Proposed Test Conditions for Optimization of Overall Distance

United States Golf Association, R&A Rules Limited

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1 Introduction

The United States Golf Association and R&A Rules Limited have proposed a change to test conditions for the Overall Distance Standard. In this proposal, it is planned to identify the optimum launch conditions within a range of 7.5° – 15° and 2,200 RPM – 3,000 RPM. The present work seeks to identify appropriate test conditions (combinations of speed and spin) for the Indoor Test Range that are relevant to optimization.

2 Background

2.1 Current test conditions

The USGA and R&A Rules Ltd currently test golf balls at a total of 15 test conditions, spanning a Reynolds number (*Re*) range of about 0.73×10^5 to 2.23×10^5. Initial ball spins range from 1,740 – 3,120 RPM and were intended to capture a range of ball launch conditions from the tee of 2,300 – 3,100 RPM. These test conditions were established as a part of the Overall Distance Standard (USGA, 2004).

Table 1: Nominal and effective test conditions used by the USGA and R&A Rules, Ltd. under the Overall Distance Standard, Phase II. *See note on average versus initial speed. †Nondimensional spin parameter, see Appendix A.

Condition	V_0, ft/s	Spin, RPM	Spin, rev/s	V_{avg}*, ft/s	$Re \times 10^{-5}$	W†
1	93	2520	42	87.2	0.733	0.21
2	92	2160	36	86.6	0.728	0.18
3	96	1800	30	90.7	0.763	0.15
4	108	2640	44	101.5	0.854	0.19
5	108	1740	29	102.3	0.860	0.12
6	130	2880	48	122.5	1.030	0.17
7	130	2340	39	123.0	1.034	0.14
8	130	1800	30	123.4	1.038	0.11
9	161	2820	47	152.3	1.281	0.14
10	161	1740	29	153.3	1.289	0.08
11	220	2940	49	209.0	1.757	0.10
12	220	2280	38	209.6	1.762	0.08
13	220	1800	30	210.0	1.766	0.06
14	278	3120	52	264.6	2.225	0.09
15	278	2100	35	265.6	2.233	0.06

2.1.1 Note on average versus initial speed

Given the effects of aerodynamic drag, the average speed for a test, with which lift and drag are associated, will necessarily be lower than the launcher exit, or initial speed. It is relatively straightforward to calculate the effect of drag on a one-dimensional trajectory as discussed in Appendix A.

3 Monte Carlo simulation

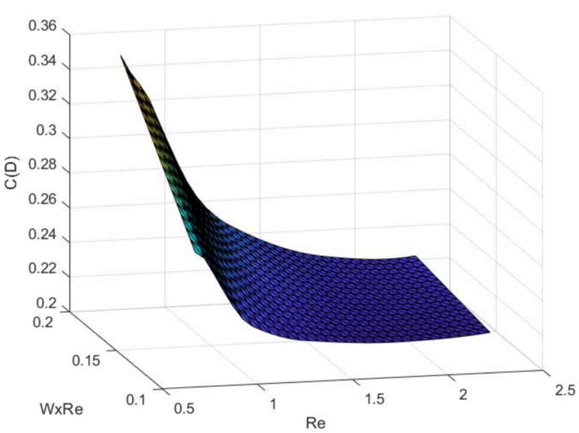
3.1 Assumptions

This work assumes that the search bounds for initial spin are 2,200 – 3,000 RPM (36.7 – 50 rev/s) (USGA/R&A Rules Ltd, 2021)(1) For the purposes of this study, bounce and roll was modeled using the proposed linear bounce and roll model (USGA/R&A Rules Ltd, 2021)(2).

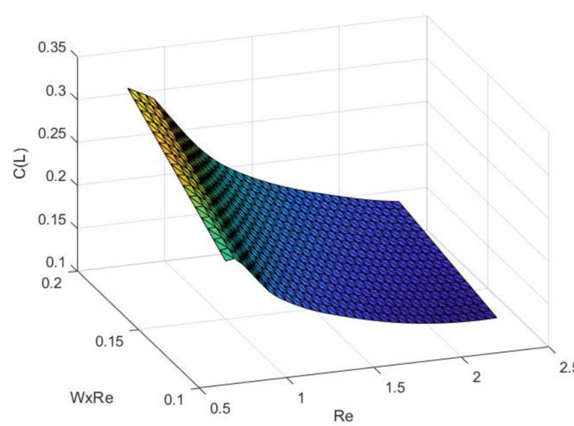
A golf ball having performance high levels indicative of types used in professional golf was selected for these simulations. This ball has been tested at 27 conditions using the Indoor Test Range, and the data fit using a 6-parameter curve fit for lift and drag in order to establish the ground 'truth'.

The surface of drag and lift coefficients versus Reynolds number ($\times 10^{-5}$) and W× Re($\times 10^{-5}$) are shown in Figure 1 (a, b). Alternative lift and drag coefficients for a golf ball having high Re sensitivity are also shown (c, d), which are considered later in this paper. The rationale for this selection is that such golf balls present the greatest challenge to testing, interpolation, and simulation.

Monte Carlo simulations were performed using the existing 15 test conditions in order to estimate the associated error. At launch conditions associated with "ALC" (10°, 2, 520 RPM), this results in a standard deviation in overall distance of 0.85 yard. At the 99% level of inclusion, this represents ±2.2 yards, which closely matches the level of uncertainty associated with the Indoor Test Range under ALC. As will be shown, using these existing test conditions does not perform as well at the lower spin boundary.



(a)



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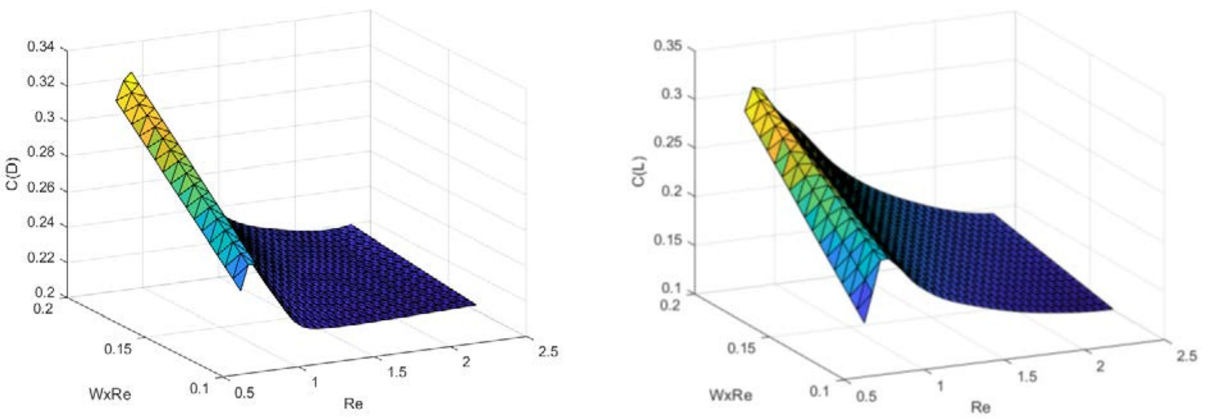

(c) (d)

Figure 1: Graphical depiction of lift and drag coefficients for a high-performance TOUR-type golf ball (a, b) and a ball with high Reynolds number sensitivity (c, d) as functions of Reynolds number and nondimensional spin (see Table 5, ball type "D").

3.2 Structure of candidate test conditions

From this ground truth, interpolated test conditions were chosen on the assumption that tests at one or more spins would be conducted at each of several Reynolds numbers, whose number would be predetermined, and varied between 6-8. The range of Reynolds number was 0.725×10^5 to 2.240×10^5 unless noted otherwise.

For each Reynolds number, 1-3 spins were evaluated. Given the assumed range of launch conditions for the boundaries of the distance search, and accounting for spin decay, the minimum and maximum spins at any Reynolds number were 1,620 RPM (27 rev/s) and 3,000 RPM, respectively. This nondimensionalizes to a nondimensional spin of $W\times(Re\times10^{-5}) = 0.1$ to 0.193.

In order to optimize the selection of Reynolds numbers, a Reynolds number 'bias' was introduced. This was defined such that if the bias is equal to one, then the tests are evenly distributed across the range of Reynolds numbers. If the bias were set to 2, the span between the third and the second Reynolds number would be double that of the first and second, i.e.,

$$Re_3 - Re_2 = 2(Re_2 - Re_1)$$

Or more simply

$$\delta_{3-2}Re = 2\delta_{2-1}Re$$

Over a normalized span of 0-1, this means that the Reynolds number groups would be set at 0, ⅓, and 1 for a bias of 2. This may be generalized for any selection of bias *b* over a number of spans *n* over a normalized range (0 to 1) such that:

$$\bar{\delta} = \left(\sum_{i=1}^{n} b^{i-1}\right)^{-1}$$

Then the selection of Reynolds number for each Reynold number group becomes:

$$Re_i = \begin{cases} Re_{min} & i = 0 \\ Re_{i-1} + (Re_{max} - Re_{min})\bar{\delta} b^i & i > 0 \end{cases}$$

This allows us to systematically apportion Reynolds numbers groups, and identify trends based on a single independent variable.

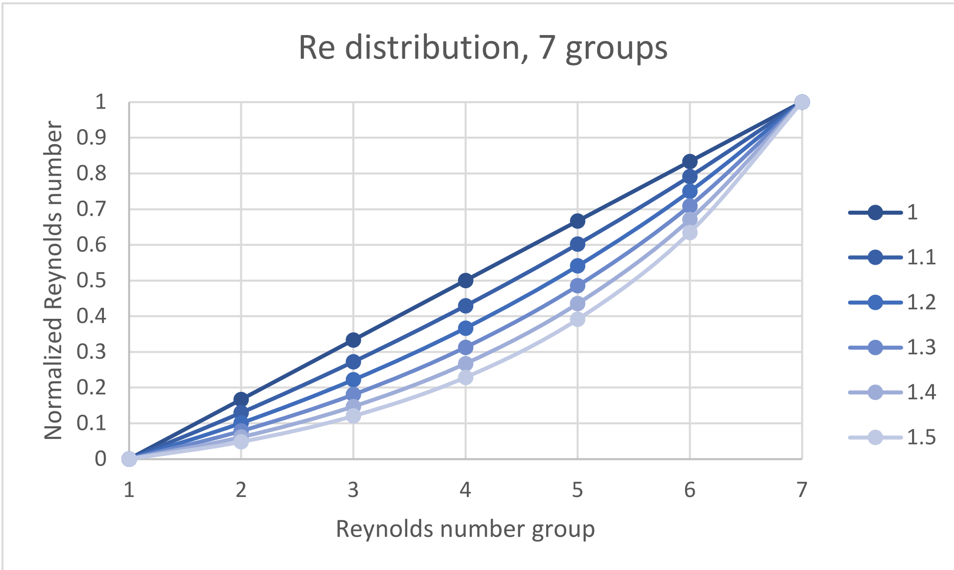

Figure 2: Normalized Reynolds number (0-1) for seven Reynolds number groups, with adjusted bias factors. A bias factor of 1.0 indicates even distribution of Reynolds numbers, while increasing this factor biases more test points near the lowest Re.

In this study, values of 1 (indicating even spacing of Reynolds number) to 1.5 were considered. It will be shown that, within limits, increasing bias tends to reduce error sensitivity, likely resulting from the benefit of better capturing greater nonlinearity at lower Reynolds number. A summary of all test condition strategies is given in the Appendix (B), along with results.

Similarly, where one or three spins were considered at a particular Reynolds number, a bias factor of 1 (even spacing) and 2 (one-third of the way between the minimum and maximum spin) were evaluated.

3.3 Monte Carlo simulation details

In the simulation, random error was applied to the test condition *i* lift and drag coefficient for each trial *j*. This was done by multiplying each lift and drag coefficient by a factor as in the following example for coefficient of lift:

$$\acute{C}_L^{i,j} = (1 + \epsilon) C_L^i$$

Where ϵ had a mean of zero standard deviation of 0.010 (or one-half percent) for Re > 0.75×10^5 and 0.018 for Re ≤ 0.8×10^5 (and similar for drag). As will be discussed, this assumption approximates the level of uncertainty with ITR measurement.

It was found that *m* = 30,000 trials in the Monte Carlo simulation (Figure 3) was sufficient to estimate the reported result, i.e., the standard deviation of total distance resulting from applied lift and drag coefficient errors, within about 1%. In this example, the estimate comes from repeated evaluations of the existing set of test conditions in identifying the overall distance at

256 ft/s, 12° and 2,200 RPM (noting that this results in higher variability due to extrapolation, as will be discussed later).

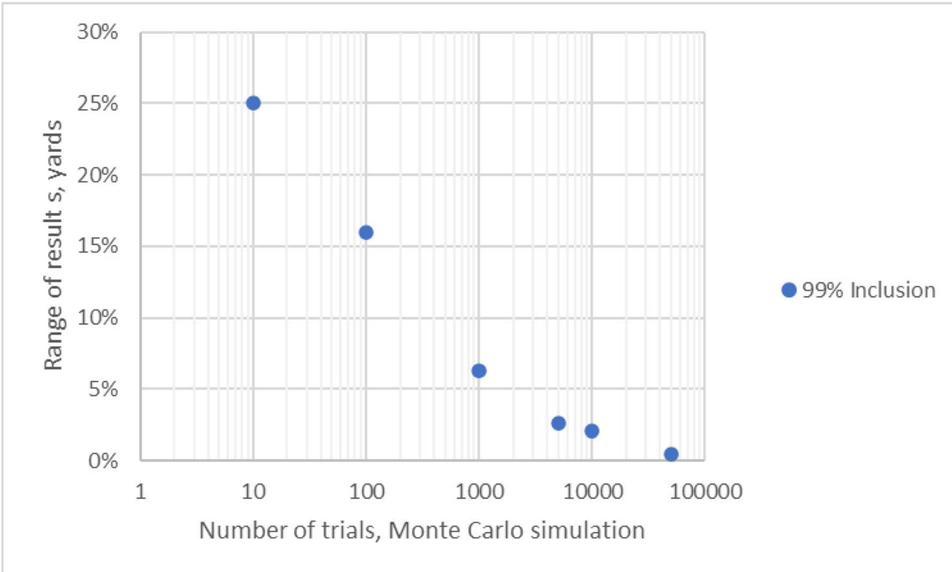

Figure 3: Range of uncertainty in estimate of the standard deviation of overall distance resulting from random error, as a function of the number of trials in Monte Carlo simulation.

4 Results

All results are provided in Appendix B. Figure 4 shows the effect of biasing settings towards lower Reynolds numbers. In Figure 5, the study distance standard deviation that is minimized by the selection of Reynolds number bias factor are shown for all combinations.

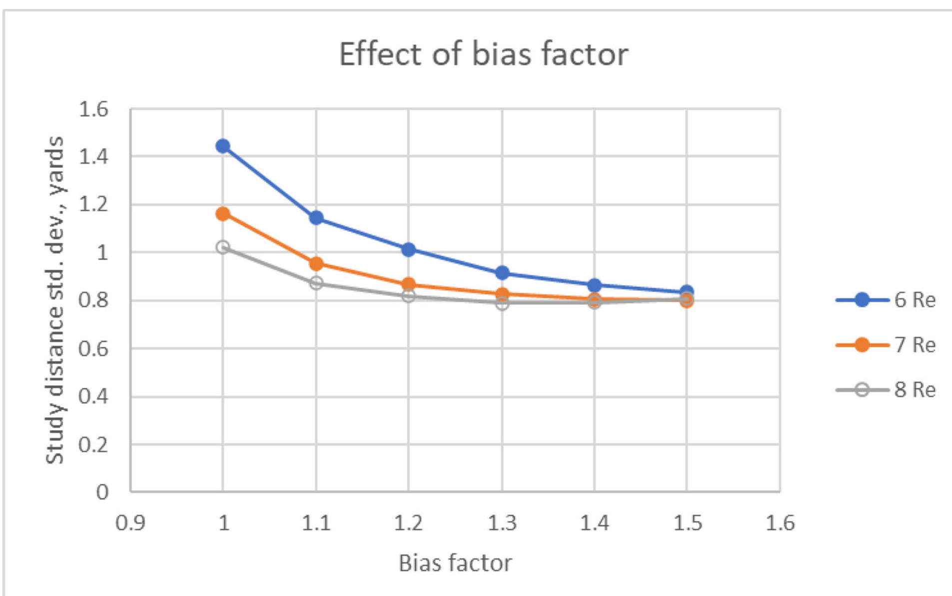

Figure 4: The effects of increasing the Reynolds number bias factor. Examples where two spins at each Reynolds number were evaluated are shown (spin bias factor = 1).

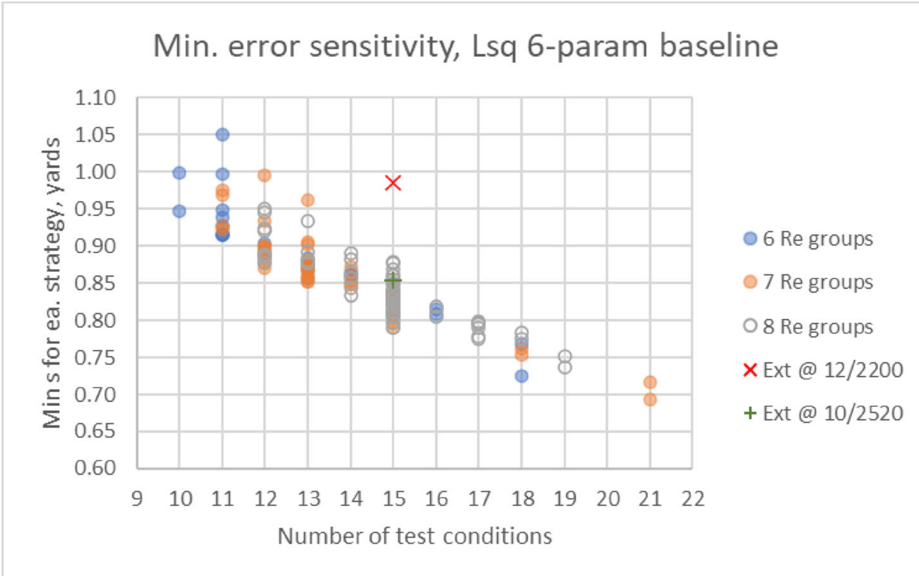

Figure 5: Minimum error sensitivity as expressed by the standard deviation of total distance estimate in response to lift and drag errors. Minima were identified through the lowest reported value based on Re bias factor (range 1.0 – 1.5).

5 Analysis

For a given strategy (number of distinct Reynolds numbers and distribution of spins within each Reynolds number), there is an optimal bias factor that minimizes the sensitivity to lift and drag error. It is seen that the minimum tends to occur at about 1.4 – 1.5, though the value does not change substantively over ±0.1.

On average, biasing intermediate spin values downwards (1/3 versus 1/2) was slightly advantageous, reducing the overall distance standard deviation by 0.018 yard on average, and in some circumstances as much as 0.08 yard (Figure 6).

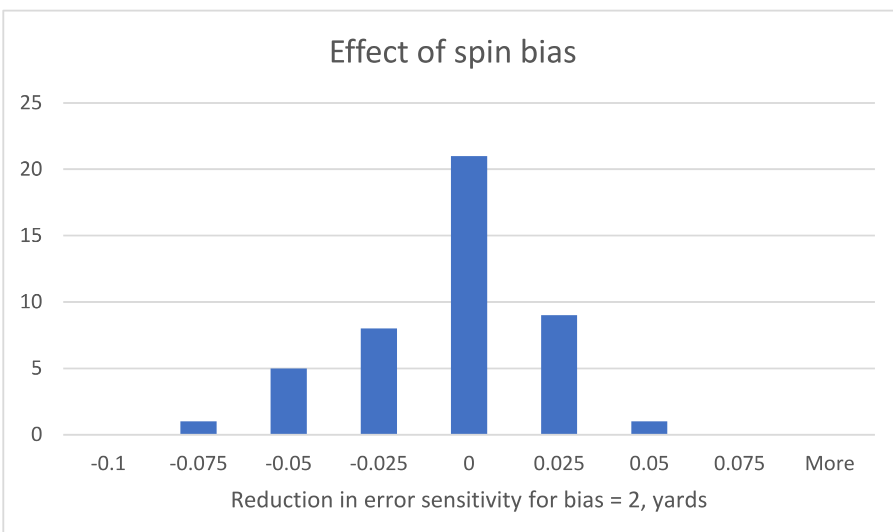

Figure 6: The reduction in the error sensitivity of all setting based on setting intermediate spin values 1/3 of the span between the minimum and maximum values (bias factor = 2) rather than midway (bias factor = 1).

It can be seen in Figure 5 that increasing the number of test conditions, within the framework described, generally reduces the error sensitivity of the ITR process with respect to error in individual lift and drag measurements. Within this, there is some variation, with combinations of speed and spin yielding moderate improvements.

Table 2: Lowest lift and drag coefficient error sensitivity identified at each number of test conditions. All simulations performed at 12° and 2,200 RPM.

Number of test conditions	Minimum error sensitivity, yards
10	0.95
11	0.92
12	0.87
13	0.85
14	0.83
15	0.79
16	0.81
17	0.77
18	0.72
15 (current)	**0.99**

Table 2 shows the minimum standard deviation identified among the test conditions reviewed at each number of test conditions. In this table, the Re bias factor was constrained in order to maintain reasonable separation between test speeds at the lowest Reynolds numbers. Therefore, for 8 Re groups, the minimum Re bias was 1.3, and for 7 Re groups, the minimum bias was 1.4.

Compared to the current set of test conditions used to estimate distance at its intended angle and spin (10°, 2,520 RPM, s = 0.85), 12-16 test conditions appear to perform at least as well, with many potentially showing significant improvement. It is also noted that, though it does not represent the best choice of test conditions, the current (15) set does a reasonable job of estimating ball distance at near-optimum angle and spin (±3 yards at 99% level of inclusion).

5.1 Selection

Sets were selected representing 13, 14, and 15 test conditions over 6, and 7 Reynolds number groups for further evaluation (Table 3). Including 8 groups does not appear to improve error sensitivity and reduces opportunities for identifying useful screening candidates. These represent sets that, based on Reynolds number and spin bias have the minimum error sensitivity for each design.

*Table 3: Test condition strategies having 15 settings or fewer, and a standard deviation of Monte Carlo trials of less than 0.87. *See Appendix B for description of terms.*

No.*	No. Conditions	No. Re groups	Spin distribution*	Re Bias	WxRe Bias	Err. Sensitivity
11	13	6	222223	1.5	1	0.86
57	13	7	2221222	1.4	1	0.85
33	14	7	2222222	1.4	1	0.85
36	14	7	3212123	1.4	2	0.85
5	15	6	323232	1.5	1	0.84
8	15	6	323223	1.5	2	0.81
38	15	7	3213123	1.4	2	0.81
74	15	7	3221223	1.4	2	0.79

5.2 Evaluation over range of initial spins

Though it is likely that most ball types will have optimum distance at lower ball spins, it is important to evaluate the effectiveness of these candidate test conditions across the range to be evaluated. Therefore, the selected groups in the preceding section were evaluated at the same speed and angle (256 ft/s, 12°), but at additional initial spins of 2,600 RPM (representing the midpoint of the range) and 3,000 RPM.

Result are shown in Table 4. It can be seen that at the midpoint, error sensitivity is not significantly affected by the assumption of spin, though there is an increase at the highest spin rates. All sets of test conditions are similarly affected.

Table 4: Effects of assumed initial spin on lift and drag error sensitivity. Reported values represent the standard deviation of total distance subject to error in C(D) and C(L). m = 5,000 trials. *Ground truth using 27 test conditions.

Spin, RPM	2,200	2,600	3,000
Distance, yards	314.0	307.7	298.2
11	0.87	0.96	1.59
57	0.86	0.98	1.62
33	0.86	0.95	1.60
36	0.86	0.92	1.54
5	0.86	0.91	1.52
8	0.80	0.87	1.51
38	0.84	0.90	1.57
74	0.81	0.87	1.53

5.3 Additional golf ball types

The rich data set described in this work to establish ‘ground truth’ has been collected for additional golf ball types. Smaller Monte Carlo simulations (m=5,000 trials, with a resulting range of error of the estimate of 2.5%) were conducted for these ball types in order to estimate the pooled variance for the use of existing test conditions to estimate optimum overall distance for each candidate set of test conditions. It should be noted that the use of the candidate test conditions do not lead to significant offsets between the ‘ground truth’ and the mean of the Monte Carlo simulations.

Table 5: Error sensitivity resulting from use of existing test conditions (designed for "ALC") to estimate optimum overall distance for different ball types, as well as proposed, alternative test conditions. Note that with the exception of Type 5, use of the Ext. full test settings at ALC-like launch conditions leads to a result that is close to the test gauge. *See Figure 1(c,d).

	A	B	C	D*	E	F	G	H	Pooled	s_{offset}	s_{total}
No./Dist	314.0	310.7	316.1	313.1	288.5	286.9	307.9	308.7	-	-	-
11	0.87	1.55	0.83	0.73	0.72	0.63	1.40	0.90	1.01	0.31	1.05
57	0.86	1.56	0.81	0.73	0.71	0.66	1.46	0.96	1.02	0.31	1.07
33	0.86	1.50	0.78	0.70	0.71	0.62	1.38	0.94	0.99	0.30	1.03
36	0.86	1.52	0.78	0.73	0.72	0.65	1.41	0.92	1.00	0.29	1.04
5	0.86	1.53	0.81	0.72	0.70	0.62	1.45	0.90	1.00	0.31	1.05
8	0.80	1.43	0.75	0.69	0.66	0.60	1.26	0.82	0.92	0.26	0.96
38	0.84	1.48	0.77	0.70	0.68	0.61	1.33	0.85	0.96	0.28	1.00
74	0.81	1.44	0.75	0.69	0.68	0.61	1.31	0.84	0.94	0.25	0.97
Curr. 15-cond	0.99	1.73	0.91	0.79	0.72	0.71	1.73	1.24	1.17	0.43	1.25
Curr. 9-cond	1.30	1.90	1.15	1.05	0.92	0.95	1.98	1.62	1.41	0.60	1.54

Table 5 shows the results of this study. In addition to the standard deviations of the Monte Carlo trials for ball profiles A-H, it is noted that there were some offsets between the mean and the ground truth. Though most were less than 0.1 yard, “B” had an offset of 0.8 yard, and “H” of about 0.5 yard. The standard deviations are shown in the column “s_{offset}” and combined with the pooled value for s_{total}. Offsets using the existing 9 or 15 test conditions were higher, with values reaching about 1.4 yards.

6 Recommendation

Table 6: Proposed test conditions for optimization. This represents set 8 in Appendix B.

Condition	V_0, ft/s	V_{avg}, ft/s	Spin, RPM	Spin, rev/s	Re	W
1	91.0	86.1	1,620	27.0	0.72	0.14
2	91.5	86.1	2,100	35.3	0.72	0.18
3	92.5	86.1	3,120	52.1	0.72	0.27
4	105.0	99.8	1,620	27.0	0.84	0.12
5	106.5	99.8	3,120	52.1	0.84	0.23
6	126.5	120.3	1,620	27.0	1.01	0.10
7	127.0	120.3	2,100	35.3	1.01	0.13
8	128.0	120.3	3,120	52.1	1.01	0.19
9	158.5	151.0	1,620	27.0	1.27	0.08
10	160.0	151.0	3,120	52.1	1.27	0.15
11	206.5	197.2	1,620	27.0	1.66	0.06
12	208.0	197.2	3,120	52.1	1.66	0.12
13	278.5	266.4	1,620	27.0	2.24	0.04
14	279.0	266.4	2,100	35.3	2.24	0.06
15	280.0	266.4	3,120	52.1	2.24	0.09

Ultimately, the selection of test conditions is based on the tradeoff between reducing error sensitivity and the cost associated with conducting additional tests. It is shown here that several sets of test conditions have an error tolerance at 12° and 2,200 RPM that represents an improvement upon the performance of the current 15-condition test at nominal "ALC" conditions. In particular, set 8 had the lowest pooled variance among all ball types evaluated, and had the lowest error sensitivity at all assumed initial spins.

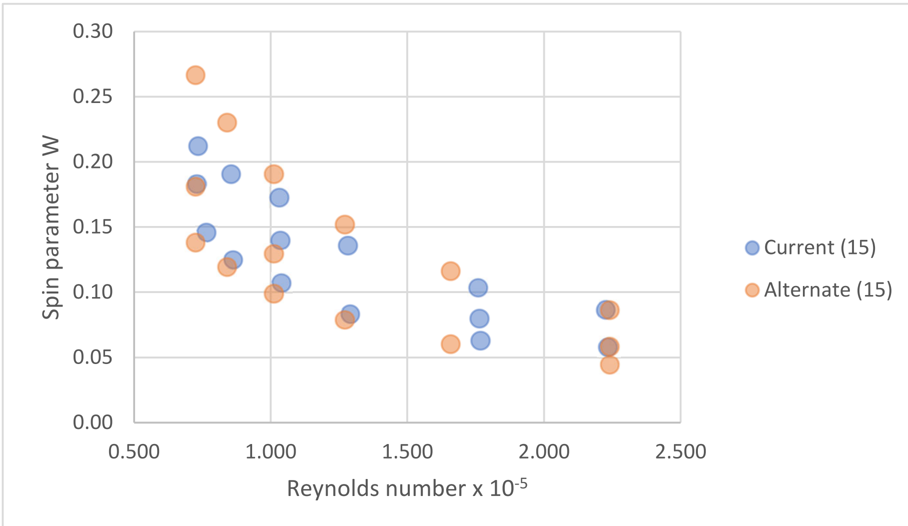

Figure 7: Graphical representation of proposed test conditions. Several proposed test conditions are near existing test conditions.

7 References

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

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

USGA/R&A Rules Ltd. (2021). *Proposed conditions for optimization.* Liberty Corner, St Andrews: United States Golf Association, R&A Rules Ltd.

8 Appendix A: Estimate of average velocity in one dimension

It can be shown that a closed-form solution for equation of motion for the position (x) of a one-dimensional projectile with aerodynamic drag:

$$x(t) = \frac{1}{\hat{c}} \ln(1 + \hat{c} v_0 t)$$

Where v_0 is the initial velocity of the ball. The parameter $\hat{c}$ is defined as

$$\hat{c} = \frac{C_D A}{2m}$$

Where C_D is the coefficient of drag, A is the cross-sectional area, and m is the ball mass. With this, the time to travel a known distance Δx is:

$$\Delta t = \frac{1}{\hat{c} v_0} \left(e^{\hat{c} \Delta x} - 1 \right)$$

The average speed of the projectile may then be calculated. A set of assumptions may be applied as appropriate for a golf ball:

Table 7: Assumptions for the estimation of the average speed of a golf ball through an Indoor Test Range. These assumptions are used for the establishment of launcher speeds only. *Characteristics of the USGA and R&A Rules, Ltd. Indoor Test Ranges as-built.

Parameter	Assumption
Air density (slug/ft³)	0.00232
Ball mass (oz.)	1.610
Ball diameter (in.)	1.684
Coefficient of drag	$C_D = 0.171 + 0.543W$
Initial position (x_0, ft.)*	6.7
Final position (x_1, ft.)*	71.7

Where W is the nondimensional spin parameter

$$W = \frac{\omega r}{v}$$

It is noted that the initial velocity must be corrected to the initial ball position measurement from the exit of a golf ball launcher. Finally, the average speed is:

$$\bar{v} = v_0 \frac{\hat{c} \Delta x}{e^{\hat{c} \Delta x} - 1}$$

And it is likewise a simple matter to identify the appropriate initial speed given a desired average speed.

9 Appendix B: Test condition strategies and individual results

Table 8 shows the test condition strategies and minimum results for each of the 124 candidate structures (each representing 6 levels of Re bias, for a total of 744). In this table, the layout of spins is described by a string of digits, as that indicates the number of spins evaluated at each Reynolds number, starting at the lowest Reynolds number. For example, “222222” indicates six Reynolds number, with two spin values at each, while “222223” adds a third spin at the highest Reynolds number.

Table 8: Monte Carlo test results for error sensitivity as expressed by standard deviation of total distance given inputs including the number of Reynolds numbers in the test structure, the number of spin conditions at each Reynolds number, and the bias factors for Reynolds number and spin distribution. *See text for description. †Closest in concept to existing.

Number	Spin distribution	No. Re groups	No. Conditions	WxRe bias	Re bias factor s_{min}	Error sensitivity (s), yards
1	333333	6	18	1	1.4	0.77
2	333333	6	18	2	1.5	0.72
3	323233	6	16	1	1.5	0.82
4	323233	6	16	2	1.5	0.81
5†	323232	6	15	1	1.5	0.84
6	323232	6	15	2	1.5	0.83
7	323223	6	15	1	1.5	0.82
8	323223	6	15	2	1.5	0.81
9	322223	6	14	1	1.4	0.86
10	322223	6	14	2	1.4	0.86
11	222223	6	13	1	1.5	0.86
12	222223	6	13	2	1.5	0.88
13	322222	6	13	1	1.5	0.87
14	322222	6	13	2	1.5	0.87
15	222222	6	12	1	1.5	0.89
16	222222	6	12	2	1.5	0.90
17	221122	6	10	1	1.4	1.00
18	221122	6	10	2	1.5	0.95
19	222212	6	11	1	1.5	0.92
20	222212	6	11	2	1.5	0.92
21	222122	6	11	1	1.5	0.92
22	222122	6	11	2	1.5	0.93
23	221222	6	11	1	1.4	0.95
24	221222	6	11	2	1.4	0.94
25	212222	6	11	1	1.5	1.05
26	212222	6	11	2	1.5	1.00
27	3333333	7	21	1	1.4	0.72
28	3333333	7	21	2	1.4	0.69
29	3232323	7	18	1	1.4	0.76
30	3232323	7	18	2	1.4	0.75
31	2222223	7	15	1	1.3	0.84
32	2222223	7	15	2	1.4	0.84

Number	Spin distribution	No. Re groups	No. Conditions	WxRe bias	Re bias factor s_{min}	Error sensitivity (s), yards
33	2222222	7	14	1	1.4	0.85
34	2222222	7	14	2	1.4	0.85
35	3212123	7	14	1	1.4	0.87
36	3212123	7	14	2	1.4	0.85
37	3213123	7	15	1	1.3	0.85
38	3213123	7	15	2	1.4	0.81
39	2212122	7	12	1	1.4	0.93
40	2212122	7	12	2	1.3	0.90
41	2221212	7	12	1	1.3	0.89
42	2221212	7	12	2	1.3	0.87
43	2121222	7	12	1	1.4	1.00
44	2121222	7	12	2	1.4	0.90
45	2121212	7	11	1	1.4	0.97
46	2121212	7	11	2	1.4	0.93
47	2221122	7	12	1	1.3	0.90
48	2221122	7	12	2	1.4	0.88
49	2221222	7	13	1	1.4	0.87
50	2221222	7	13	2	1.4	0.86
51	2211122	7	11	1	1.2	0.98
52	2211122	7	11	2	1.3	0.92
53	2222212	7	13	1	1.4	0.86
54	2222212	7	13	2	1.4	0.87
55	2222122	7	13	1	1.4	0.88
56	2222122	7	13	2	1.4	0.85
57	2221222	7	13	1	1.4	0.85
58	2221222	7	13	2	1.4	0.87
59	2212222	7	13	1	1.4	0.91
60	2212222	7	13	2	1.4	0.88
61	2122222	7	13	1	1.4	0.96
62	2122222	7	13	2	1.4	0.90
63	2222232	7	15	1	1.4	0.84
64	2222232	7	15	2	1.4	0.84
65	2223222	7	15	1	1.3	0.83
66	2223222	7	15	2	1.4	0.83
67	2232222	7	15	1	1.4	0.84
68	2232222	7	15	2	1.4	0.82
69	2322222	7	15	1	1.3	0.82
70	2322222	7	15	2	1.4	0.80
71	3222123	7	15	1	1.4	0.81
72	3222123	7	15	2	1.4	0.81
73	3221223	7	15	1	1.4	0.83
74	3221223	7	15	2	1.4	0.79
75	3221223	7	15	1	1.4	0.82

Number	Spin distribution	No. Re groups	No. Conditions	WxRe bias	Re bias factor s_{min}	Error sensitivity (s), yards
76	3221223	7	15	2	1.4	0.81
77	22222222	8	16	1	1.3	0.81
78	22222222	8	16	2	1.3	0.82
79	21212122	8	13	1	1.3	0.93
80	21212122	8	13	2	1.3	0.88
81	22121212	8	13	1	1.2	0.89
82	22121212	8	13	2	1.3	0.88
83	22122122	8	14	1	1.2	0.88
84	22122122	8	14	2	1.3	0.86
85	22122122	8	14	1	1.2	0.89
86	22122122	8	14	2	1.2	0.86
87	22212122	8	14	1	1.2	0.84
88	22212122	8	14	2	1.3	0.83
89	32222222	8	17	1	1.3	0.77
90	32222222	8	17	2	1.3	0.78
91	22222223	8	17	1	1.3	0.80
92	22222223	8	17	2	1.3	0.80
93	22223223	8	18	1	1.3	0.77
94	22223223	8	18	2	1.3	0.78
95	23223223	8	19	1	1.2	0.75
96	23223223	8	19	2	1.3	0.74
97	22111122	8	12	1	1.1	0.95
98	22111122	8	12	2	1.2	0.88
99	22111212	8	12	1	1.1	0.94
100	22111212	8	12	2	1.2	0.89
101	22112112	8	12	1	1.2	0.92
102	22112112	8	12	2	1.2	0.89
103	22121112	8	12	1	1.2	0.92
104	22121112	8	12	2	1.3	0.88
105	22222212	8	15	1	1.3	0.82
106	22222212	8	15	2	1.3	0.84
107	22222122	8	15	1	1.3	0.81
108	22222122	8	15	2	1.3	0.82
109	22221222	8	15	1	1.3	0.82
110	22221222	8	15	2	1.3	0.82
111	22212222	8	15	1	1.3	0.83
112	22212222	8	15	2	1.3	0.83
113	22122222	8	15	1	1.3	0.88
114	22122222	8	15	2	1.2	0.86
115	22222223	8	17	1	1.3	0.79
116	22222223	8	17	2	1.3	0.80
117	22122123	8	15	1	1.3	0.86
118	22122123	8	15	2	1.3	0.85

Number	Spin distribution	No. Re groups	No. Conditions	WxRe bias	Re bias factor s_{min}	Error sensitivity (s), yards
119	22121223	8	15	1	1.2	0.87
120	22121223	8	15	2	1.3	0.85
121	22212132	8	15	1	1.2	0.84
122	22212132	8	15	2	1.3	0.81
123	22121232	8	15	1	1.2	0.88
124	22121232	8	15	2	1.3	0.86