Historical Equipment Research and Testing

1. Executive Summary

Concern about the distance the golf ball travels has been expressed for 100 years or more. Throughout that time there have been studies conducted on the performance of the golf ball, primarily its resilience and aerodynamics, with a goal toward developing a test or tests to limit that performance. While some of the test and measurement methods were crude and imprecise by today's standard, this seminal research can provide qualitative, and some limited quantitative, insight into the historical performance of golf equipment.

2. History of Equipment Research and Testing

2.1 Coefficient of Restitution

When two objects travelling in a straight line collide (direct central impact) they first experience a period of deformation (at which time both objects have the same velocity) followed by a period of restitution at which point the objects will regain their shape (assuming elastic impact) and separate from each other at some relative velocity. The coefficient of restitution (e) can be expressed as a ratio of the pre- and post-impact velocities.

$$e = \frac{(V_b' - V'_c)}{(V_c - V_b)} \qquad (1)$$

Where V_c and V_b are the pre-impact velocities of the club and ball, respectively, and V'_c and V'_b are the post-impact velocities of the club and ball, respectively. It is often difficult to measure the post-impact velocities, however, conservation of momentum allows us to eliminate one of the post impact variables and calculate e as a function of the masses of the objects and the pre-impact velocities.

$$m_c V_c + m_b V_b = m_c V'_c + m_b V'_b \qquad (2)$$

Where m_c and m_b, are the mass of the club and ball respectively.

2.1.1 Golf Ball

In 1940 the Armour Research Foundation built a new device for the USGA for measuring ball resilience. This device used a heavy fly wheel with a striker that projected from the rim. The ball traveled on a conveyor that is synchronized with the fly wheel so that the ball and striker arrived at the impact position simultaneously. The ball was struck by the striker at a speed of 144 ft/sec. The velocity of the ball was measured by photo electric cells that were 10.62 feet apart. The resilience was stated in terms of this velocity.

In March, 1941, in preparation for the 1942 adoption of this testing device and the "Initial Velocity (IV) Standard (DIPr, 2019), 39 brands of golf balls (42 dozen total) were tested on the USGA device. Figure 1 shows the distribution of the IVs for the balls tested. The average IV of these 39 brands was 249.8 ft/sec.

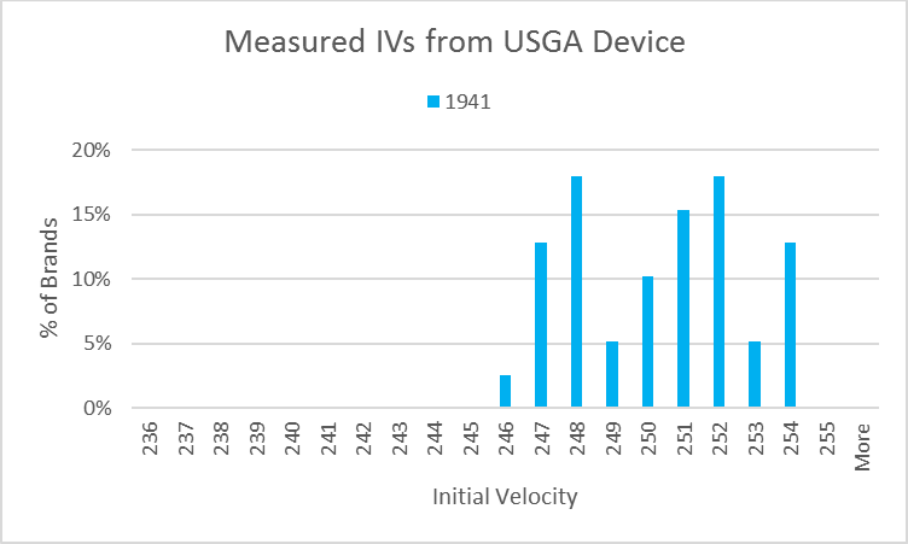


Figure 1 – Distribution of Initial Velocity for 39 Ball Brands in 1941

The IV Standard established in 1942. The limit was set at 250 ft/s with a 5 ft/s tolerance. The standard and limits remain in place today, although the devices used to measure it have changed over time. A new test device (ITW) was developed by Illinois Tool Works in 1968 and adopted as the official IV test apparatus a couple of years later. Like the original device, the ITW used a heavy fly wheel with a striker that projected from the rim. The ball was teed automatically and struck by the striker at a speed of 143.8 ft/sec. The velocity of the ball was measured with light screens that were 6.28 feet apart (rather than 10.62 feet in the original device.) Figure 2 shows the distribution of the IVs for the balls tested in 1992 (the earliest date that raw IV data from the ITW is available) and 2017 (the last year before a CoR machine replaced the ITW) along with the data from 1941.

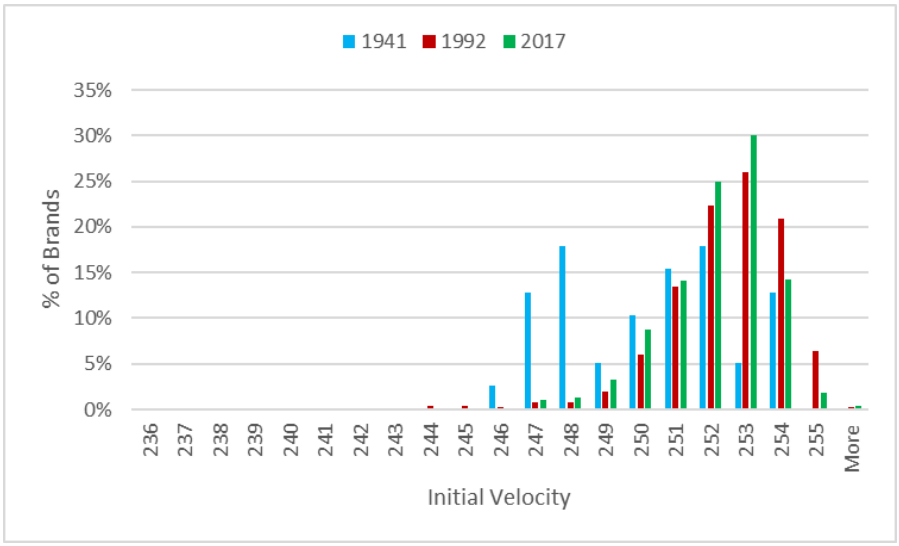


Figure 2 – Distribution of Initial Velocity for Ball Brands from 1941, 1992 and 2017

The 1992 data includes 511 brands with a mean IV of 252. There are 1124 brands in the 2017 data with a mean IV of 251.6. The distributions in 1992 and 2017 are nearly identical. The graph also indicates that in recent times there are very few balls with IVs less than 250 ft/sec while roughly 40% of the balls were less than 250 ft/sec in 1941.

2.1.2 Influence of the Golf Club

More than a decade before the Armour Machine, Professor H. A. Thomas of the Carnegie Institute of Technology developed an apparatus for measuring the coefficient of restitution (e). (Arthur D. Little, December 31, 1958) The machine was entirely mechanical, and unlike the Armour Machine and the ITW, which struck the ball with effectively an "infinite" mass compared to the weight of the golf ball, (i.e. in equation (2) $m_c >> m_b$ therefore $m_b \doteq 0$), Professor Thomas' device used a 6.5oz wooden projectile to better represent a clubhead. The projectile was shot from an air gun at a velocity of 175 ft/sec and struck a resting golf ball. Both objects were propelled along a path where they were intercepted by two ballistic pendulums. The ball flew through the first pendulum and was caught by the second pendulum, the wooden projectile was caught by the first pendulum. The square root of the height to which the pendulum swings was the measure of the velocity of object (striker or ball).

Thomas tested 9 brands of golf balls and measured coefficients of restitution between 0.57 and 0.64. These values are much lower than values measured in subsequent tests in the 1940's, late 1950's and today, perhaps due to less resilience in the balls of that period, errors in velocity measurement using the ballistic pendulum (a very small error in the measurement of the pendulum height can lead to large variations in the predicted velocity) or some combination of the two.

Subsequent to Thomas' testing, Lyman Briggs of the National Bureau of Standards used Thomas' machine to extend his research over a broader range of impact velocities. As the USGA was researching different diameter and weight combination in golf balls, Briggs also tested a variety of these combinations. With tests on a 1.68-in diameter ball with a weight of 1.62-oz in 1931, the same size and weight limits in effect today, he measured a value for e of 0.726. Figure 3 shows the results of testing conducted by Thomas and Briggs.

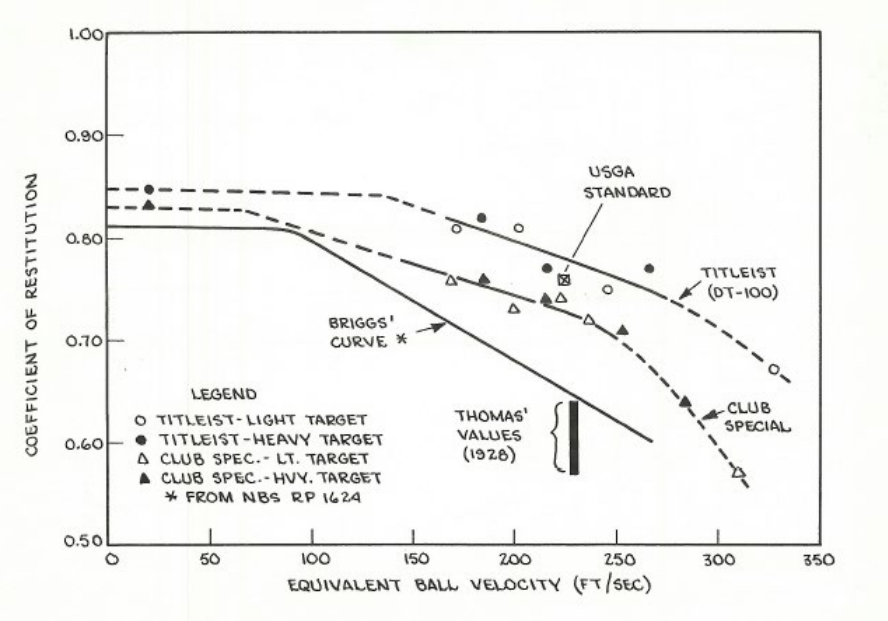


Figure 3 – Comparison of then current 1958 Tests to results from 1928, 1931 and the 1942 USGA Standard

Also shown in Figure 3 are results from tests conducted by the Arthur D. Little Company. In 1958, while endeavoring to develop a new device for the USGA that could test across a range of impact velocities and with different striker weights, the Arthur D. Little Company tested two brands of golf

balls, the Titleist DT-100 (Acushnet's highest compression brand at that time) and the Club Special (their lowest compression brand). The 1958 results were compared with earlier historical results and it was noted; "The e-value of 0.726 obtained by Briggs for the official ball in 1931 compares closely with the present value for the Club Special."

The "light target" data in Figure 3 are from tests where the ball is fired into a target weighing 6.4-oz, more representative of the weight of a clubhead. From the testing, they also concluded that if a ball is hit at the same velocity from two machines, one with a heavy striker and one with a light striker, the ball is more highly compressed by the light striker and thus more energy is lost from the ball when impacted by the light striker than the heavy striker. Therefore to compare results of a light and heavy striker they relied on an "equivalent ball velocity" which they defined as "the velocity of the ball when so struck by a golf club that the amount of stored energy is equal to that of the test." It is the reduced energy loss of the ball relative to the initial energy that is exploited in today's thin faced drivers leading to higher values of e and greater ball velocity.

In 1996 while researching spring-like effect, Johnson and Hubbell (Hubbell, 1998) conducted a number of experiments on impacts of golf balls with plates of various thicknesses to determine the effect that the flexibility had on ball rebound velocity. They concluded that velocity ratio (the ball rebound speed divided by the inbound speed) increased as the plate thickness decreased. These tests formed the basis for the adoption of a limit and test for the spring-like effect in 1998.

Studies were conducted later by Hocknell, (Hocknell, 2002) over a broad range of impact speeds. He concluded that modern drivers improved efficiency by a combination of driver features including face area, face thickness and moment of inertia and "[O]f these, face thickness is the design parameter which has been modified by the greatest extent to increase the COR [e]." The results of Hocknell's research as well as the test by Johnson and Hubbell and the earlier work by Arthur D. Little are shown in Figure 4.

From this, it can be concluded that the combination of increased ball resilience and improved club head flexibility, combined, have led to an increase in the coefficient of restitution at a constant speed (for example, 160 ft/s) of 0.07, or about 9%, from 1958 to the-present.

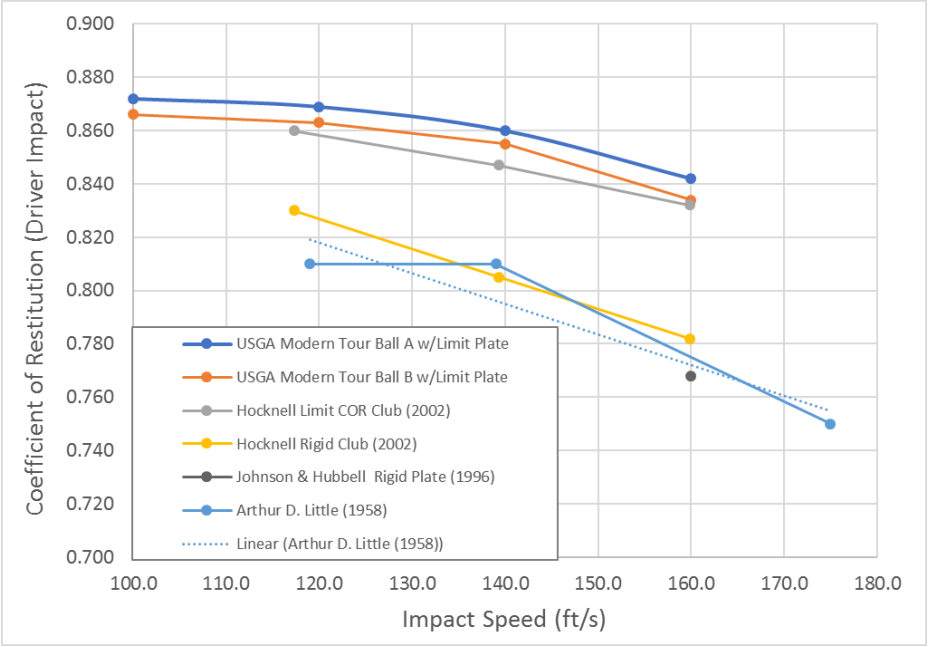


Figure 4: Coefficient of restitution for some modern balls with rigid and flexible targets

2.1.3 Aerodynamics

In addition to performance gains from golf ball resilience and club face flexibility, aerodynamics have greatly improved through the decades. In 1994, Aoyama (Aoyama, 1994) conducted a study comparing the aerodynamics of a golf ball popular on the professional tours in 1970, the Titleist "K2" with one popular with tour players in the early 1990s, the Titleist Tour Balata.

Leading up to that time golf balls were all very similar in construction and used a 336 octahedron dimple pattern known as the Atti pattern. Aoyama conducted drop tunnel, mechanical golfer testing and trajectory simulations over a wide range of launch conditions. He concluded that while the results were very launch condition dependent, there was a distance advantage for the 1990's era ball for a majority of the tested launch conditions. He noted that, "[O]ver the range of launch conditions typically generated by today's professional tour players , no player is likely to gain more than 10 yd and no player us like to lose more than 5 by playing the Tour Balata versus the K2."

The K2 ball aerodynamics were studied by the USGA and compared to those of a modern multilayer tour ball. The results are shown in Figure 5, with an increase in distance of about 15 yards when comparing pre-1970 and modern aerodynamics.

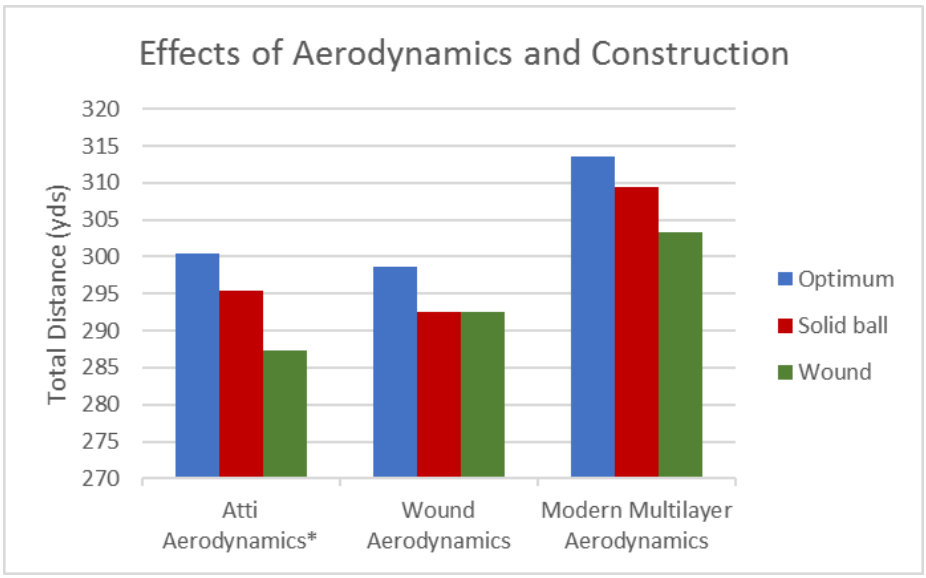


Figure 5: Effects of Different Dimple Patterns at Varying Ball Speeds

Simulations were conducted at a launch speed of 256 ft/s for all golf balls. It's important to note that it is challenging to examine the effects of aerodynamics changes in golf balls without recognizing that those aerodynamics were tailored to the way the ball was being driven at the time. For instance, using a launch angle and spin appropriate to a solid ball, the Atti would appear to have a distance advantage over a wound ball (red columns). However, in the context of a more appropriate launch angle and spin for a wound ball, the wound aerodynamics had a clear distance advantage over the Atti (green columns). The magnitude of this advantage compares favorably to the Aoyama research. Modern aerodynamics have a distinct advantage over both the Atti and wound aerodynamics. These effects are shown at various ball speeds in Figure 6

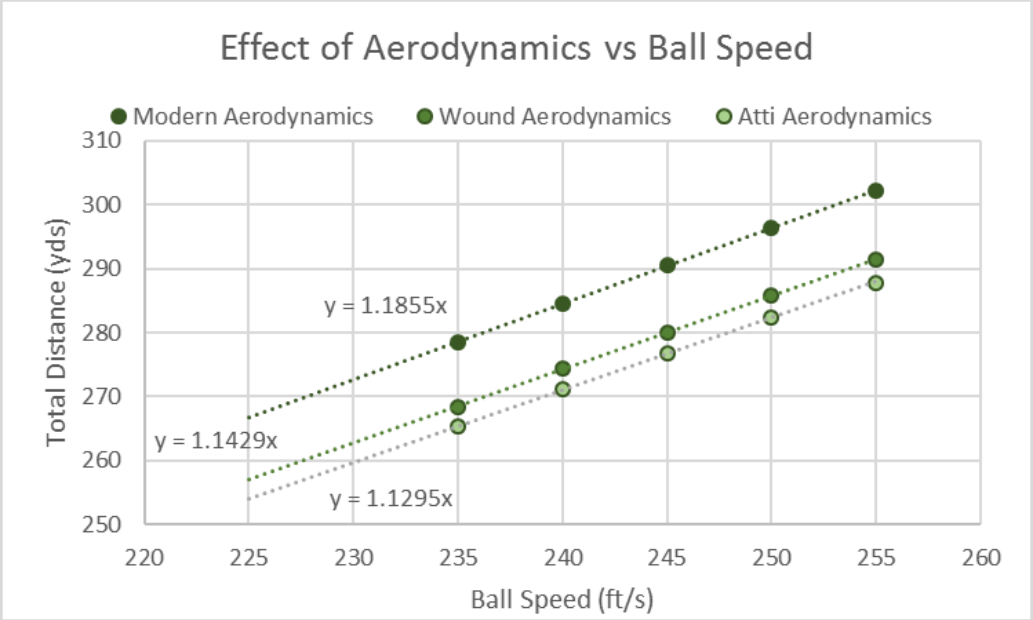


Figure 6: Effects of Different Dimple Patterns at Varying Ball Speeds

3. Conclusions

Testing of golf balls has been conducted for more than 100 years. The data show that improvements in Coefficient of Restitution and golf ball aerodynamics have made substantive contributions to ball velocity and distance.