysia. Not only did it make a cheap and durable golf ball, it also made a lively, rounder and smoother one without the featherie's ugly stitched seams. Thus it was both unfortunate and inexplicable that the guttie's performance was no match for the featherie. It ducked and veered unpredictably, falling considerably short of the old bag of feathers.



Bramble Pattern (c. 1890)

But hackers soon noticed that the more they scarred the ball, the longer and straighter it flew. So why wait? Fresh new gutties were soon being mercilessly hammered right out of the box, before the first stroke was taken. Golf ball aerodynamics had been discovered, if not understood. For 400 years, no one had suspected that the featherie owed its graceful flight to its ugly seams, which acted like the scars of a veteran guttie.

Behold the Dimple



Early Dimple Pattern

Pounding each new guttie must have been quite inconvenient, not to mention inconsistent. So it didn't take a rocket scientist (fortunately, considering the era) to figure out that there would be a marketing advantage for a pre-hammered ball. By the turn of the century, gutties were being sold with all manner of grooves, gouges, divots, bumps, and lumps already molded into their surfaces. Of course, aerodynamics was still a murky endeavor at that time, so these designs were more artistic than scientific. But they were still far better than smoothness. Out of this field, the emerging early winner was a design called the bramble pattern, which featured a closely packed array of bumps like the surface of a raspberry.

Modern Dimple Pattern

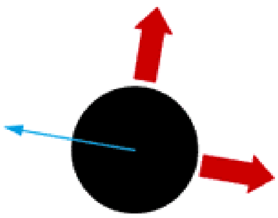
Taken from http://www.titleist.com/technology/aero.asp

Today, we might still be using golf balls resembling fruit if not for English engineer William Taylor. In 1908 he received a patent for, among other things, an inverted bramble pattern which consisted of evenly distributed circular depressions covering the surface of the ball. That's patentese for dimples. Unlike many of the other configurations, dimples proved to be as effective aerodynamically as they were cosmetically, and they virtually owned the market by 1930. Aside from occasional departures, the circular dimple in one form or another has been pretty much standard equipment ever since.

Aerodynamic Basics

Why is There Air?

Given that golf is the most technical sport, and scientists are the explorers of technology, it was only a matter of time before the two got together. From an aerodynamics standpoint, that didn't happen until near the turn of the century, by which time golf was already hundreds of years old. The science of aerodynamics, however, was still young at that point. It should come as no surprise that the momentous event occurred in Scotland, when physicist Peter Guthrie Tait began publishing a series of scientific papers in 1890, which were pioneering in their recognition that air had a lot to do with a golf ball's amazing trajectory.



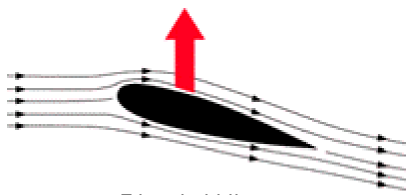
The Aerodynamic Forces on a Golf Ball

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 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 farther even though wind resistance (or drag, as aerodynamicists call it) is slowing down. If the air were to disappear, then the drag would disappear, but so would the lift. The net result? You'd be pulling out the Big Stick for a middling par 3 (assuming you could swing it while wearing a space suit).

Simple Wing Aligned with Airflow

Lift and Drag

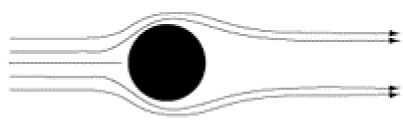
Every time we stick a hand out the window at 65 mph (don't try this at home if you live in a 55 state!), we're reminded that air exerts a force on any object moving through it. Scientists like to break this force down into two basic components: drag, which acts directly opposite the motion to slow the object down; and lift, which acts at right angles to the drag and generally upward.



Simple Wing at Angle of Attack

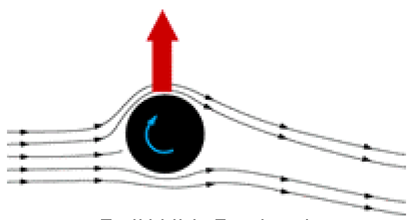
The Origins of Lift

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 as far as a towering second-deck home run. All of this goodness is possible because of the aerodynamic lift force. But where does it come from?



Ball with No Spin

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 hoopla, and generates no lift. 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.)



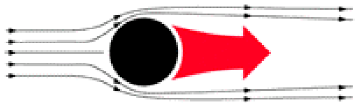
Ball With Backspin

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: given some backspin, it warps the airflow very much like the angled wing, deflecting it downward and creating lift.

Taken from http://www.titleist.com/technology/aero.asp

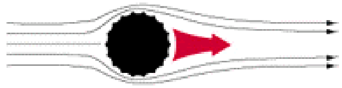
Aerodynamic Basics

The Origins of Drag



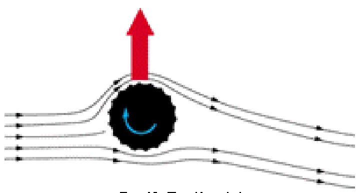
Ball Punching Through the Air

Move any object through the air, and you'll get some drag. Most flying bodies (not including the occasional golf club) have a streamlined profile by design or by nature, so that they cut through the air cleanly with minimal 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.



Dimpled Ball Punching Through the Air

The air hits the front of the ball, creating a high pressure area, and splits around to the sides. The air however is going too fast to make the turn around 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 on the front of the ball with low pressure on the back is the main source of a ball's drag.

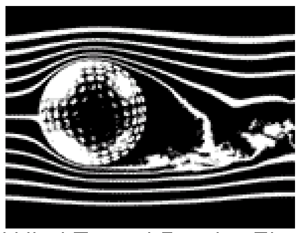


Golf Ball with Spin and Dimples

This may seem hopeless, but it's not. Maybe you can't control the teenager, but you can put better tires on his or her car. The solution? 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 microscopic pattern of fluctuations and randomized flow. Here's the good part: a turbulent boundary layer has better tires. It can better follow the curvature of the ball's profile. It travels farther 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.

Putting it all Together

If we combine the spinning motion, which warps the airflow and creates the lift, with the dimples, which reduce the wake and cut the drag, we get the flow pattern around a golf ball.



Wind Tunnel Smoke Flow (Picture F.N.M. Brown)

Proof, you say? Professor F. N. M. Brown of the University of Notre Dame was famous for his work in visualizing flow patterns by injecting streams of smoke into a wind tunnel.

To the left is one of his pictures of an actual spinning dimpled ball. While the spin rate he used appears to have been quite low by golf ball standards, you can still see the warpage of the flow field, especially in the angle at which the wake trails away from the back of the ball.

Common Myths

Golf ball aerodynamics is one of the most pervasively misunderstood (or just un-understood) technical subjects in the game. Not that there's a shortage of "experts", there's just a shortage of actual knowledge. Misinformation rules in print and broadcast media, advertising, and sometimes even in technical documents like patents. Here are some of the more common misconceptions, along with the truth.

Myth: Dimples give the ball "traction" on the air.

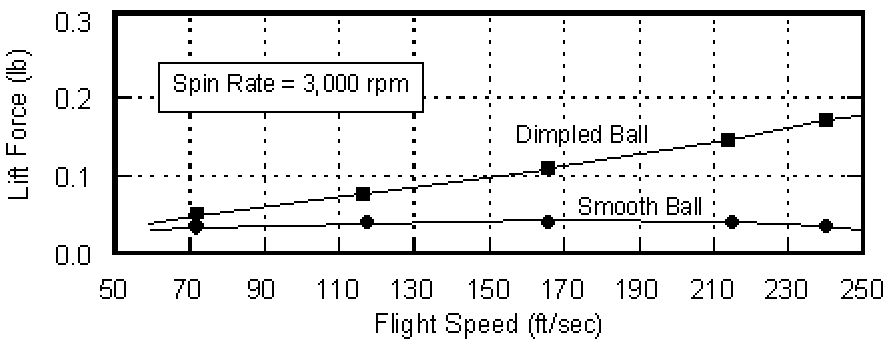
Sort of like a snow tire? This is one which appeals to our common sense notions about airflow. Unfortunately, common sense is often wrong about aerodynamics, and that's the case here. Truth #1 taken from Intro to Aerodynamics I: When a golf ball or any other solid object moves through the atmosphere, a thin layer of air (the boundary layer) sticks to it and is dragged along with it. There is no slipping between the object and the air. Therefore, the issue of "traction on the air" is completely irrelevant and without a shred of meaning. Slipping never occurs, no matter how smooth and slick the surface of the ball may be.

Taken from http://www.titleist.com/technology/aero.asp

Myth: Dimples create lift

Amazing but true: A smooth golf ball will only fly about half as far as one with dimples. But why does this happen? Many a golf ball guru would explain that a ball without dimples creates no lift. But more than 250 years ago, B. Robins was able to demonstrate the lift force on a spinning dimpleless musket ball. 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 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.



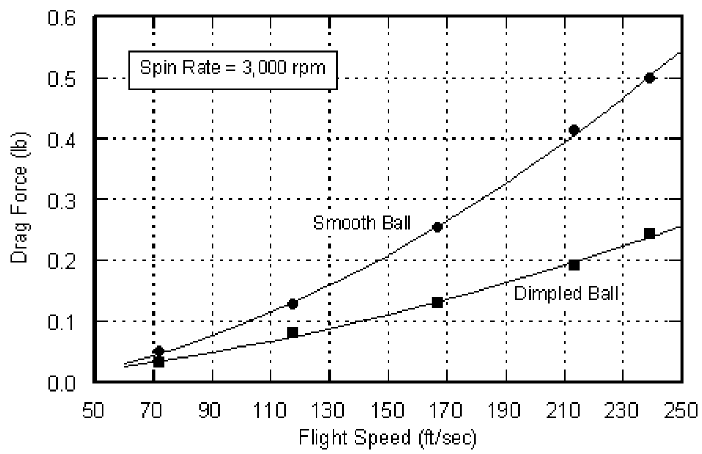
Lift Force on Smooth and Dimpled Golf Balls

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 rpm (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.

While the improved lift on a dimpled ball is part of the reason for the extra distance, that's not the whole story. It's not even most of the story. As we've seen above and will verify below, the dimples cut the drag, which pays off even bigger.

Myth: Dimples increase the drag

It is often said 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.



Drag Force on Smooth and Dimpled Golf Balls

First, as we have discovered, the dimples don't create the lift, they only improve it. And second, as shown in History of the Golf Ball, Aerodynamics, 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. Strike two for common sense.

Common Myths (continued)

Myth: Large, shallow dimples make a ball fly higher.

This notion is only half wrong. It probably traces back to the early 1970s, when the so-called "Big Dimple" Titleist was introduced. This ball had a noticeably higher trajectory than many of its contemporaries, and its novel dimple pattern had noticeably large and shallow looking dimples, and thus was made the connection. But the truth is somewhat different: All else being the same, its true that shallower dimples will generally make a golf ball fly higher. But larger dimples will actually make it fly lower. Why, then, was the "Big Dimple" Titleist a high flier? Because even though the dimples were large, they were also very shallow for their size, shallow enough that the net result was a higher trajectory.

Myth: More dimples make a longer ball.

In 1983, Titleist introduced the 384 Tour, a new generation ball which had 60 more dimples and, for many golfers, significantly more distance than its predecessor. This ignited a "dimple war" in the industry, when many companies' marketers went for the easy sell with "more dimples = more distance" campaigns. If this sounds entirely too easy (Want more distance? Just put more dimples on the ball . . .), well, it is. Just a little thought will reveal that it doesn't even make sense. If it were true, then thousands of tiny dimples would make a very long ball. And millions of microscopic dimples would let anyone reach par fives in one. But aren't these balls becoming more like smooth balls? We already know that smooth balls only go about half the distance of dimpled ones.

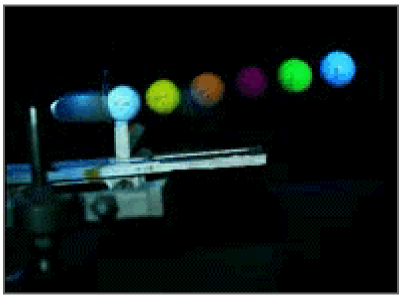
The truth is that the number of dimples is not a very important parameter. Any number from around 300 to around 500 works quite well. It's far more important to carefully optimize the dimensions of the dimples to provide the desired lift and drag characteristics.

Myth: Golf balls lose distance in humid air.

This is another one that is easy to believe because it agrees with our common sense. Humid air feels heavy, and therefore the ball should have a tougher time punching through it. But in truth, humid air is actually lighter than dry air, and the ball will actually fly farther. Strike three. But don't bother seeking out muggy days to do a John Daly impression, because the advantage is truly minuscule. The best one could hope for would be a gain of about 18 inches.

Myth: Put overspin on the ball for more distance.

There are television golf commentators who time and again will attribute a particularly long carrying and/or rolling shot to the player "putting a lot of overspin on the ball." This is utter nonsense for two reasons: first, it is impossible to put any overspin on any shot other than a cold-topped one, and second, even if it could be done, the shot would be much shorter than one with backspin. With overspin, the lift force, which normally helps hold the ball in the air against gravity, reverses and helps gravity pull the ball down. Such a shot would only fly a small fraction (perhaps 1/4) of the normal distance, and even with a lot of extra roll will still wind up short by about half.



To beginners and pros alike, the flight of a smartly struck golf ball is a thing of beauty, marvelous to behold and boosting to the ego. No matter how badly we might play on any given day, no matter how many three-putts in a round, it's that one purely struck shot that keeps us coming back for more. If this is the addiction of golf, then dimples must bear the shame. Without them, we wouldn't bother.