Prediction of ALC ball speed using IV-test derived values

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May 2025

1 Introduction

The Overall Distance and Symmetry Test Protocol (1) published by R&A Rules Ltd. ("The R&A") and the USGA includes control of clubhead speed (120 MPH) as measured by a 2003 USGA-designed laser array and includes USGA/R&A Calibration ball speed as a reference value.

There are many ways to define and measure clubhead speed. Different definitions vary location on the clubhead (e.g., center of mass, center of face, and location of impact), the velocity components used, and the time or position of the club relative to impact and result in different values of clubhead speed. Different measurement technologies (including optical, radar-based, or using beam-breaking) favour different definitions of clubhead speed, making it challenging to reproduce testing based on clubhead speed alone.

For this reason, those wishing to reproduce the standard have reported relying on setting up the test according to ball speed. Ball speed measurement is more consistently reproduced between different methodologies, and it is recognized that ball speed ties directly to overall distance.

However, variation such as that caused by ball aging may result in different ball speeds in identical testing setups, using what is nominally the same ball. Such variation needs to be accounted for. In past practice, this has involved "round-robin" testing, where a reference value is obtained from testing by The R&A or USGA and then used to set up a mechanical golfer at another location.

A way to normalize for the age and condition of a golf ball is advantageous, and may lead to a more consistent and reproducible means of setting up a mechanical golfer.

1.1 Background

A pilot study using a limited number of ball types (*n*=173) conducted based on ball data initially tested in 2017 (2) demonstrated that variables measured during the Initial Velocity (or IV) test (3) could be used to predict the ball speed measured from robot testing for the Overall Distance Standard (known as the "Actual Launch Condition" speed, or V_{ALC}). A regression was found with a Pearson R^2 value of 94.3%:

$$V_{ALC} = 178.06 + 121.13e - 0.03401t_C$$

Equation 1

Since that pilot study, a significantly greater range of golf ball types has been tested over several years and provides the possibility of refinement of this regression.

2 Samples used

A further regression was performed using a large set (n≈2,900 ball types), representing constructions submitted for conformance testing over the period 2019 - 2024. The 99% range of coefficient of restitution was 0.732 – 0.802 and of contact time was 413 – 603 microseconds as measured by the Hye PTM3. The 99% range of ball speed, V_{ALC}, was 247 – 262 ft/s.

As these data include tests conducted over six years of conformance testing, results include all common cause variation in both the Initial Velocity and Actual Launch Condition (ALC) test.

Included in the study were a number of examples of USGA/R&A Calibration balls manufactured over the span 2006 – 2021, all tested in 2023. These included some newer balls artificially aged through, for example, storage in hot and humid conditions (4). For balls in that study there was a range of coefficients of restitution 0.758 – 0.789, and a range of contact times of 447 – 469 microseconds (one outlier being removed).

3 Results

3.1 Regression and statistics

The regression equation is given by Equation 2. The quality of fit of the regression is excellent, with an adjusted Pearson R^2 value of 96.1%.

$$V_{ALC} = 180.13 + 123.712e - 0.04309t_C$$

Equation 2

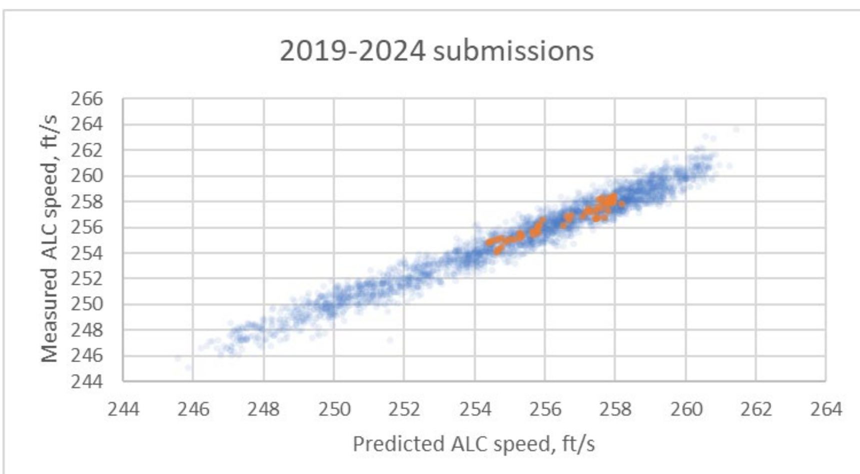

Figure 1: Measured ALC ball speed vs. predicted ALC ball speed for approximately 2,900 ball types. This is overlaid with a smaller population of USGA/R&A Calibration balls having different levels of aging (orange).

Predicted and measured values are shown in Figure 1, with the USGA/R&A Calibration balls highlighted: the average difference for these was less than 0.1 ft/s, with a maximum difference of 0.9 ft/s (well within the variability of the measurement of V_{ALC}).

Both contact time and coefficient of restitution are significant. A best-subset regression demonstrates that use of either of these predictors singly results in a significantly lower R^2 (75% and 67%, respectively). Contact time is the stronger predictor of ball speed (see Table 1).

Table 1: ANOVA of the regression. Contact time is the slightly stronger predictor of ALC speed

Source	DF	Adj. Sum of Squares	Adj. Mean Squares	F-Value	P-Value
Regression	2	3277.9	1638.95	3729.45	< 0.001
e	1	821.7	821.72	1869.83	< 0.001
t_C	1	1120	1120.01	2548.6	< 0.001
Error	300	131.8	0.44		
Total	302	3409.7			

The residuals are normally distributed (Kolmogorov-Smirnov test, P>0.150, see Figure 2) with a standard deviation of 0.68 ft/s over all years (compared to a process standard deviation for the ALC test of 0.48 ft/s). Residuals are uncorrelated to ball speed (Figure 3).

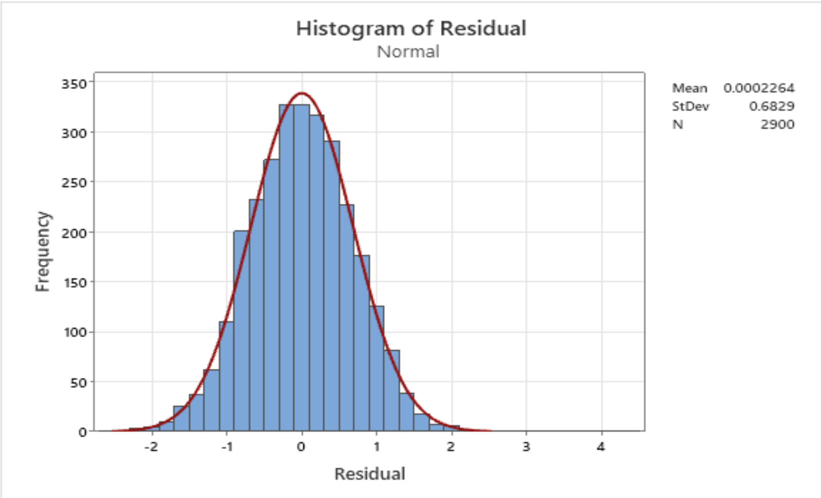

Figure 2: Residual ALC ball speed (V_{ALC}), following a normal distribution.

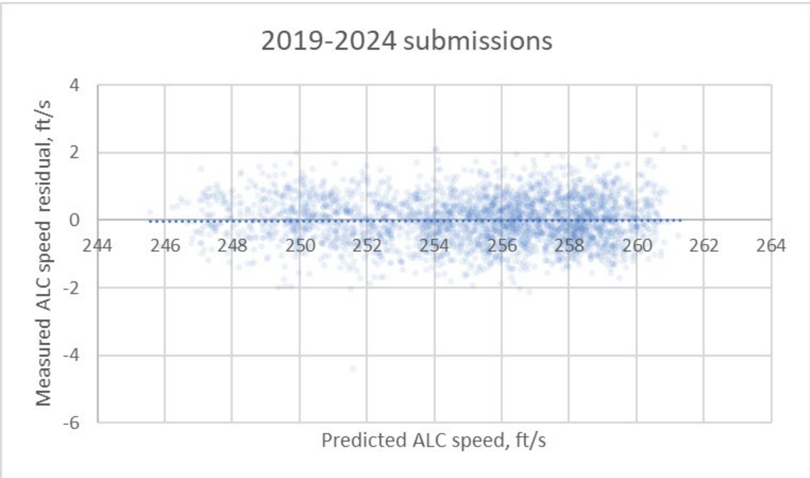

Figure 3: Residual as a function of predicted ALC ball speed. Residuals are uncorrelated to ball speed.

3.2 Accounting for year tested

To identify whether the relationship between the IV outputs and ALC ball speeds is a stable one, a multiple regression was performed using year as a category predictor. This leads to a slight increase in Pearson's R^2 coefficient to 96.2%, and a negligible change in the standard deviation of residuals to 0.67 ft/s (i.e., an improvement of 0.01 ft/s). The total range of 'year' coefficients ±0.18 ft/s from the mean and is not well-correlated ($R2 \approx 5\%$), indicating a stationary relationship.

3.3 Accounting for ball mass

It is to be expected that ball mass affects ALC ball speed, independent of the measured barrier-impact coefficient of restitution and contact time over a wide range of ball masses. The total range of ball mass in the population of approximately 2,900 ball types is 44.31 g – 46.43 g (or 2.11 g), and 99% of ball masses fall within 45.20 g - 45.87g(or 0.66 g). If a regression were to include ball mass, these would account for 0.13 and 0.04 ft/s respectively. When considering the USGA/R&A Calibration ball, the range of masses is tightly controlled (with a total range of 0.30 g). Over this range, the range in predicted ball speed based on the effect of mass would be 0.02 ft/s, and therefore ball mass is not an important feature in predicting control ball speed within expected ranges for the USGA/R&A Calibration ball.

3.4 Contribution to variability

A Gage R&R study for Initial Velocity conducted in 2023 recorded the coefficient of restitution and contact time, permitting a Gage R&R analysis of the predicted ALC ball speed. As shown in Table 2, the process standard deviation is 0.12 ft/s, compared to 0.48 ft/s for measured ALC speed. As such, the contribution of using predicted ball speed to ALC measurement variation is expected to be very small (on the order of 0.01 ft/s).

Table 2: Gage R&R study results for predicted ALC ball speed. Process standard deviation is approximately 1/4 that of ALC speed measurement.

Source	StdDev (SD)	Study Var (5.15 × SD)	%Study Var (%SV)
Total Gage R&R	0.12063	0.6212	3.12
Repeatability	0.12063	0.6212	3.12
Reproducibility	0.00000	0.0000	0.00
Operator	0.00000	0.0000	0.00
Part-To-Part	3.86967	19.9288	99.95
Total Variation	3.87155	19.9385	100.00

3.5 Summary

The regression represented in Equation 2 has been shown to be effective over a broad range of ball constructions and over a period of multiple years' testing. Particularly, it predicts Calibration ball speed well with an average difference of less than 0.1 ft/s. The measurement process for coefficient of restitution and contact time, and the resulting ALC ball speed prediction, are well-controlled, with significantly less process variation than the measurement of ALC ball speed.

4 Trial

Based on the findings of section 3, a trial was conducted using the following procedure:

a. Perform an Initial Velocity test on a selection of USGA/R&A Calibration balls to identify the average coefficient of restitution and contact time.
b. Using these values, compute the target ALC ball speed for that (specific) selection according to Equation 2.
c. Set up the mechanical golfer to achieve the target ball speed from step (b).
d. Test a selection of 32 golf ball types selected for construction.
e. Repeat (a) – (d) at a second location using similar equipment and compare results.

Samples were selected from populations of golf balls submitted to The R&A and the USGA, and represent different constructions (including but not limited to contact time, coefficient of restitution, and spin properties) from multiple manufacturers.

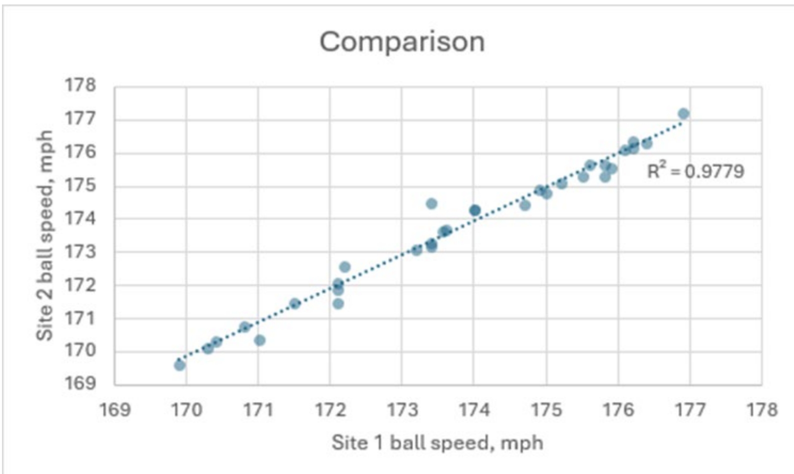

Figure 4: Comparison of the results of setting up mechanical golfers to target USGA/R&A Calibration ball speed based on Equation 2, showing excellent agreement.

The results of this comparison are shown in Figure 4. Overall agreement was excellent: the average difference between the two locations was less than 0.1 mph (not statistically significant, with a standard deviation of 0.3 mph, and a maximum difference of 1 mph (all within testing variation of either mechanical golfer).

5 Conclusions

This work has shown that outputs from the Initial Velocity test are strong predictors of the ALC ball speed of the USGA/R&A Calibration ball regardless of age within the range studied. It has been shown that such a method has minimal impact on test variation, and that the Initial Velocity test outputs and their correspondence to ALC ball speed has been stable over an extended period. Finally, it has been demonstrated that using the approach of setting up a mechanical golfer to achieve a target ball speed calculated using Equation 2 led to excellent reproducibility.

6 References

1. **R&A Rules Ltd., United States Golf Association.** *Overall Distance Standard and Symmetry Test Protocol.* St Andrews, Liberty Corner : R&A Rules Ltd., United States Golf Association, 2019.

2. **USGA, R&A Rules Ltd.** *Correspondence between IV and ALC speed for golf balls.* Liberty Corner, St Andrews : United States Golf Association, R&A Rules Ltd., 2021.

3. **R&A Rules Ltd., United States Golf Association.** *Initial Velocity Test Protocol (TPX3007).* St Andrews, Liberty Corner : s.n., 2019.

4. **USGA.** *2021 Calibration Ball Aging Study.* Liberty Corner : United States Golf Association, 2023.