THE GOLF BALL PROBLEM -- AN INTERIM REPORT

BY

DR. W. E. GORDON
Arthur D. Little, Inc.

PERHAPS the golfer's most gratifying sensation is the crisp reaction he gets from a well-hit ball. The drive is a big part of the game. Its importance and much of the game's popularity have followed the development of a really good ball.

The modern golf ball is a gem of mass-produced perfection, far removed from the old gutty and the ancient feather ball. For the last 20 years or more, however, the ball has remained substantially unchanged.

The Rules of the United States Golf Association are one deterrent to a livelier ball. The USGA opposes, and quite naturally, chaotic and irresponsible merchandising and technical changes that would tend to spoil the game. Its Rules represent an effort to standardize the golf ball in the best long-term interests of the game.

If drives should become much longer, courses would begin to lose their challenge to the player and the game would suffer immensely. Obsolescence has indeed already overtaken some of the older courses. Many clubs are so fenced in by real-estate developments that they cannot expand their courses without exorbitant expense.

Manufacturers certainly would not benefit from a radical change in the ball. One of the improvements in recent years that has benefited golfers and generally improved the game is the standardization of the ball through mass production.

The spirit of industrial enterprise being what it is, however, the ball manufacturer is constantly improving his product and trying to outdistance his competition.

USGA Control

The USGA therefore has the difficult problem of framing rules that allow genuine improvements in golf implements on the one hand and prevent undesirable changes on the other.

In 1940 the USGA engaged the Armour Research Foundation to assist it in framing a rule that would put an upper limit on the liveliness of the golf ball. The Foundation developed a machine that drives the ball and measures its velocity in a reproducible and accurate way. Rule 2-3 in The Rules of Golf specifies that the ball shall not travel faster than 250 feet per second when tested on this machine. A reasonable tolerance of 2 per cent is allowed. The machine is set up in "Golf House," in New York.

Balls of all makes are tested by the USGA at regular intervals; the balls usually are obtained through normal retail sources. Over the years since the Rule was put into effect, the velocity has changed very little. Within each brand the uniformity is amazingly good, and the total spread between brands is not large. The velocity of many brands does crowd the prescribed limit.

The USGA would like, however, a portable and more convenient apparatus than its present one. With a portable apparatus, tests could be made at Championships to ensure that balls used complied with the Rules. And, of course, it is interested in a scientific reappraisal of its procedures.

In December, 1957, the Implements and Ball Committee submitted this problem as part of an assignment to Arthur D. Little, Inc., of Cambridge, Mass. A portable test machine can be made from any one of several present designs; the problem is one of accuracy.

The job has not been simple. An idea of the problem's complexity can be obtained from the following questions that bring out various phases:

> Does the present USGA velocity rule sufficiently define or restrict

> the distance that the ball may travel when struck by a modern long driver?
>
> Can a long driver gain extra yards by using a certain type of ball that would not give a corresponding or proportional extra yardage to an average driver?

The belief is fairly common that a hard, tightly wound, or high compression, ball does indeed give the long driver this advantage. We can therefore phrase another question:

> What is the relationship between the compression, or hardness, of the ball and its performance when struck by the long driver and by the average driver?

These questions seem to be based on the assumption that the length of the drive is more or less proportional to the velocity of the ball when it leaves the club. Lord Brabazon, of Great Britain, has questioned this assumption by making a rather startling suggestion, implied in the following question:

> Does a long driver gain a disproportionate advantage because of a natural phenomenon having to do with a so-called critical Reynold's Number?*

Distance Bonus for the Long Hitter?

This idea of a critical Reynold's Number has been supported by some theoretical scientists in Great Britain. It can be simply described as a disproportionately small air resistance encountered by a ball when it travels above a certain critical speed. According to this idea, a driver whose ball can reach this magic velocity gets a bonus not available to his less gifted brother.

Another important question brings the club into the picture:

> Does the long driver obtain a high velocity by using a heavier than average club?

Although it may seem obvious that a long driver strikes the ball with more force than the average golfer, it may not be altogether foolish to ask this question:

> Does the long driver by virtue only of superior skill obtain a more efficient impact with the ball or perhaps a better trajectory, thus getting a longer drive without a significantly harder stroke? (Surely if this were so, no one should wish to reduce his relative advantage!)

There are questions pertaining not to the ball, but to the club. For example:

> Does the improved shaft in the modern golf club bring about longer drives?

Or one can worry about the future by asking such questions as these:

> Could there be developed from new synthetic materials a ball that would differ markedly in behavior from the present ball and make the present velocity rule inadequate?
>
> Could wood, plastic and bone be replaced with a clubhead material that would give a more efficient impact with the ball?

Many scientists would say offhand that most of these questions could be answered very simply if the elementary physics of Newton's Laws were applied. Unfortunately, this is not the case. Newton's Laws do indeed provide the basic framework for the theory of impact and flight of the ball, but the theory is by no means so simple. Ultimately a good working theory, or model, as the scientists call it, would have to be derived if all of these questions were to be answered satisfactorily.

Coefficient of Restitution

The attempt to develop this theory was the point of departure for our study. From

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* *The Reynold's Number is a physicists' term which describes properties of the relative motion of solid objects and fluids. One can arrive at this number in a particular case by multiplying the velocity of the object by its diameter and by the density of the medium through which it is moving and then by dividing this product by the viscosity of the medium.*

our own work and the published works of others, we have derived a mathematical theory for the behavior of a golf ball during impact.

In order to describe other phases of our attack on the golf-ball problem, we must introduce here an important scientific concept. This is the so-called coefficient of restitution.

This quantity with the imposing name we shall call "e." It is defined simply as the ratio of the relative velocity of the ball and the club after impact to their relative velocity before impact.

Suppose, for example, that the club strikes the ball with a velocity of 200 feet per second. This number is the relative velocity before impact, because the ball is standing still (zero velocity). Suppose that the ball leaves the club after impact at a velocity of 250 feet per second, and that the club is slowed down to 120 feet per second. The relative velocity after impact is therefore (250-120, or) 130 feet per second; this is the velocity with which the ball travels away from the club. Therefore, "e" has the value 130/200 or 0.65. (These are typical figures.)

The ideal value of "e" is 1; it can never be greater than this. It is sometimes thought (and this idea is common in elementary physics textbooks) that a perfect or ideal ball would have this ideal value of "e". According to our present thinking, however, this idea is erroneous; no golf ball could possibly be developed with $e=1$.

This, then, is one line of progress on the golf ball problem: We now know that the yardstick for measuring "e" does not have a top reading of 1; it has something less. Actually a good golf ball—and it is hard to find a poor one nowadays—has an "e" value of 0.75 to 0.80 for a very light impact (for example, when dropped on a concrete floor). For the hard-hit ball, the "e" value drops to about 0.65. The big question is: How close are these values to the top of the yardstick? Here is one place where a theory is needed, only theory can tell us whether the present ball is close to ideal.

Theory or no, there is no substitute for facts. Several of the questions can be answered only by actual measurements of the speed of the ball and the club, the carry of the drive and so on. Many of these measurements should be made in the laboratory, where wind and rain and muscles and nerves can be eliminated. For preliminary orientation, however, ADL in cooperation with USGA made a series of measurements on real flesh-and-blood golfers during the 57th Amateur Championship at The Country Club, Brookline, Mass., last September.

Drum Camera in Action

The high-speed stroboscope used at Brookline is a fairly recent development of Professor Edgerton of Massachusetts Institute of Technology, and his associates at Edgerton, Germeshausen and Grier, Inc. Combination of this high-speed strobe with a simple drum camera is a departure from common practice. Unlike a movie camera, this drum camera has no framing mechanism; it relies on the stroboscope to stop the motion and on the rapid uniform motion of the drum to separate the individual shots on the film.

The strobe was operated at a speed of 9,000 flashes per second. At this strobe speed, the golf ball travels only about ¼ inch between flashes. For comparison, an automobile traveling 60 mph would move about 1/10 inch between flashes, and a high-speed rifle bullet would go about 4 inches in the same period of time. The strobe operation was synchronized with the golfer's stroke through use of an electric-eye device. In addition to being turned on at the proper time, the strobe had to be turned off before the second revolution of the camera drum, so that the film would not be exposed twice. The operating period of the strobe had also to be reduced to a minimum, so that the unit could operate above its rated maximum speed of 6,000 flashes per second. With the total operating time cut to about 1/100 second, or 90 flashes at 9,000 per second, both of these objectives were accomplished.

Through the use of the high-speed photographs, several measurements were made. Club and ball velocities were computed from the movement in successive frames, and the loft angle of the ball was determined. Careful observation of the twist of the clubhead after impact indicated whether the ball had been hit squarely on center or on the heel or toe of the club face. A major improvement could be made in the experimental setup if a well defined marker were located on the clubhead close to the center of gravity.

The balls were taken from the production of a single manufacturer, so that comparisons could be made between balls that differed in hardness, or compression. Individual balls having PGA compression ratings close to 50, 60, 70, 80 and 90 were selected at the factory. These numbers give an indication of ball hardness, a 50 rating being about as soft as any ball in common use and a 90 rating being near the top of the scale. The 70, 80 and 90 balls were constructed similarly and differed only in the tightness of the thread winding. The 50 and 60 balls were constructed differently from the others and from each other. A strict comparison on the basis of compression can therefore be made only between the 70, 80 and 90 balls.

Willie Turnesa, Dave Smith, Billy Joe Patton, Joe Carr, Bob Kuntz and Tim Holland and several others very kindly participated in the test under conditions in which no golfer could be at his best.

One must be cautious in interpreting the results, because there were many uncontrolled variables. Great meaning, therefore, should not be attached to a single measurement. For exact answers from tests of this kind, many times the number of trials at Brookline would have to be performed, and the results would have to be analyzed on a statistical basis.

Some of the best data, from the standpoint of the consistency of the player and the clarity of the photographs, is given in the accompanying table for Bob Kuntz and Tim Holland. The first five columns in the table give, successively, the ball compression, the club velocity before impact, the ball velocity, the carry of the drive (distance in the air, not including the roll) and the angle of loft. The next column gives the approximate time (measured in frames or flashes of the stroboscope) during which the ball remained in contact with the club face. The next to last column gives the point of the club face that struck the ball, as inferred from the twist of the clubhead after impact. The last column indicates where the ball landed. The terms "right" and "left" mean simply that the ball landed in the rough on the right or left.

Some tentative generalizations can be drawn from the data although, as previously pointed out, they should be used with caution:

Consistency: The most consistent thing

Player	Ball Compression	Club Velocity Before Impact (ft./sec.)	Ball Velocity (ft./sec.)	Carry (yards)	Loft (degrees)	Contact Time (frames)	Point Struck	Location
Kuntz	50	199	253	188	5	5	heel	fairway
	60	206	247	221	8	4	sl. heel	fairway
	70	203	255	230	11	4	sl. heel	right
	80	217	250	232	8	3.5	center	fairway
	80	213	228	227	12	3.5	sl. toe	fairway
	90	200	*	233	9	3.5	center	right
Holland	50	212	227	200	2	5	heel	left
	60	212	247	197	6	5	heel	left
	70	217	250	251	11	4	sl. heel	fairway
	80	212	275	258	11	3.5	center	fairway
	90	207	272	248	12	3	sl. heel	right

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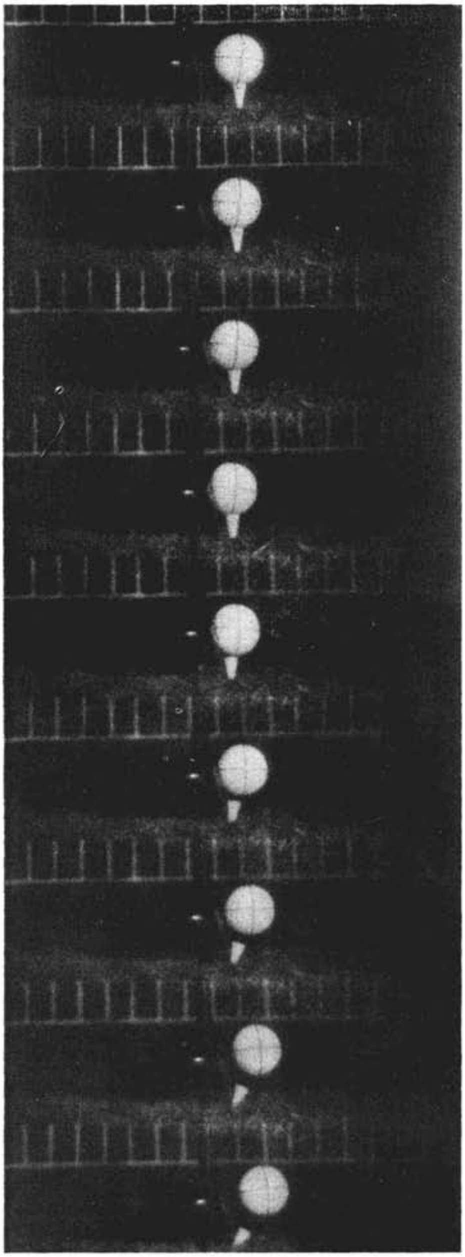
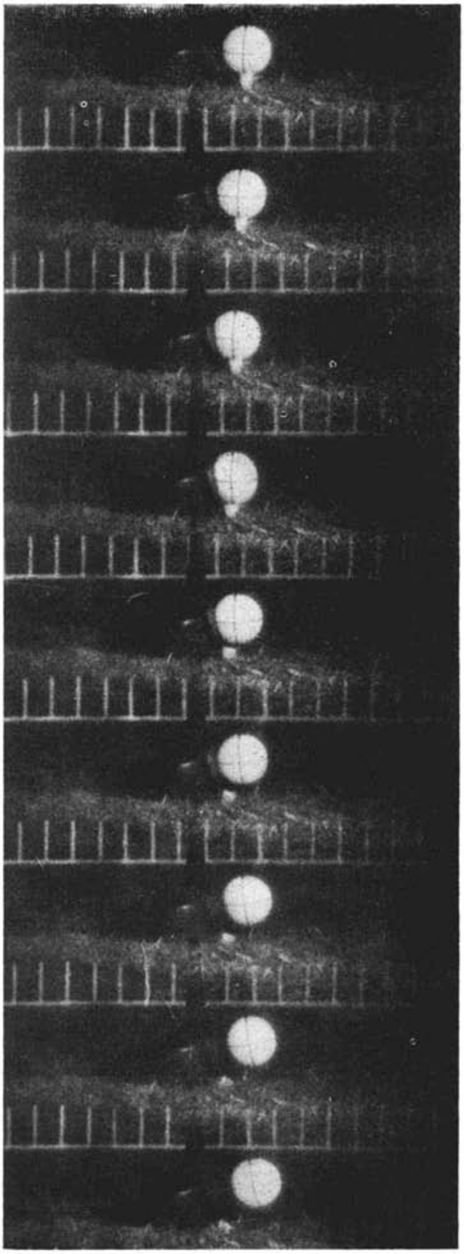
* Probable measurement error.



BOB KUNTZ

Ball Comp. 80 Club Velocity (B) 217 ft/sec.
Carry 232 yds. Club Velocity (A) 106 ft/sec.
Drive 257 yds. Loft 8° 15'
Ball Velocity Spin 37.5 rps.
250 ft/sec.
Coeff. of Restitution 0.66



TIM HOLLAND

Ball Comp. 80 Club Velocity (B) 212 ft/sec.
Carry 258 yds. Club Velocity (A) 143 ft/sec.
Drive 283 yds. Loft 11° 19'
Ball Velocity Spin 62 rps.
275 ft/sec.
Coeff. of Restitution 0.63

about a golfer is his swing. An individual's clubhead velocity at the bottom of the stroke does not vary very much, as the table shows. When the possible errors in these measurements and the very adverse conditions under which these golfers were working are considered, the uniformity of these numbers is amazing.

The ball velocity varies over a much wider range and seems to depend more on how squarely the ball is hit than on how fast the clubhead is traveling.

Distance: The most important factor for distance appears to be not so much speed as loft. The best loft angle appears from the table to be around 11 or 12 degrees. The table shows that whenever the angle of ascent was low, the distance was also low even though the ball velocity in some cases was high. The photographs showed that in Holland's first two shots, his club was still descending when it struck the ball; only a small degree of loft was therefore given to the ball, and although his club speed was normal and the ball speed was relatively good, the distance was short. Holland's best shot, with a carry of 258 yards and a total distance including roll of 283 yards, was obtained with only his average clubhead speed of 212 feet per second.

Of course, to say that loft is important is only to say that the ball should be hit squarely, with the club precisely at the bottom of the stroke.

Unfortunately, the amount of data from the Brookline tests is not nearly great enough to give a quantitative relationship between speed and distance for an otherwise perfectly hit ball.

For a well-hit ball, the data show that there is a fairly close one-to-one correspondence between total length of the drive including roll as measured in yards and ball velocity leaving the club as measured in feet per second. This is a convenient rule. From it, one may conclude that the USGA velocity limit, being 250 feet per second, corresponds to a 250-yard drive; this is probably a well-chosen value to represent the performance of a better-than-average golfer.

Compression: If attention is confined to balls with compression numbers 70, 80 and 90 that are otherwise similar in construction, the tests seem to show that there is little significant difference in the driving distance, other factors being equal. The over-all average carry for all the drives at Brookline with each type of ball was as follows: 50:204; 60:205; 70:232; 80:227; and 90:234. The last three values are substantially the same if allowance is made for variable factors and the relatively small number of shots.

The two softer grades, 50 and 60, are significantly less lively than the higher-compression grades. The data in the table should not be taken as evidence for this statement, since from the standpoint of loft both Kuntz and Holland had relatively poor shots on the 50 and 60 balls. The over-all average figures just listed can be given considerable weight, however, and they definitely seem to show a poorer performance for these low-compression balls. The poorer performance of these balls should not, however, be entirely attributed to their softness, because their construction is also quite different, especially in the core.

To say that compression, within limits has little effect on driving distance is not to say that compression makes no difference to the behavior of the ball. The photographs clearly show large differences: the softer ball is flattened more by impact with the club than is the harder ball. Even more apparent in the photographs is the fact that the softer ball stays in contact with the club for a longer time; the time of contact varied five frames for the 50-compression ball to three frames for the 90-compression ball. The golfer notices this effect in what he describes as the "feel" of the ball; the high-compression ball gives him a sharper reaction.

The effect of compression is probably much more important for control than for distance. It seems likely that better control can be obtained with a soft ball than with a hard one. Because it flattens out more and covers a larger area of the club face at impact, the soft ball requires less critical accuracy at impact than the hard ball.