October 18, 2017

Indoor Test Range (ITR) Equipment Change

1 Rationale of Equipment Change

The Rules of Golf Appendix III Rule 4 (Spherical Symmetry) and Rule 6 (Overall Distance, "ODS") are evaluated according to TPX3006 "Actual Launch Conditions Overall Distance and Symmetry Test Procedure (Phase II)", revision 2.0.0. This procedure uses an Indoor Test Range ("ITR") (see 2.1, TPX3006) for acquisition of aerodynamic data. The existing ITR technology, while effective, is subject to limitations related to its structure, and in certain rare circumstances, nonlinearities in the operation of its underlying ballistic screens (see 3.2.1).

In October 2017, The R&A will begin conformance testing of golf balls produced by manufacturers having operating headquarters outside of the United States and Mexico. This will mark a change from the previous state, in which the USGA performed all golf ball conformance testing.

The addition of The R&A beginning ball conformance testing provides the perfect opportunity to implement upgraded technology to test conformance of golf balls to Appendix III, Rules 4 and 6. This was initially communicated in the May 11, 2015 Notice to Golf Ball Manufacturers ("Equipment Research – Area of Interest Changes to Golf Ball Testing Equipment").

2 Description of Test Equipment Change

2.1 Existing test

The test method consists of launching golf balls through an Indoor Test Range having ball position and environmental sensors at predetermined conditions, using the resulting information to determine the aerodynamic properties of said golf balls, and using these aerodynamic properties to calculate golf ball distance. There is no change to the overall method or test conditions at this time. However, the ball position sensing system (or "ITR system") is being updated.

2.2 Test Equipment Change

The new ITR system consists of five measurement stations located every 16 ft. along a 65-ft. indoor range. Each station consists of:

- Two non-proprietary 36 megapixel digital cameras arranged to operate stereoscopically.
- High discharge flashes used for ball illumination: each station utilizes four flashes in a single flash unit. The total flash time is less than two microseconds.

When a golf ball is launched through the system, strobes illuminate the ball twice per station according to a pre-programmed schedule, such that a total of ten three-dimensional ball positions are captured.

For all colors except very dark balls, images are captured against a black, matte background. Matte white hidden panels are exposed for dark-colored and some chrome finish balls.

Optical patterns are used for camera calibration. Surveyed landmarks are used to set the global co-ordinate system of each of the five camera stations. Additional markers are measured with each shot, such that the cameras are continuously error-checked against known measurements.

Finally, spin measurements are made at the first and last stations.

2.3 Vendor

IMAGO Machine Vision Inc. is an optical tracking specialist headquartered in Quebec, Canada.

3 Appropriateness of Equipment and Method Change

Validation testing included position accuracy testing (relative and absolute), along with dynamic testing.

3.1 Static Relative Position Accuracy Tests

Acceptance testing included validation of the relative ball position accuracy within each station, using white precision ground metal spheres in place of golf balls, with the spheres located on a steel rod a known distance (1m) apart. System-reported sphere positions were compared with the known separation in a number of different orientations within each station's test volume. Results are shown in Table 1 and Table 2.

Table 1: Results: white ball, black background

Station	*n* tests	Mean Error (mm)	Std. Dev. (mm)	Abs. Max. Error (mm)
1	23	-0.38	0.23	0.93
2	25	0.21	0.29	0.65
3	25	0.31	0.20	0.65
4	40	0.05	0.19	0.41
5	23	0.45	0.23	0.91

Table 2: Results: color ball, white background

Color	*n* tests	Mean Error (mm)	Std. Dev. (mm)	Abs. Max. Error (mm)
Gloss Black	17	0.31	0.05	0.38
Chrome	12	0.45	0.15	0.75
Matte Med. Gray	14	0.44	0.05	0.51

Further testing of the global coordinate demonstrated that vertical positions were within 1.4mm of expected values at 99% confidence, with similar results in downrange position (latter based on

measurements using a Leica Disto D8 LRF). Out-of-plane position differences were larger, up to 2mm. However, it should be noted that aerodynamic parameter identification is relatively insensitive to this measurement.

3.2 Bias and Linearity Study Results

Initial bias and linearity testing was performed using 115 ball types screened using the existing ballistic-screen based ITR. Full tests were performed using the new ITR, with initially positive results: the average bias was found to be 1.7 yards, with good linearity (Pearson R^2 0.92). This level of difference may be expected given the difference between screening tests and full tests.

More detailed testing was then performed on golf ball types selected from the larger study, such that comparisons were based on full tests using both devices, with tests conducted over consecutive days. The ball types selected represented a similar distribution of differences (1.75 yards bias). Additionally, seven ball types having a significant history of indoor and outdoor comparison were included in order to identify possible sources of difference. The result of the more detailed, full-test comparison was an average difference of 0.75 yard bias, with excellent linearity (R^2 0.95, see Figure 1).

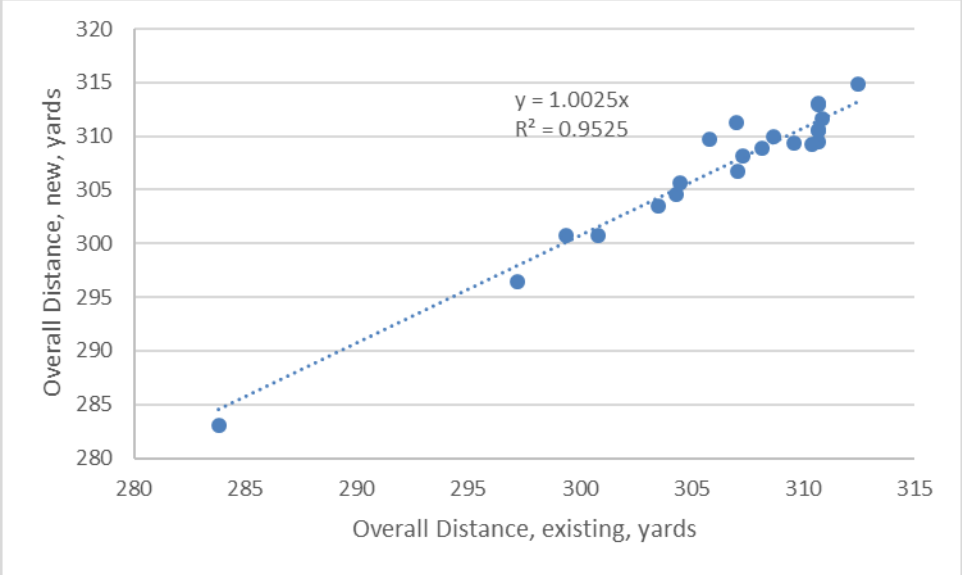

Figure 1: Bias and linearity study results, full test to full test comparison, tests performed on consecutive days.

3.2.1 Discussion

Both the bias and linearity results were adversely affected to a degree by two golf ball types having a near-4 yard difference. It was identified that ballistic-screen ITR distance projections these ball types were influenced by a more-than-usual lift drop-off at low Reynolds numbers. Further investigation showed that the underlying issue resulted from unusually large transverse ball motion within the test range (i.e., hook and slice) at these Reynolds numbers, which significantly affected the vertical position measurement using the ballistic screens.

3.2.2 Effects on conformance results

Study of golf ball types submitted between 2013-2016 whose conformance status could be affected (as determined through apparent high-Re sensitivity and overall performance) showed that there were three ball types in 2012-2014 that would likely have been affected, and one in 2015 (the latter from a now-defunct manufacturer).

3.3 Gage R&R Study Results

Four golf ball types were selected, having the following nominal performance characteristics (Table 3).

Table 3: Performance characteristics of selected golf balls.

Ball Type	Time (s)	Carry (y)	Total (y)
1	6.0	262	286
2	7.0	292	311
3	7.1	297	315
4	6.6	278	299

A crossed Gage R&R study was performed using three operators and three trials apiece in a randomized fashion. Results are as follows (Table 4).

Table 4: Gauge R&R study results.

	Time (s)	Carry (y)	Total (y)
Total Gage, std. dev.	0.02	0.7	0.9
Repeatability	0.02	0.7	0.8
Reproducibility	0.01	0.0	0.1
Total Gage, +/- at 99%	0.06	1.7	2.0

These results equal or exceed the performance of the existing ballistic-screen ITR.

4 Implementation Plan

This testing method will be used for balls to be listed from December 2017.