SOMETHING IN THE AIR

Separating fact from folklore about the effects of temperature, humidity, altitude, and wind.

BY DAN VUKELICH

Roy: "I nutted that thing. Little gust from the gods cost me."

Romeo: "Helluva move you put on that sucker. Now let's get up there and take the drop and make our par…."

Well, we know how that movie ends. A little gust. A puff. A swirl. Do we have to read the tea leaves—or tree leaves—to figure out how much a given wind will affect a given golf shot? And what about altitude, heat or humidity? Or gravity?

Yes, gravity.

In Albuquerque, N.M., 5,000 feet above sea level, the task of quantifying golf's environmental variables has vexed me for years. Traveling to a place closer to sea level like most of the New York metropolitan area, I typically need two or three holes to figure out how far my shots will go, and by then the round's shot. At least, that's my story.

So let's tackle these environmental variables in order, from least to most important.

First, gravity.

I made a quick call to James Thomas, associate professor of physics and astronomy at the University of New Mexico. The effect of gravitational force, he said, depends on how far from the center of the Earth that force is being measured.

"That distance, about 3,950 miles, is large compared with the additional mile you might add going from sea level to Albuquerque," he said, so the effect of gravity on a golf ball anywhere on earth is negligible – on the order of 0.04 percent, or a mere 3.6 inches for a 250-yard drive.

So, no, not gravity.

But here's a fact you'll likely read here and nowhere else: The effect of a golf shot's direction of travel relative to the rotation of the Earth can be calculated. Hitting east to west, against the Earth's rotational direction, means your shot will travel farther than the same shot hit west to east. If you doubt this, talk to a military sniper who actually has to do this calculation to "lead" his target enough to compensate for the Earth's movement beneath the bullet in flight.

The difference, about 3 inches over 1,000 yards, matters when a rifle shot has to travel that far to reach a target the size of a human organ. For us, trying to hit a fairway or a green over a distance of 200 yards or so, it's less than an inch – like gravity, not worth figuring into my calculations.

Next, humidity. Living in the desert, I assumed that when I played at Bandon Dunes in a light fog, humidity was to blame for my puny drives. Here, too, Professor Thomas set me straight. Higher humidity actually *increases* your drive's distance.

Although we think of humidity as making the air "heavy," a molecule of water vapor has less mass than the molecule of air it displaces; humid air is lighter and "easier for the golf ball to push aside," Thomas said. But again, the effect is slight – just 0.5 percent, or 1.25 yards, for a 250-yard drive hit on a muggy day in which the relative humidity is above 50 percent.

Next came temperature. This is where the guys who make their living designing golf balls stepped up. I spoke by phone with Eric Loper, head of golf ball R&D at TaylorMade-adidas, and I got an email response to my questions from Steve Aoyama, principal scientist for golf ball R&D at Acushnet, the maker of Titleist golf balls.

First: hotter means longer, because just as with humidity, hot air is less dense than cold air and offers less resistance to the ball in flight.

Loper broke down the effect of temperature on players of different abilities – a long-hitting PGA Tour player with a swing speed of 125 miles an hour and an amateur with a swing speed of 100. Then he parsed things further by club used.

Between 30 to 110 degrees Fahrenheit, each 10-degree change represents a 3.4-yard difference in driver distance for a Tour player and 1.9 yards for an amateur. (A player with a swing speed around 90 mph would see a difference of roughly nine-tenths that of the 100-mph swing-speed player – and all these calculations assume solid and dependable contact.)

With a 5-iron, each 10-degree increment translates into 2.1 yards for the Tour player and 0.8 for the amateur. But it's not consistent for all irons. "As you go up in loft you see a smaller and smaller increase in distance" for shots struck in warmer air, Loper said.

Next, we discussed altitude. Titleist's Aoyama prefaced his remarks with the caveat that "the effect will vary greatly depending on the golfer and what club is being used." He offered a rule of thumb for shots that are well-struck, not thinned, chunked, heeled, or toed.

"[A]s a starting point," he wrote, "one can estimate the percentage distance increase (compared to sea level) by multiplying the elevation (in feet) by 0.00116.

"For example, at 5,000 feet elevation the increase is about 5,000 multiplied by 0.00116, which equals 5.8 percent. Thus, a golfer who drives the ball 250 yards in Los Angeles might see an increase of 14.5 yards (5.8 percent of 250 yards) when playing in Denver."

Aoyama also noted that at a higher elevation, a ball's trajectory "is less influenced by lift, and thus has a 'flatter' shape and a more glancing impact with the ground…This produces extra roll, which contributes to the increased distance but also makes it harder to hold the green, even though the spin is the same," he wrote.

Amateurs, he added, also should recognize that thinner air decreases the severity of a slice, fade, draw or hook because lifting forces created by sidespin are reduced. He calculated that at 5,000 feet, a shot curves 14 percent less than the same shot struck the same way at sea level.

The USGA people who decide what balls and clubs make their conforming equipment list take this stuff seriously. Their protocol for golf ball testing mandates that a ball isn't conforming if it

travels more than 317 yards when hit by an "Iron Byron" ball-striking machine under specific environmental conditions: 75 degrees Fahrenheit, 50 percent relative humidity, and at 30 inches of mercury (a measure of air pressure).

Everyone I talked to, however, said all of these variables are chump change compared to the effect of wind. Loper laid it out in the most detail and in the process confirmed my first golf teacher's maxim that, "Any wind you can feel on your face is a one-club wind."

All of these variables—**temperature, humidity, altitude, gravity**—are chump change compared to the effect of wind.

As measured by TaylorMade, for an amateur with a 100-mile-an-hour swing speed, each 5 miles an hour of head wind reduces driver distance by 9.7 yards and 5-iron distance by 5.3 yards. For a Tour player, that same head wind will cut driver distance by 16 yards and 5-iron distance by 11.7 yards. (The effect on the Tour player's ball is greater because it's in the air longer).

Loper said the effect of a tail wind is roughly the opposite of a head wind. A ball hit in a tail wind won't climb as high as the same shot hit into a head wind. Nonetheless, the tail wind shot goes farther because of its higher velocity, and its lower flight path translates into more roll.

Crosswinds are trickier because there is an infinite number of possibilities, but for simplicity's sake, Roper calculated that a 5 mph crosswind blowing directly across the line of play at a 90-degree angle will move a Tour player's drive offline by 12.2 yards and the amateur's by 7.6 yards. With a 5-iron, the Tour player's deviation is 9 yards; for the amateur it's 4.8 yards.

While calculating the effect of the individual variables is easy, calculating their combined effects is tougher – playing at between 5,000 and 6,000 feet in the Barracuda Championship in Reno, Nev., for example, on a 90-degree day, in a 10 mph crosswind, on a hard and fast golf course. You'd need the computing power of a golf app that hasn't been invented yet – or the services of a good Tour caddie.

I asked about downhill and uphill lies and hitting to an uphill or downhill target, but Loper said there are too many player-related variables in those scenarios to develop a meaningful rule of thumb.

To put all this in context, I called Curt Byrum, a Golf Channel commentator who played his college golf at altitude in Albuquerque for the University of New Mexico, then went on to compete in 371 PGA Tour events from 1982 to 2002.

He typically calculated altitude's effect on distance at 10 percent when he traveled to play at sea level, but thanks to the digital revolution, he said, that kind of "guesstimation" largely has been replaced by technology – principally TrackMan radar ball-flight analysis and the Kestrel pocket anemometer.

"At the World Golf Championship two years ago at 8,000 feet in Mexico City, I went by the range and 25 guys were hitting balls. All had their TrackMan out. They weren't worried about the ball's path, just how far it was going," he said.

With data from the range and practice rounds, by the time a Tour player steps onto the first tee only a few variables remain – mostly wind and firmness of the fairways and greens.

For the rest of us, he suggested amateurs put the other variables aside and focus on whether the wind is blowing, then take more club and put a smoother swing on it.

"I've played in plenty of pro-ams on windy days and see 10- and 12-handicaps hitting it OK, but they just don't seem to take enough club for the wind," he said.

Because it's that little gust from the gods that will get you. ■

Elevations and Adjustments

Steve Quintavalla, USGA director of equipment research and testing, provided us a detailed breakdown of the proper yardage adjustments for altitude at a variety of swing speeds. The chart below assumes a temperature of 70 degrees Fahrenheit, 50 percent relative humidity, and no wind; the numbers in the chart show how much farther a ball will travel at the various swing speeds compared to a 225-yard drive at sea level.

DISTANCE ADDED IN YARDS BY ELEVATION AT VARIOUS SWING SPEEDS

Elevation (ft.)		1000	2000	3000	4000	5000	6000
City		Atlanta/ Phoenix	Las Vegas	Billings, MT	El Paso	Albuquerque	Colorado Springs
Swing Speed (mph)	90	2	4	6	7	9	10
	100	3	6	8	11	13	15
	110	4	8	11	15	18	21
	120	5	9	14	18	23	27
	125	5	10	15	20	25	29

DISTANCE ADJUSTMENTS BY TEMPERATURE

Assuming constant humidity and no wind, these are the expected distances for a Tour pro and amateur based on a driver distance of 280 yards at 70 degrees Fahrenheit for the pro and 225 yards for the amateur, and 200 and 170 respectively with a five-iron.

TEMPERATURE	DRIVER		5-IRON	
	Tour Player	Amateur	Tour Player	Amateur
30°	266.4	217.4	191.6	166.8
40°	269.8	219.3	193.7	167.6
50°	273.2	221.2	195.8	168.4
60°	276.6	223.1	197.9	169.2
70°	280	225	200	170
80°	283.4	226.9	202.1	170.8
90°	286.8	228.8	204.2	171.6
100°	293.2	230.7	206.3	172.4
110°	296.6	232.6	208.4	173.2