R22-04 Effects of club flexibility at different swing speeds

United States Golf Association, R&A Rules, Ltd.

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1 Abstract

Driver heads have been tested representing different manufacturers and levels of flexibility as indicated by characteristic time. It has been found that there is a relationship between characteristic time and distance, and that higher swing speeds are associated with greater distance sensitivity to characteristic time. This sensitivity is less pronounced when expressed as a percentage of the drive distances associated with the highest club head speeds.

2 Introduction

Primary factors that contribute to the distance traveled by a golf ball when struck by a golf club include are the initial speed, angle, and spin, along with the size and mass of the ball, and its aerodynamic properties. In particular, the relationship between ball speed and distance is a strong one.

The initial speed of a golf ball when struck by a driver is, in turn, controlled by the clubhead speed, the relative masses of the club and the ball, and the coefficient of restitution of impact between the club and ball. The latter quantity reflects ball construction and chemistry, and the flexibility of the golf club (Yamaguchi, 1999).

The USGA and R&A Rules Ltd limit the flexibility of the clubhead through measurement of its characteristic time (CT), which correlates linearly to coefficient of restitution, *e* (USGA, R&A, 2003). However, a direct relationship between characteristic time and distance at different clubhead speeds has not been previously published. However, a direct relationship between characteristic time and distance at different clubhead speeds has not been previously published.

2.1 Previous work

The correlation between characteristic time (*CT*) and coefficient of restitution (*e*) for drivers is defined by the linear relationship:

$$e = 0.718 + 0.000436CT \tag{1}$$

over a *CT* range of about 210 to 290 microseconds ($R^2 = 0.89$). This correlation is based on impacts using a two-piece golf ball at a speed of 160 ft/s (109 MPH), where *e* is normalized based on the results of the same golf ball and test speed using a 190 g titanium plate (R&A Rules Ltd., USGA, 2019).

Further work examined plates with different membrane thickness over a range of impact speed (55 – 110 MPH, 80 – 160 ft/s) (USGA; R&A Rules, Ltd., 2020) with total distance predicted using other assumptions based on the Overall Distance Standard (USGA, 2004).

3 Approach

In the present study, normal coefficient of restitution test was conducted at 68 MPH (representative of an average female amateur), 95 MPH (representative of LPGA Tour players and close to that of the Average Male Amateur) and 120 MPH (representing the USGA/R&A Overall Distance Standard).

The protocol for measuring the coefficient of restitution for iron clubheads was followed (R&A Rules Ltd., USGA, 2019), with the exception that results were not normalized based on a standard plate, and impact speed varied (as above). Results were not normalized based on a standard plate,

The rebound angle of the ball (from horizontal) was recorded as a quality measure, with an expected average downward angle of approximately 4°. Both inbound and rebound velocities were corrected to reflect the normal (horizontal) ball velocity component in computing coefficient of restitution.

3.1 Club and ball selection

Ten drivers representing different manufacturers were selected from a population of clubheads whose coefficients of restitution have been measured. These represented a wide range of both centre characteristic times. The full population from which clubheads were selected is shown in Figure 1.

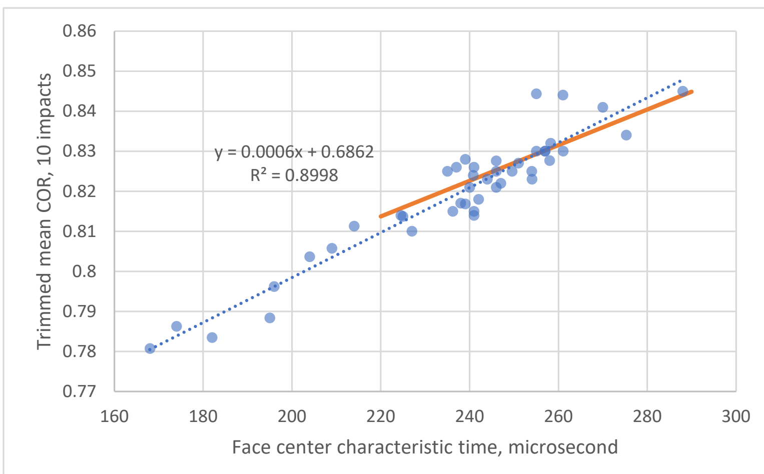

Figure 1: Relationship between driver characteristic time and coefficient of restition (at 109 MPH, 160 ft/s) for clubs tested. Equation 1 is represented in orange over the range 220 – 290 microseconds..

Though using a different type of control ball, and absent normalization to the titanium reference plate in prior work, the relationship between characteristic time and coefficient of restitution is similar to that represented by Equation 1.

The selected subset identified is shown in Figure 2, and is representative of the larger population. As shown in Figure 1, the measured coefficient of restitution at any characteristic time may vary, in the observed cases here by as much as 0.010.

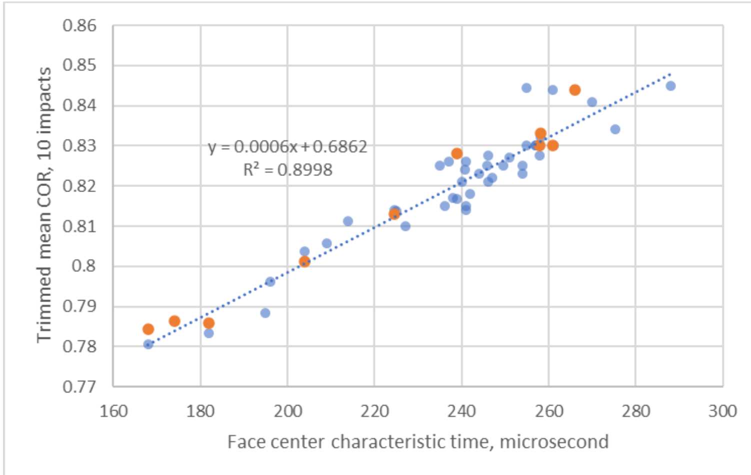

Figure 2: Data from Figure 1, with subset of driver heads selected for the present study highlighted (orange).

A modern, high-performance multilayer golf ball typical of those used in elite competitions was used in all tests and distance calculations.

3.2 Distance calculation

Using a one-dimensional conservation of momentum assuming central impact, Equation 2 may be derived, allowing for the calculation of initial ball speed.

$$v_{ball} = (1 + e)v_{club}\left(\frac{m_{club}}{m_{club} + m_{ball}}\right)$$

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For the calculation of ball speed, an assumed mass at 200g was used (in practice, club head masses varied from 181-201g) along with each club's measured coefficient of restitution to isolate the effects of club flexibility. This does not accommodate the inclusion of bonded shaft mass (see Appendix, 7). The mass of the ball was 45.8g.

Distance calculations were similarly based on driver launch conditions typical of PGA TOUR average, LPGA Tour average, average male amateurs or "AMA" (TrackMan Golf, 2021), (Trackman Golf(a), 2021), and average or typical female amateurs or "AFA" (USGA, R&A Rules, Ltd., 2021). Bounce and roll distance was calculated using a model that is applicable over a wide range of conditions (USGA/R&A Rules Ltd. [2], 2021).

4 Results

4.1 Coefficient of restitution

Coefficients of restitution at three impact speeds are shown as a function of club flexibility as expressed by characteristic time in Figure 3 (data of coefficient of restitution as a function of impact speed are provided in the Appendix, 8). Here we see that the dependence of coefficient of restitution on characteristic time is greatest at the highest impact speeds, and that values appear to converge at the highest characteristic times.

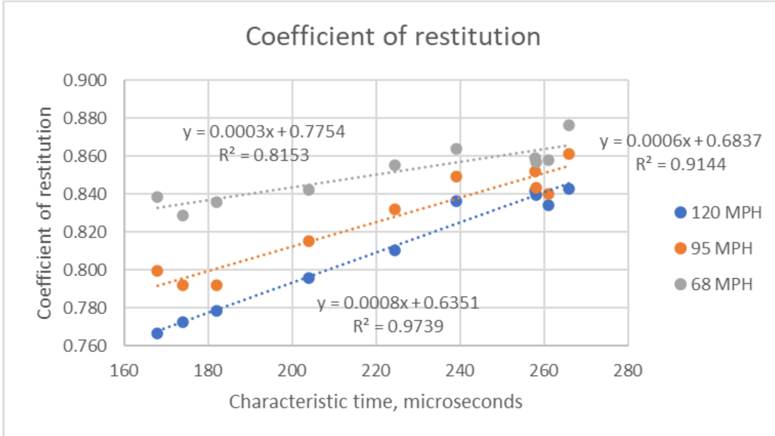

Figure 3: Coefficient of restitution for a modern, high-performance golf ball as a function of characteristic time for three impact speeds.

4.2 Distance

Due to the significant differences in distance between the highest and lowest speeds of interest, distance as a function of characteristic time for these clubs is shown in three separate charts (Figure 4 through Figure 6). Both the dependence of distance on characteristic time and the correlation are strongest at the highest speeds.

It should be noted that these results were based on a central impact. This better reflects the clubhead speed – ball speed relationship for more accurate golfers (and the Overall Distance Standard) where impacts are generally close to the centre of the face. For other golfer types having wider impact distributions, average ball speeds and resulting distances will be lower. This is particularly evident for the AMA category.

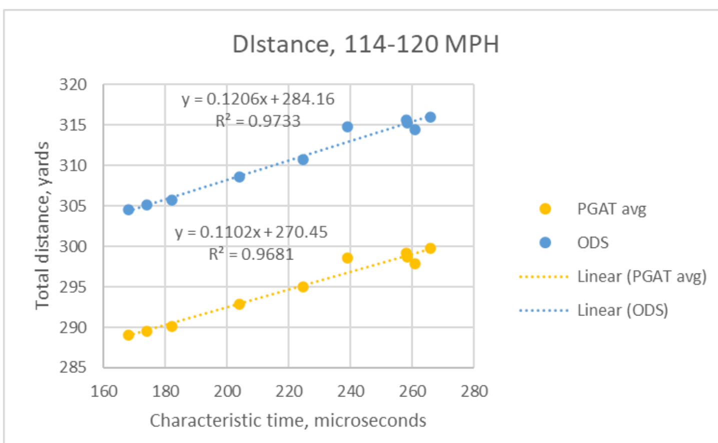

Figure 4: Distance for player groups at 114-120 MPH clubhead speed (PGA TOUR average and Overall Distance Standard). Note that correlation to characteristic time is particularly strong.

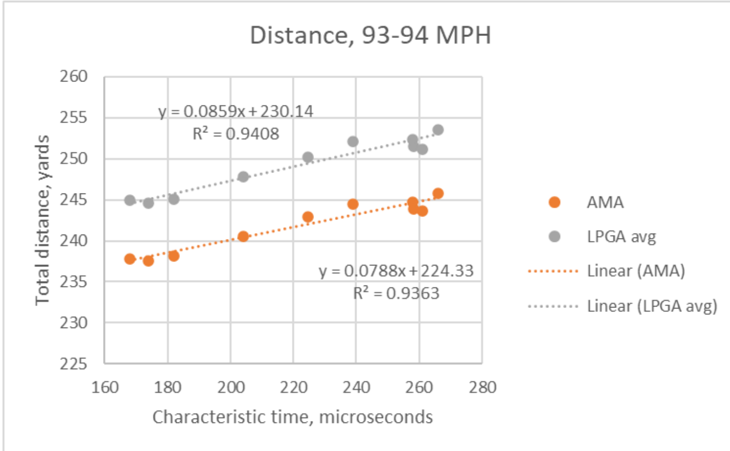

Figure 5: Distance for player groups at 93-94 MPH clubhead speed (LPGA Tour average and AMA). Correlation coefficients R^2 are in the 85-86% range. It is noted that these distances are overestimates for the AMA golfer, due to higher ball speeds more closely aligned with 'Optimal' rather than 'Actual' impacts.

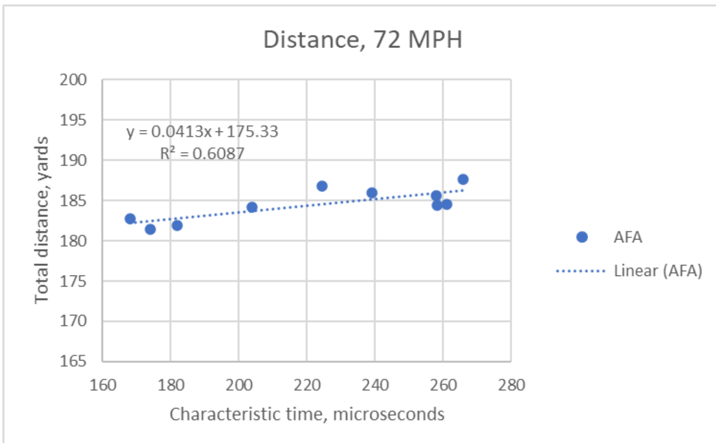

Figure 6: Distance for 72 MPH clubhead speeds. This group had a weaker dependence on characteristic time (0.04 yards per microsecond, compared to 0.12 yards per microsecond for the highest swing speed group). These results, similar to AMA golfers, are higher estimates.

The sensitivity of distance with respect to increasing characteristic time is summarized in Table 1.

Table 1: Relative sensitivity of total distance to characteristic time.

Swing speed group	**Total distance sensitivity vs *CT* (yards/microsecond)**
AFA	0.04
AMA	0.08
LPGA	0.09
PGA TOUR Avg	0.11
Overall Distance Std.	0.12

Using this information, it is possible to identify the change in distance that would result from changing the characteristic time of a club from a high value, such as the limit plus tolerance at 257 microsecond), to a lower value, for example 170 microseconds. Results are expressed as magnitudes and as percentages in Figure 7 and Figure 8, respectively.

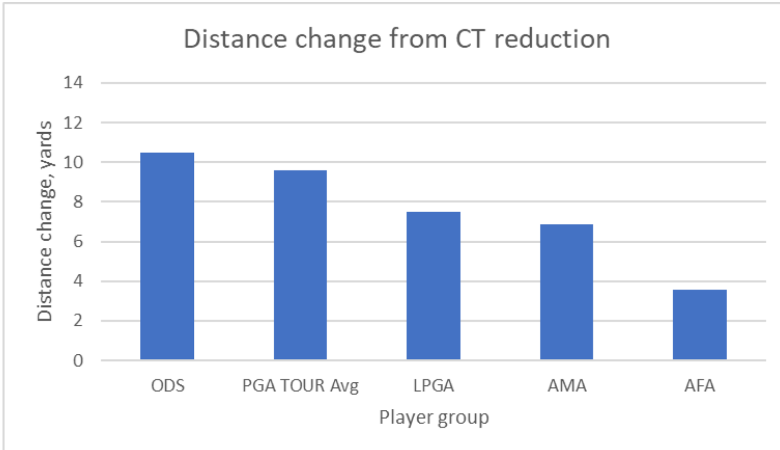

Figure 7: Distance change in yards associated with a CT reduction from 257 to 170 µs.

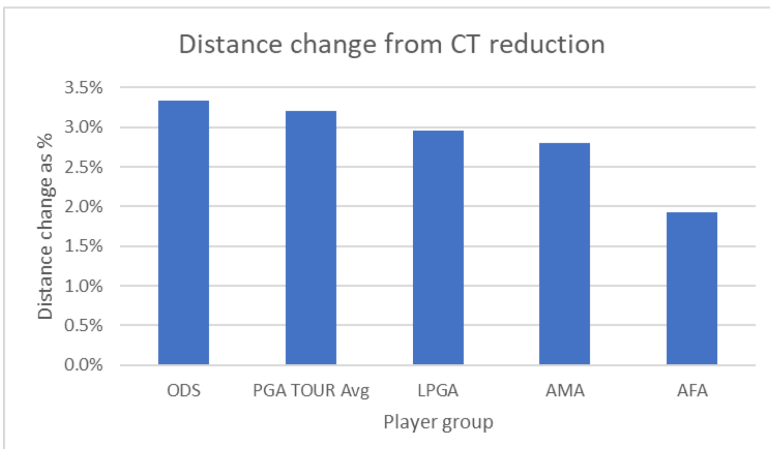

Figure 8: Relative distance change as a percentage of distance associated with a CT reduction from 257 to 170 µs.

As a percentage, the distance change is greater for PGA TOUR level swing speeds (between 3.2 and 3.3%) compared to the 72 MPH Average Female Amateur group (1.9%). The LPGA Tour average and AMA groups experience an intermediate level of change, 2.8-3.1%.

5 Conclusions

Modern driver heads have been tested representing levels of flexibility as indicated by characteristic time. These clubs were selected based on representing the relationship between coefficient of restitution and characteristic time over a wider population of clubheads.

It has been found that, other factors being equal, there is a relationship between characteristic time and distance, and that higher swing speeds are associated with greater distance sensitivity to characteristic time.

6 References

Pringle. (2003). *The relationship between coefficient of restiution and infinite velocity characteristic time (RC/cor2003-N01).* Liberty Corner: United States Golf Association.

Pringle. (2008). *Initial results of experiments on the effect of plate flexibility .* Liberty Corner: United States Golf Association.

R&A Rules Ltd., USGA. (2019). *Protocol for measuring the coefficient of restitution of a clubhead relative to a baseline plate.* St. Andrews, Liberty Corner: R&A Rules, Ltd., United States Golf Association.

TrackMan Golf. (2021, March 27). *TrackMan Average Tour Stats*. Retrieved from TrackManGolf.com: https://blog.trackmangolf.com/trackman-average-tour-stats/

Trackman Golf(a). (2021, 10 12). *Performance of the Average Male Amateur Golfer*. Retrieved from Trackman Golf: https://blog.trackmangolf.com/performance-of-the-average-male-amateur/

USGA. (2004). *Addenda to the ITR Technical Description and Operation Manual - Phase II.* Liberty Corner: United States Golf Association.

USGA, R&A. (2003). *Technical Description of the Pendulum Test.* Far Hills, St Andrews: United States Golf Association, The Royal and Ancient Golf Club of.

USGA, R&A Rules, Ltd. (2021). *Effects of specification changes on ball performance.* Liberty Corner, St. Andrews: United States Golf Association, R&A Rules, Ltd.

USGA/R&A Rules Ltd. [2]. (2021). *A simplified bounce model for evaluating optimum overall distance.* Liberty Corner, St Andrews: United States Golf Association, R&A Rules Ltd.

USGA; R&A Rules, Ltd. (2020). *Effect of Equipment on Distance - Driver (Report 19).* Liberty Corner, St Andrews: United States Golf Association, R&A Rules, Ltd.

Yamaguchi, T. I. (1999). Optimium Design of Golf Club Considering the Mechanical Impedance Matching. In M. C. Farrally, *Science and Golf III* (pp. 500-509). Leeds: Human Kinetics.

7 Appendix: Sensitivity to assumptions

7.1 Calculation of ball speed

7.1.1 Club mass

The assumed mass in this document was 200g for all clubs. This may be seen as a typical mass for a clubhead but does not account for added mass on the part of bonded shaft (typically about 10g), for other added mass. In addition, some driver heads may be lighter (for example, 180g).

Clubhead speed and club mass are not independent: increasing the club mass would, other factors being equal, reduce clubhead speed. This would reduce the effect of changing club mass. However, even without considering the offsetting reduction of clubhead speed, an aggressive estimate is that the influence of a ±10g weight change would lead to a 0.9 – 1.0% change in ball speed for all club/player combinations studied.

7.1.2 Normal, central impact

The testing in the present work maximizes the post-impact ball velocity. This testing and the use of Equation 1 to calculate ball velocity assume a normal, central impact.

For non-central impacts, ball velocity will be lower to a degree that depends on the clubhead moment of inertia and CG location. Assuming average golfers (male and female) are less accurate than, for example, LPGA Tour professionals, actual distances will be shorter compared to estimates for those groups. The effects of flexibility distribution and the degree of distance loss for off-centre hits are beyond the scope of this study.

If it may be assumed that the difference from normality can be characterized by driver loft (e.g., 7-12°), then the normal component of the velocity vector would be 98-99% of the total velocity. In a like-for-like comparison within a golfer group, this would not lead to a substantive change in the relative effects of club flexibility.

As a final note, given the launch conditions assumed in this study, spin accounts for about 2.5% of the total kinetic energy of the ball struck by AFA (highest percentage), and about 1% of the kinetic energy of the ball struck by the PGA TOUR long hitter (lowest percentage).

7.2 Distance calculations

In this document, distances are evaluated based on a modern multilayer ball typical of those used by elite golfers. The effect of this assumption is tested here. Specifically, distances were simulated based on the following assumptions:

i. High-drag ball: 10.8% increase at 177 MPH, 2,500 RPM
ii. Low-drag ball: -4.6% decrease at 177 MPH, 2,500 RPM

Relative results are not significantly altered from that in Figure 8, as shown in Table 2.

Table 2: Effects of different assumptions on distance change in characteristic time between 170 and 257 microseconds.

	AFA	AMA	LPGA	PGAT Avg.	PGAT Long
High Drag Ball	1.9%	2.7%	2.9%	3.1%	3.3%
Low Drag Ball	2.0%	2.8%	3.0%	3.2%	3.3%

8 Appendix: Coefficient of restitution test data

Individual test coefficient of restitution results are shown in Table 3 and Figure 9. The linear relationship between coefficient of restitution and impact speed observed in previous work is preserved here, with a typical R^2 of 97%.

*Table 3: Characteristic time and coefficient of restitution data for tested clubs. *Uses USGA/R&A Calibration ball.*

Club	Mass, grams	CT, microseconds	e(109)*	e(68)	e(95)	e(120)
A	199.4	182	0.786	0.836	0.792	0.779
B	199.7	168	0.784	0.839	0.799	0.767
C	200.2	204	0.801	0.842	0.815	0.796
D	199.1	174	0.786	0.829	0.792	0.773
E	198.9	225	0.813	0.855	0.832	0.810
F	196.2	258	0.833	0.857	0.843	0.840
G	198.7	261	0.830	0.858	0.840	0.834
H	186.3	266	0.844	0.877	0.861	0.843
I	181.0	239	0.828	0.864	0.849	0.836
J	200.9	258	0.801	0.859	0.852	0.842

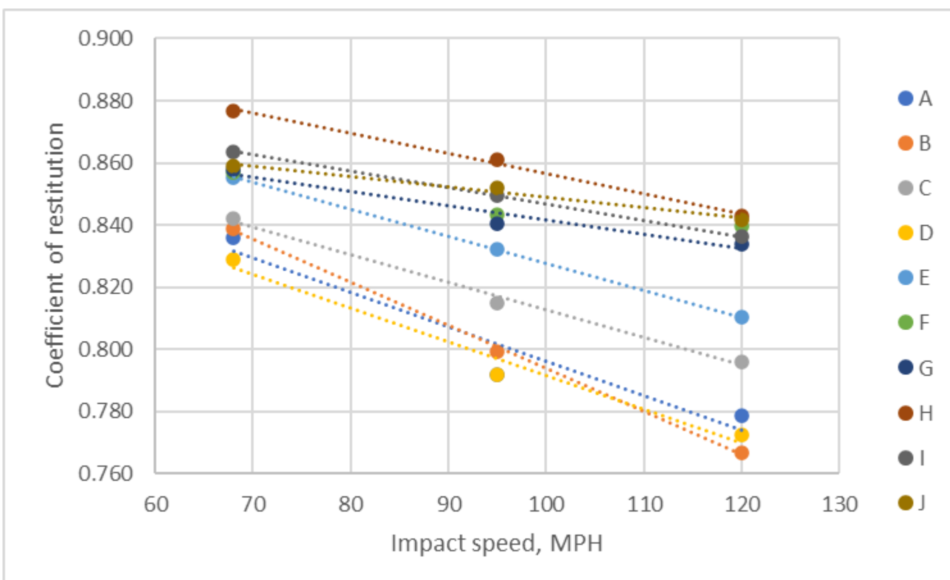

Figure 9: Individual club coefficient of restitution data as a function of impact speed. The linear behavior observed in previous testing is preserved here.

Table 4: Ball speed and distance projections for clubs A-J used in this study. Note that in the calculation of ball speed, a mass of 200g was assumed for all clubs to isolate the effects of coefficient of restitution.

	Speed AFA MPH	Dist., AFA yards	Speed, AMA, MPH	Dist., AMA, yards	Speed, LPGA, MPH	Dist., LPGA, yards	Speed, PGAT Avg., MPH	Dist., PGAT Avg., yards	Speed, PGAT Long, MPH	Dist., PGAT Long, yards
A	106	182	136	238	137	245	164	290	176	309
B	106	183	136	238	137	245	163	289	175	308
C	107	184	138	241	139	248	166	293	178	312
D	105	182	136	238	137	245	163	290	176	308
E	108	187	139	243	140	250	167	295	180	314
F	107	184	139	244	141	252	169	299	183	318
G	107	185	139	244	141	251	169	298	182	318
H	108	188	141	246	142	254	170	300	183	319
I	108	186	140	245	141	252	169	299	182	318
J	107	186	140	245	141	252	170	299	183	319

9 Appendix: Comparison of ball types

As noted in the text, the ball type used in this work is a modern, high-performance golf ball typically used in elite professional and other high-level competitions. As this is not the ball type traditionally used in the evaluation of coefficient of restitution for golf clubs, a comparison is warranted.

The coefficient of restitution data from **Error! Reference source not found.** may be compared to the coefficient of restitution for the ball used in the present study, with the values shown in Figure 3 interpolated to an impact speed of 109 MPH. Comparisons of results for each club (at different characteristic times) are shown in Figure 10. It is evident that the ball used in this study shows a higher coefficient of restitution, particularly for clubs with higher characteristic time.

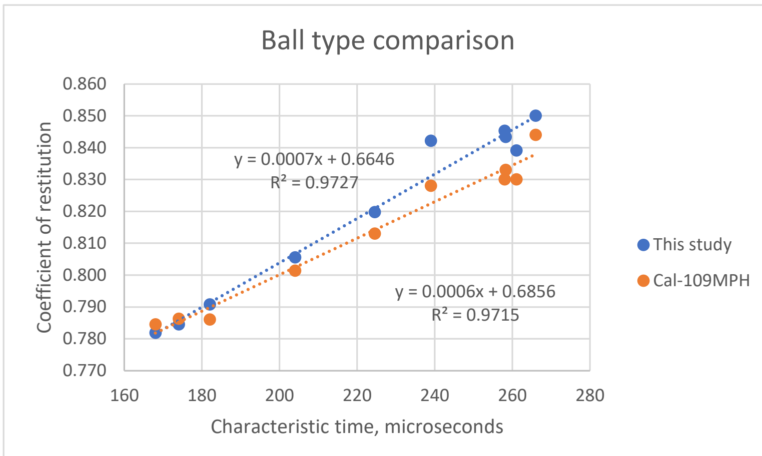

Figure 10: Comparison between testing using the USGA/R&A Calibration ball and the ball used in this study.

The coefficient of restitution results for these clubs using the two different ball types are very well correlated, as shown in Figure 11.

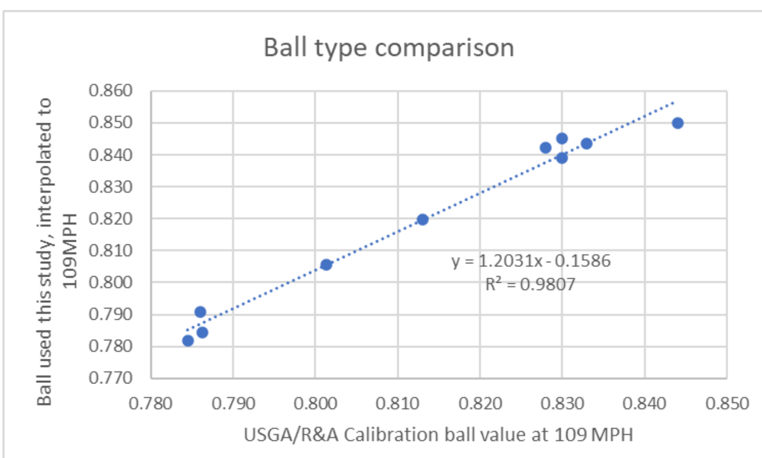

Figure 11: Correlation between the interpolated performance of the ball used in this study and the USGA/R&A Calibration ball. The best-fit line approximately intercepts 0.830, 0.840 near the CT limit.