Proposed Bounce Model for Use in Evaluating Optimum Overall Distance

United States Golf Association, R&A Rules Limited.

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1 Abstract

A simplified model for bounce distance (also called bounce and roll) is presented. This model represents an improvement to the sensitivity of bounce distance to terminal trajectory conditions as compared with the model previously used by the USGA and R&A Rules Ltd, and as such is more suitable for optimization. Finally, it preserves a linkage to the existing standard in that it does not, on average, lead to a significant change in the overall distance for golf balls tested by the USGA and R&A Rules Ltd

2 Introduction

The optimum launch conditions for maximizing total distance of a golf ball will be influenced by, among other factors, the conditions of the playing surface or turf. For example, turf conditions that are insensitive to the terminal velocity and spin of a golf ball (for example, soft turf) tend to favor longer carry. In order to ensure relevance of any effort to identify optimum launch conditions, an appropriate choice of turf model should be employed informed by data from actual ball-turf impact. Furthermore, the turf tested should fall within the scope of playing surfaces encountered in competitive golf and provide linkage to the USGA test range that was the basis for the Overall Distance Standard between 1976-2003 and other subsequent work. In this paper, previous experimental work is examined, and effort is made to identify the range of playing characteristics of competitive golf

3 Background

There is a body of work, as exemplified by Haake (1994) and more recently, by Roh and Lee (2010), that is focused on the mechanics of ball-turf interaction and especially backing up a ball on the green. Though related, these works are not considered here as they focus primarily on the interaction between golf balls and greens. This may be considered to be substantially different to that with fairways, in terms of the conditions of the surface, as well as the range of impact conditions considered.

In published works related to fairway bounce and roll distance, Penner (2001) considered the earlier work of Daish in modeling the initial bounce length as dependent upon the product of the vertical and horizontal components of impact velocity after rebound, with subsequent bounces totaling the length of the initial bounce. The results of this modeling were compared to the experimental work of, for example Cochran and Stobbs (1968), in comparing bounce and roll distance to ball speed off the tee.

More recently, Johnson, et. al. (2008) used a ball launcher at a fixed set of condition (including ‘Driver’, 64 MPH, 36°, 2250 RPM). This work compared bounce and roll distance to stiffness, resilience, and other parameters for a number of venues using two ball types using a golf ball launching mechanism. Bounce and roll distance ranged from 5 yards to 30 yards over the five venues, with a statistically significant difference in bounce and roll distance at only one ('Practice Centre').

3.1 Experimental determination of the effects of landing conditions on bounce and roll distance

The following work was conducted by the USGA in order to relate the inbound conditions of a golf ball (post-trajectory) to the bounce and roll distance, with a primary focus on fairways.

The USGA (2003) performed testing using a golf ball cannon impinging the turf at its test range in Liberty Corner, NJ. Though it did not relate the inbound conditions to bounce and roll distance, the information from these tests was retained and are considered here.

Pringle (2005), working with a similar launching mechanism to that of Johnson et. al., tested golf ball/fairway impacts at Pinehurst Golf Resort No. 2 using a golf ball launching device over a broad range of inbound angles, spins, and speeds, identifying relationships with turf factors such as hardness. This work was repeated by Pringle (2013) at another venue (Philadelphia CC) with the finding that among the characteristics of the ball trajectory, inbound angle was the predominant factor.

Quintavalla and Rogers (2008) repeated the work of Pringle using different grass cultivars at turf research plots maintained by Rutgers University. More recently, at Lehigh CC, (USGA/R&A Rules Ltd 2020) confirmed the strong dependence of distance on landing angle and noted that irrigation level had an effect on that relationship.

Finally, Scott (2020) extended the range of inbound angles and speeds in experimental work at the same location as the original 2003 USGA testing, further demonstrating linearity between terminal trajectory angle and bounce and roll distance.

The results of these individual studies may be found in the appendix. A summary of research tests conducted is provided below.

Table 1: Experimental results of testing the response to golf playing surfaces to different terminal ball conditions.

Date	Location	Angle range, deg.	Speed range, ft/s	Slope, vs. angle, yards/deg.	Intercept, yards	Interp. Dist., 39°, yards	Notes
2003	USGA Range	30-50°	85-105	-1.56	90.7	30	No spin
2011	Philadelphia CC	20-50°	90-125	-1.91	110.8	23	(17th)
				-2.01	100.8	37	(18th)
2014	RU turf farm	30-45°	90	-0.74	54.6	19	(Creeping)
				-1.43	74.7	26	(Colonial)
2018	Lehigh CC	30-50°	90	-2.45	120.3	25	(Pre-irrigation)
				-0.98	58.2	15	(Post-irrigation)
2019	USGA Range	10-36°	75-90	-1.79	88.3	18	Focus on low-speed trajectories

3.2 Observations using PGA TOUR ShotLink data

The PGA TOUR reports total distance results for measured drive holes and reports terminal angle and carry distance data for these same holes as evaluated through TrackMan RADAR monitoring. This represents a uniquely rich set of information and allows evaluation of bounce and roll distance and correlation to inbound conditions.

Quintavalla and Rogers (2008) estimated bounce and roll data for 19 PGA TOUR venues in the 2007 season, noting that there was a strong dependence on landing angle that was venue- or championship-dependent. At an average terminal angle of 39°, bounce and roll distance over all these championships averaged 30 yards, ranging from 17.9 yards to 41.6. The average dependence on terminal angle was reported as -1.24 yards/degree, with a standard deviation of 0.37. For each venue, a bounce and roll distance penalty of 8-9 yards was identified for reported rough lies, with a lower average dependence on terminal angle (-0.45 yards/degree).

This work was updated and expanded in 2020 by Lieberman, who used ShotLink and TrackMan data reported for the 2016-2018 PGA TOUR seasons. Results are shown in Figure 1 – Figure 3. The first figure shows a range of interpolated distances at 39° (again, typical average terminal angle) between 10-60 yards, with median of 21 yards and a mean of 22 yards. The best-fit average slope is -1.52 yards/degree (Figure 2, falling reasonably near testing at the USGA test range, Table 1), with an average intercept of 81 yards (see Figure *3*).

As will be seen in the next section, slopes and intercepts, arrived at based solely on data from individual championships, are not independent. Rather, these appear to be linearly correlated, and in fact, proportional.

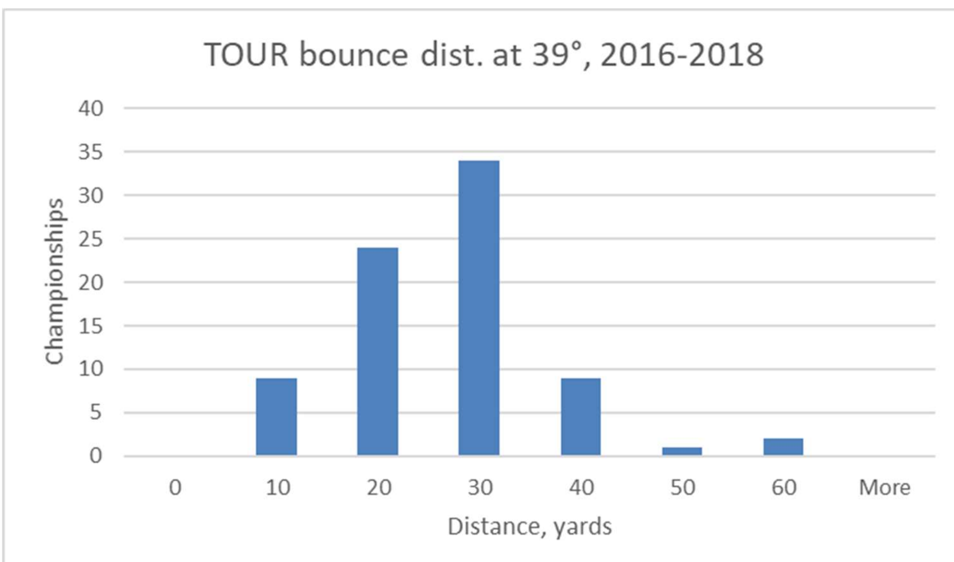

Figure 1: Bounce and roll distance for PGA TOUR championships, 2016-2018, normalized to 39° terminal trajectory angle. The mean is approximately 26.5 yards.

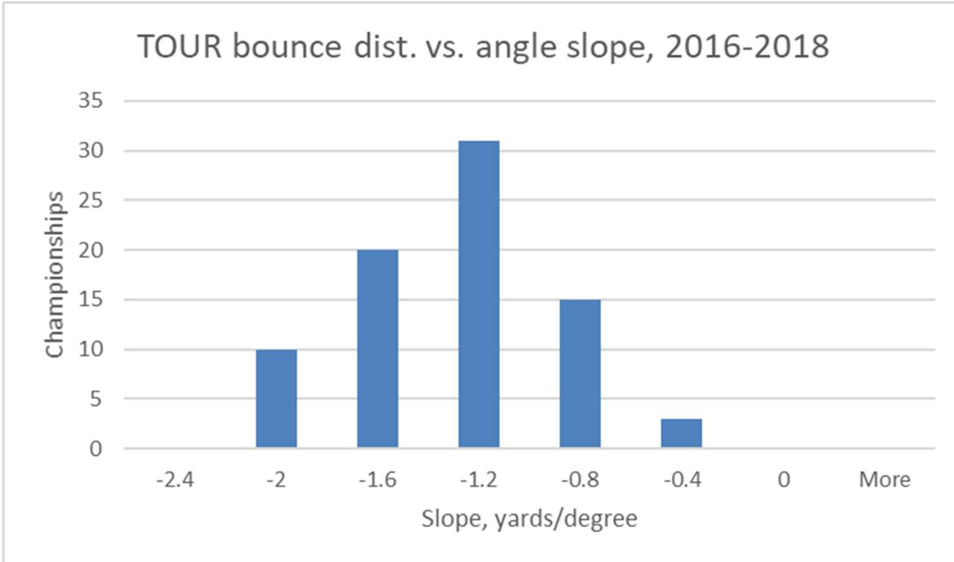

Figure 2: Slope or sensitivity of bounce distance to terminal trajectory angle. The negative value indicates that the steeper the angle, the shorter the ultimate bounce and roll.

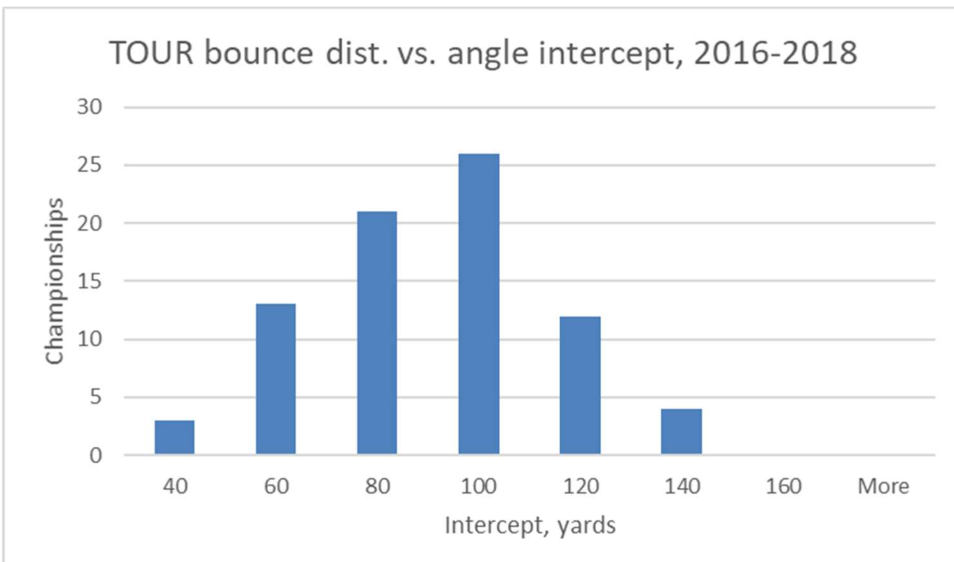

Figure 3: Intercept of the linearization of bounce distance as a function of terminal trajectory angle. It will be seen that this is not entirely independent from the slope presented in Figure 2.

3.3 Summary of Correlated Results

Results from the identified best-fit slopes and intercepts of PGA TOUR championships for 2016-2018 seasons are presented in Figure 4. Included in this figure are the slopes and identified through research tests conducted by the USGA as described in section 2.1 and illustrated in the appendix. The results are well-correlated, and a fit of the data showing a proportional relationship is shown.

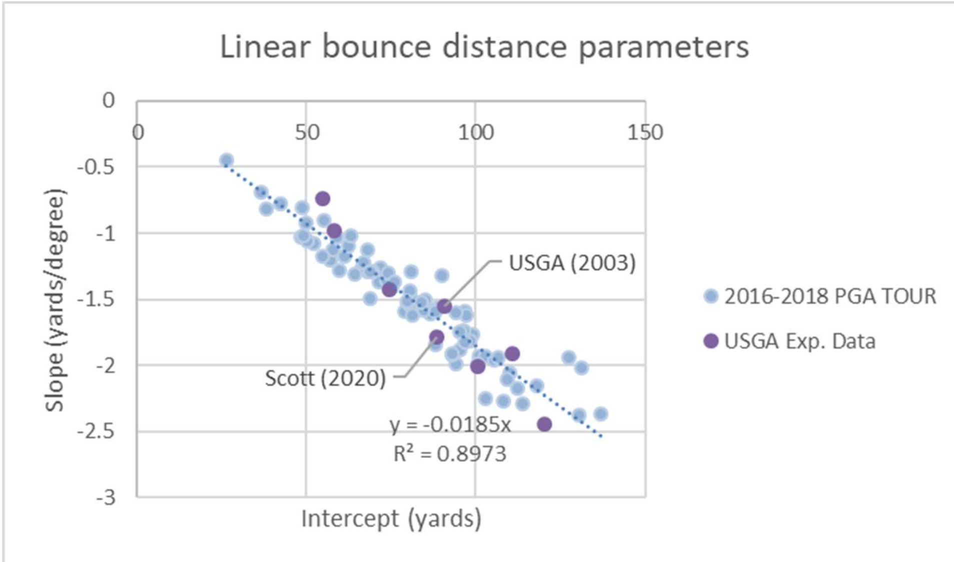

Figure 4: The relationship of slope and intercept for the linearized data from PGA TOUR ShotLink and TrackMan, superimposed with expiermental data collected by the USGA *between 2003 and 2019*.

For illustration, the use of the best fit shown in Figure 4 over a range, for example, of 30-45 degrees is shown in Figure 5: this may be compared to the figures in the appendix. One may note that given the approximate proportionality between slope and intercept, these lines would be expected to converge at a point where the angle is the inverse of the proportionality constant, 1/0.0185, or 54 deg.

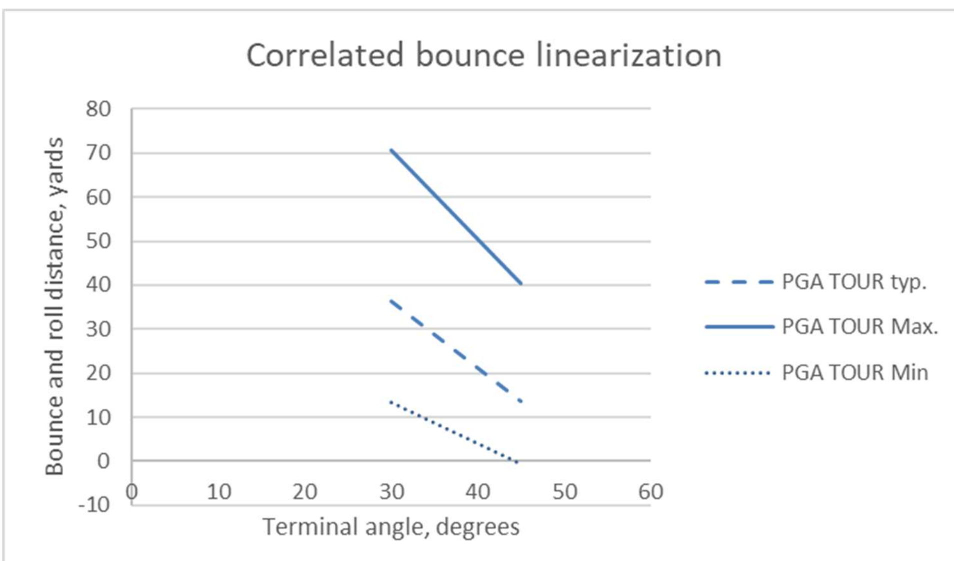

Figure 5: Depictions of the results of using the regression equation from Figure 4 at three levels of sensitity or slope.

3.4 Published USGA Bounce Model (2003)

As part of the USGA's Overall Distance Standard incorporated in 2003, bounce and roll distance is calculated based on the simulation of individual bounces and post-bounce trajectories. This simulation starts with the initial impact between the ball and the turf and continuing until the calculated bounce height is less than the ball radius.

This model uses parameters such as turf tilt and coefficient of restitution to estimate the post-impact conditions (i.e., speed angle and spin), and assumptions about the aerodynamic performance to simulate post-bounce trajectories.

The parameters for the model were based on the USGA test range, under conditions such that the bounce and roll distance were 7-9 percent of the total distance of a control ball struck by a driver at 109 MPH, nominally about 22.5 yards. This was a key feature of the 2003 bounce and roll model, in that it preserved a continuity between the previous outdoor testing and the revised standard.

Despite its complexity, the result of this model is well correlated to inbound angle. In Figure 6, the results of the USGA 2003 bounce model are presented for all golf balls subject to a full test for Overall Distance by the USGA and R&A Rules Ltd in 2020. For clarity, a second, closer view of this data is presented in Figure 7.

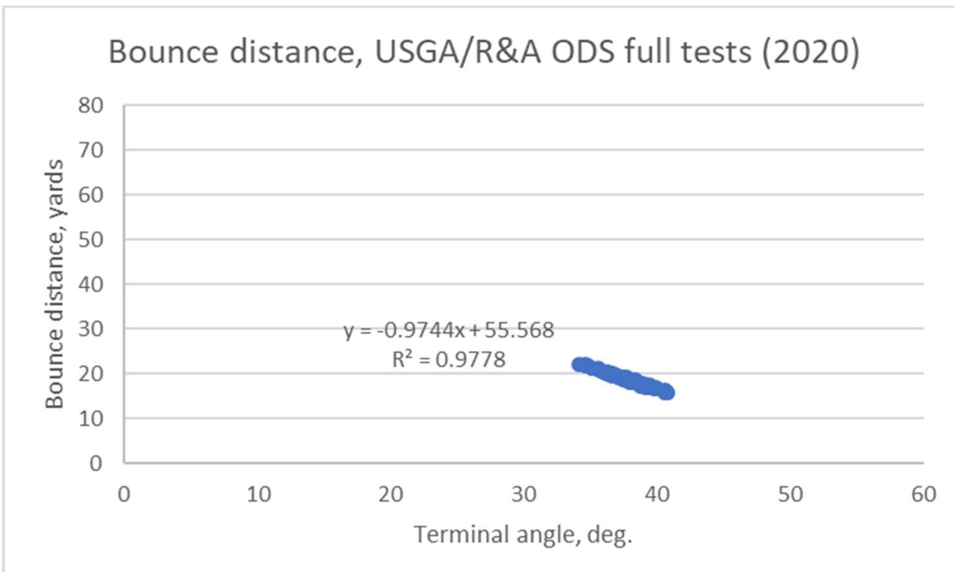

Figure 6: Linearization of the USGA 2003 bounce model based on terminal conditions for golf balls tested by the USGA and R&A Rules Ltd for Overall Distance in 2020. For reference, the scale is identical to that for experimental data presented in the Appendix.

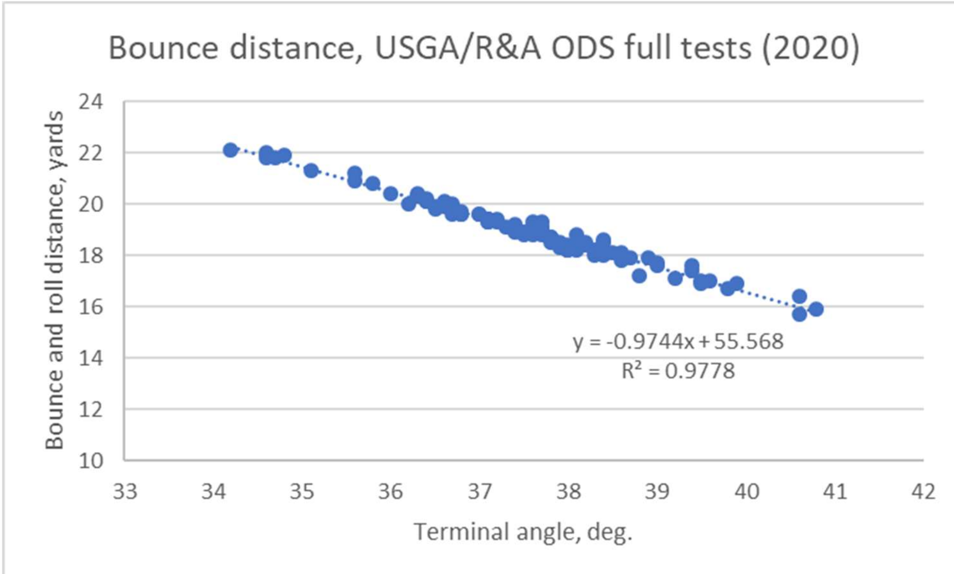

Figure 7: Linearization of the USGA 2003 bounce model based on terminal conditions for golf balls tested by the USGA and R&A Rules Ltd for Overall Distance in 2020, as in Figure 6. The scale is changed to illustrate the linearity of the 2003 bounce model over this range.

4 Proposed turf model

In reviewing Figure 6 and Figure 7 in the context of Table 1 and Figure 1 to Figure 4, it is apparent that the existing USGA (2003) bounce model may not be the most relevant choice for optimization. That is, the relatively low effective slope of bounce distance versus terminal angle does not appear to represent the central tendency of either experiments conducted by the USGA, or evaluation of competitive playing surfaces. A slope that is uncharacteristically low may lead to optimum launch angles that are higher than would be expected in actuality.

The choice of parameters for a linearized bounce model would therefore be as follows. First, the turf model should have a relevant sensitivity of bounce distance to terminal angle. Second, in honoring the link to previous established standards, the choice of intercept should be set such that, on average, golf balls recently tested for total distance by the USGA and R&A Rules Ltd, should not be affected by a change in the model.

With respect to the slope, distance change due to change in terminal angle, a value of -1.6 agrees with experimental data gained from the USGA test range (-1.8 to -1.6) and PGA TOUR playing surface result for 2016-2018 (-1.5), though it slightly underestimates the central tendency of other USGA experimental results (for example, the median of all slopes, Table 1, is -1.7).

In order to establish the intercept, consideration is given to previous conformance test results. For all golf balls submitted to the USGA and R&A Rules Ltd in 2020, 94 were subject to a full test in order to determine their conformance to the Overall Distance Standard: the terminal angle for these ranged from 35° to greater than 40° (Figure 8), with an average of 37.6°. Using the mean intercept of the 2016-2018 PGA TOUR data (81 yards) would result in a net increase of about 5 yards in those golf balls tested for ODS under ALC.

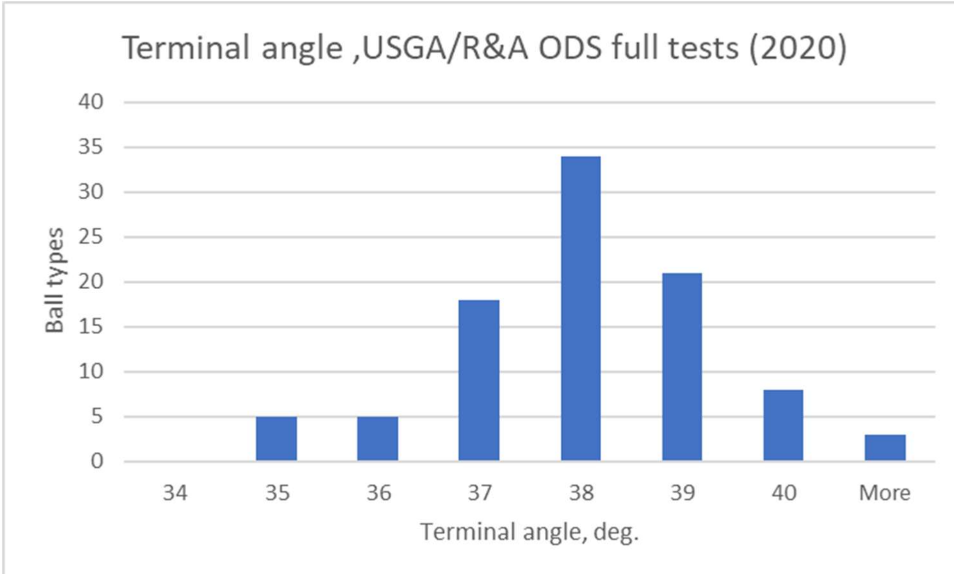

Figure 8: The terminal trajectory angle of all golf balls subject to full testing by the USGA and R&A Rules Ltd for Overall Distance. The mean is 37.6°, slightly shallower than the mean identified from TrackMan data.

Accordingly, as we do not wish to change the average result for these ball types, we set the intercept at 79.1 yards, such that the proposed bounce and roll model becomes:

$$d_{bounce} = 79.1 - 1.6 \cdot \alpha_f \tag{1}$$

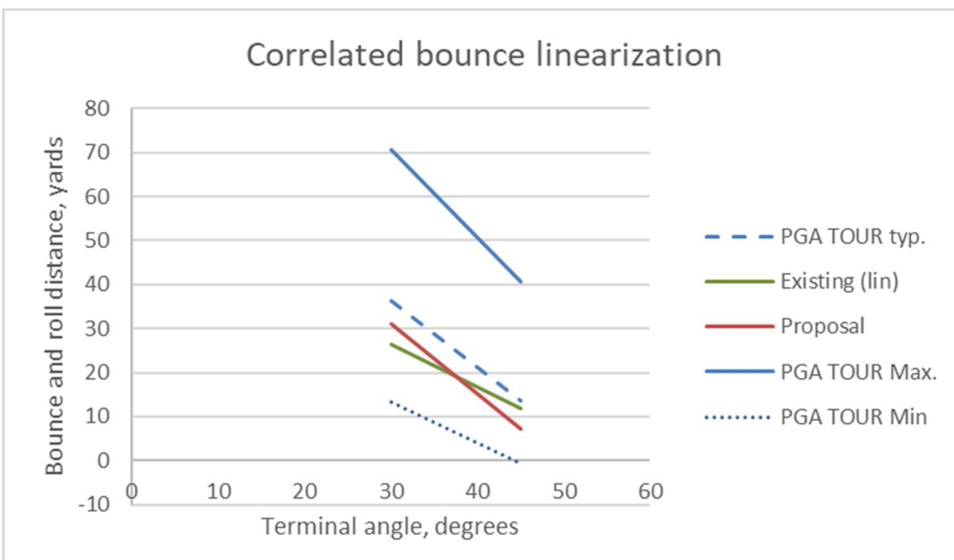

Figure 9: Illustration of the existing USGA 2003 bounce model (linearized) and the proposed model. The intersection is at 37.6° by definition of the proposal.

As shown in Figure 9. Viewed in the context of existing competitive playing surfaces and experimental data discussed in previous sections, the proposed model may be set against the data represented in Figure 4 (see Figure 10). It is noted that the proposed model does not represent the median of PGA TOUR data, it is within the range of expected values, and is close to the regression line. It also represents an improvement over the parameters for the linearized USGA 2003 models with respect to experimental results for the USGA test range.

The effects of the change to the bounce model under the conditions of the current Overall Distance Standard can be seen in Figure 11. The average distance of the ball types evaluated is 316.6 yards with both the existing model and the proposal represented in Equation 1.

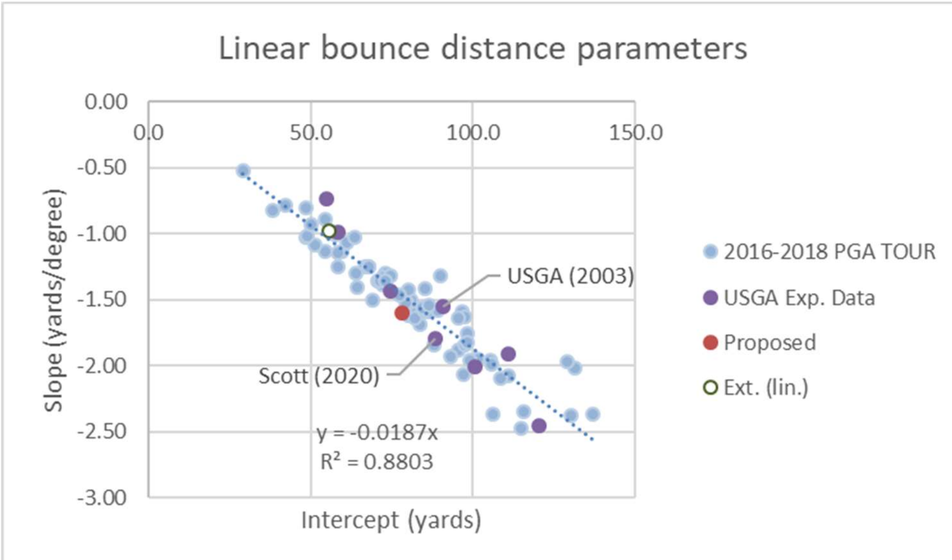

Figure 10: PGA TOUR and USGA experimental turf data, with the proposed (red) and existing, linearized model (white). Tests conducted at the USGA test range are highlighted for reference.

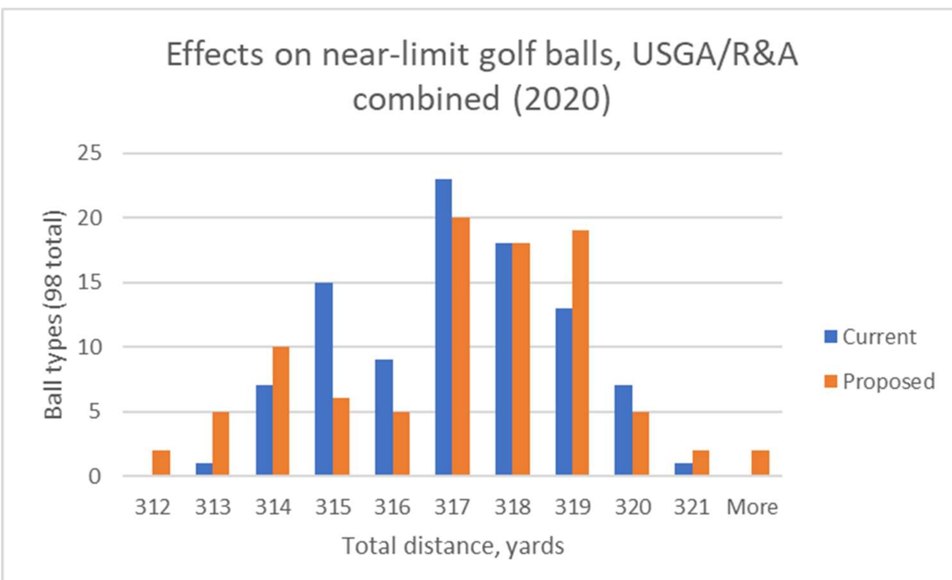

Figure 11: Change in total distance for golf balls subject to full testing for the Overall Distance Standard by the USGA and R&A Rules Ltd in 2020. The average increase is zero yards, providing an important linkage between the existing and proposed models.

5 Conclusions

A simplified bounce model has been proposed that better reflects the sensitivity of bounce distance to the terminal angle of the golf ball, while preserving the mean distance of golf ball types for which full tests have been conducted under the current Overall Distance Standard. This model is relatively simple to implement, and experimental evidence suggests that such a linear model is robust over a broad range of terminal conditions.

6 References

Cochran, A., Stobbs, J. (1968) The search for the perfect swing, Triumph Books, Chicago

Haake, S. (1994) Golf ball impacts, greens and the golfer, Science and golf II: proceedings of the 1994 World scientific congress of golf, Taylor and Francis, Abington

Penner, A. (2001) The physics of golf: the optimum loft of a driver, Am. J. Phys., Vol 69, No. 5

Pringle, M. (2005) Preliminary results of turf testing at Pinehurst No 2 Spring 2005, USGA internal report

Quintavalla, S., Rogers, M.J. (2008), Survey of bounce and roll at 2007 PGA TOUR, USGA internal report.

Johnson, A., et. al. (2008), An investigation into ball-turf impact characteristics. R&A Rules, Limited report. St Andrews, UK

Rho, W.J., Lee, C.W. (2010) Golf ball, landing, bounce, and roll on turf, Proceedings from the 8th Conference of the international sports engineering association, 3237-3242

Pringle, M. (2013) Bounce and roll testing at Philadelphia Cricket Club (Militia Hill course), USGA internal report.

USGA/R&A Rules Ltd (2020) Agronomic impacts on bounce and roll distance, Distance Insights Library Report R03.

Scott, K. (2020) Low speed bounce and roll analysis, USGA internal report.

7 Appendix: USGA Experimental Turf Research Data

Figure 12 through Figure 15 illustrate the results of the use of equipment as described by Johnson et. al. in order to evaluate the effects of terminal trajectory conditions on bounce and roll distance (shortened 'Bounce distance' for convenience in the figures). These tests are described in Table 1 of the text. Most tests were conducted at 1,800 rev/s, with the exception of Philadelphia Cricket Club (which used a broad range of spins). Note that 2018 tests conducted at Lehigh CC (USGA/R&A Rules Ltd. 2020) were performed in evaluating the effects of pre- and post-irrigation and direction (with/down or against grain), and these results represent a single fairway.

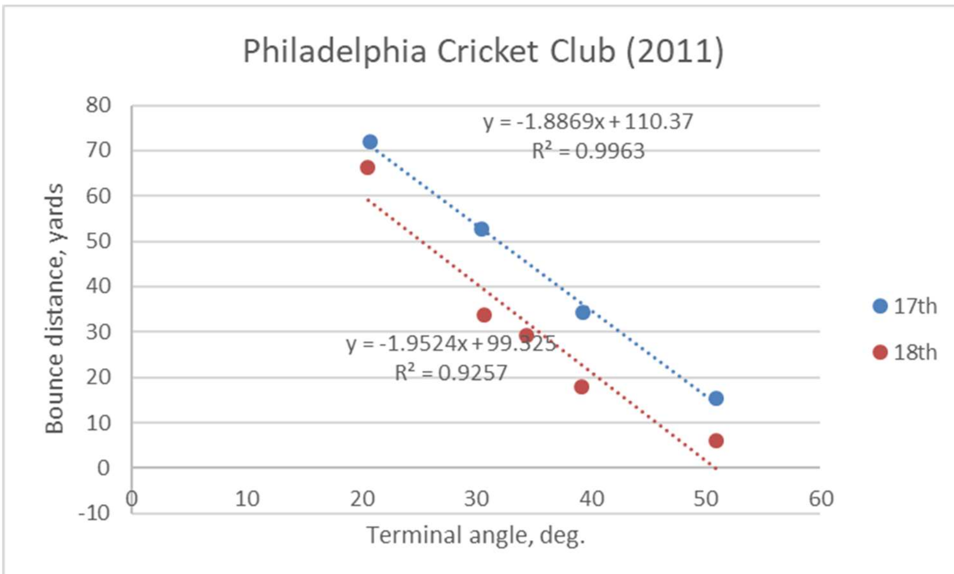

Figure 12: Philadelphia Cricket Club, Militia Hill Course

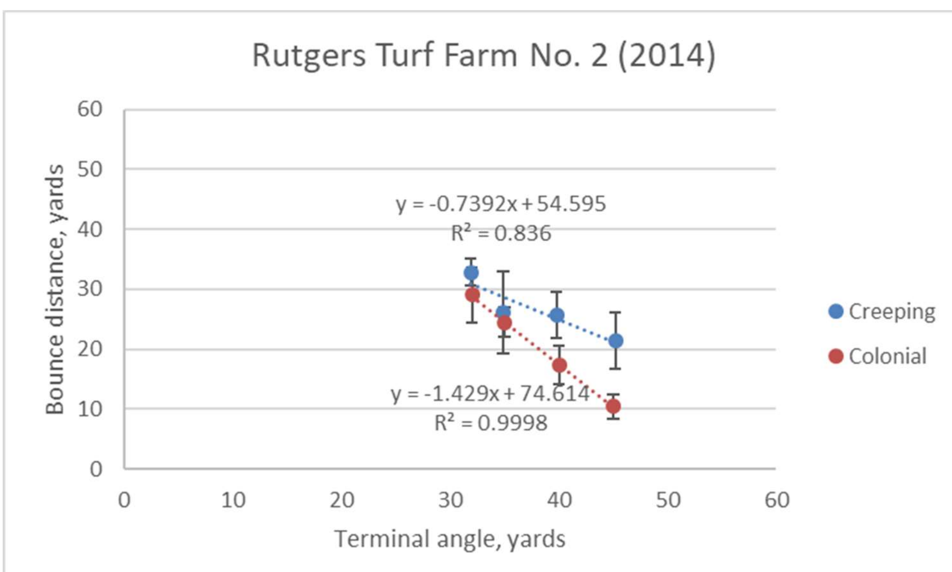

Figure 13: Rutgers Turf Farm No. 2.

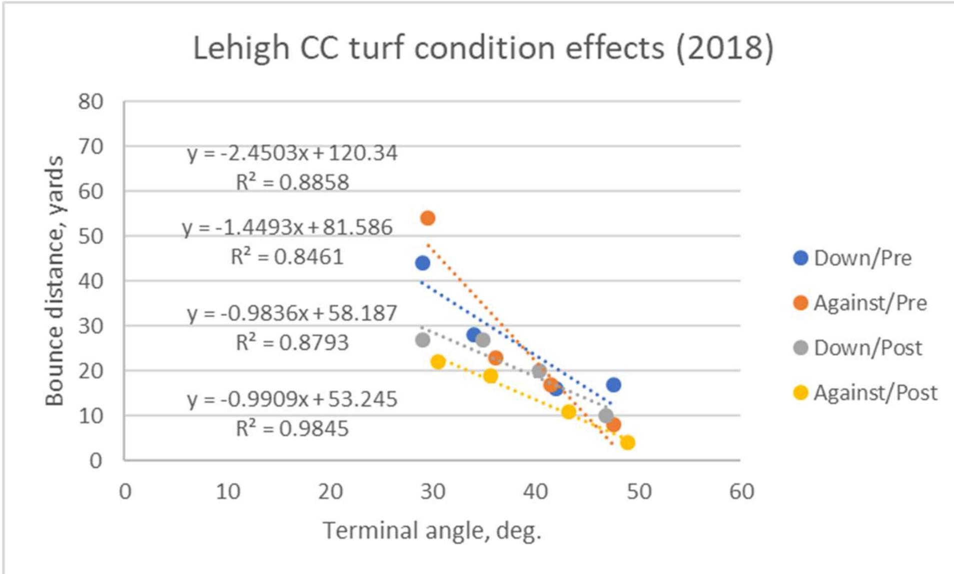

Figure 14: Lehigh CC

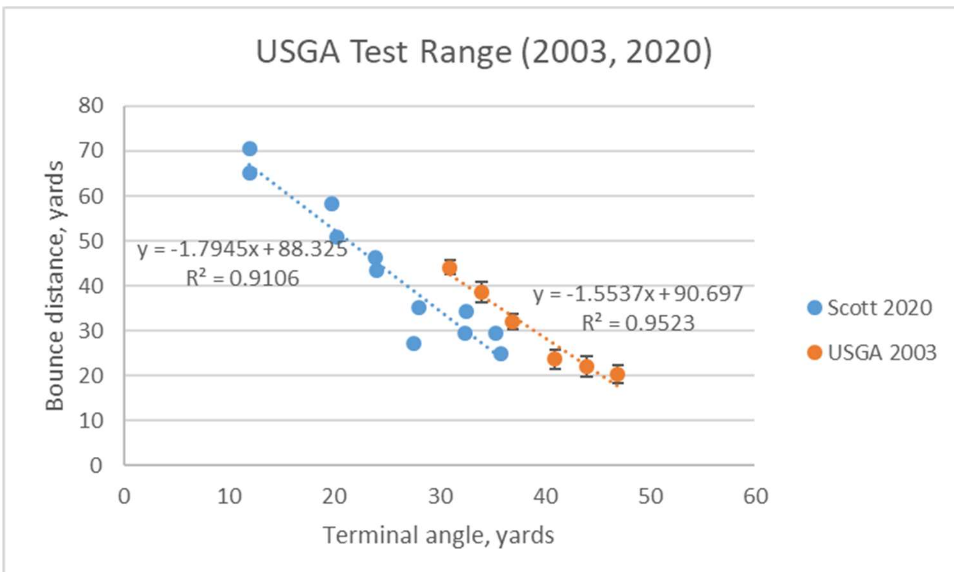

Figure 15: USGA Test Range