ENGINEERING REPORT

Subject: RG and Differential RG Study- Quantify Ball Motion Effects

Date: 9/9/15

Place: International Training & Research Center

Present: Danny Speranza

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Purpose:

To quantify the ball motion effects of varying both RG and total differential RG.

Summary:

General conclusions about RG and differential RG effect on the following:

- Total boards of hook
  - High RG balls hooked the most boards independent of the amount of differential RG
    - averaged 20.6 boards for low differential ball and 21.7 for high differential ball
  - Low RG balls had a large variation in the amount of boards hooked when the differential RG was varied
    - averaged 16.8 boards for low differential balls and 20.6 for high differential balls
- Entry angle and total angle change
  - The RG had the most effect on the angle change
    - 7.2 degrees of total angle change for high RG balls vs. 6.4 for low RG balls
  - Total differential significantly affected the angle change but slightly less than RG
    - 7.1 degrees of total angle change for high differential balls vs. 6.5 degrees for low differential balls
- Breakpoint location (feet down the lane)
  - High RG balls hooked the earliest (43 feet), and varying the total differential RG of high RG balls did not change the breakpoint distance
  - Low RG balls with low differential RG went much longer (46 feet)
  - Low RG balls with high differential RG hooked sooner than low RG balls with low differential RG, but at the same distance as high RG balls (43 feet) with varying differential RG

Data:

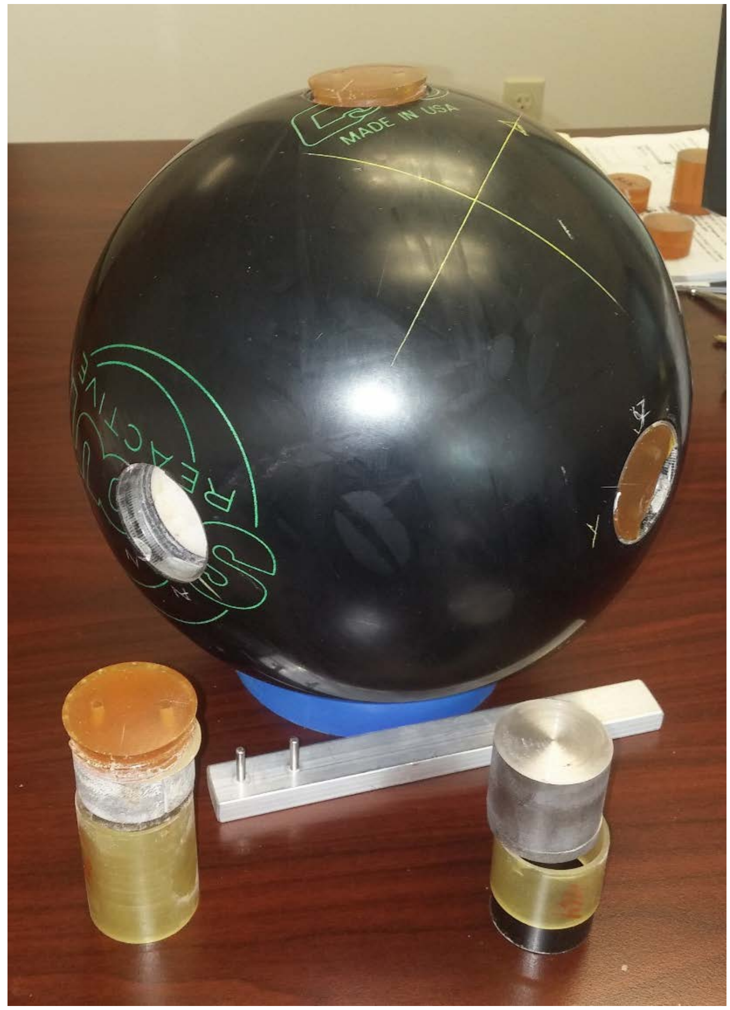
Test parameters

The basic test in this study is the same as outlined during the previous differential RG test. The only difference is that both the RG and differential RG were varied vs. just the differential RG in the previous tests.

This RG and differential RG study is a test to quantify the lane performance from these two ball properties. In this test, both, the RG and differential RG of a ball was varied. This was achieved by drilling six large 1-3/8" diameter holes in a ball on the x, y, z, -x, -y and -z axes and then inserting weights to adjust the ball properties. Two balls were needed for this test to create both high and low RG properties. (See picture).

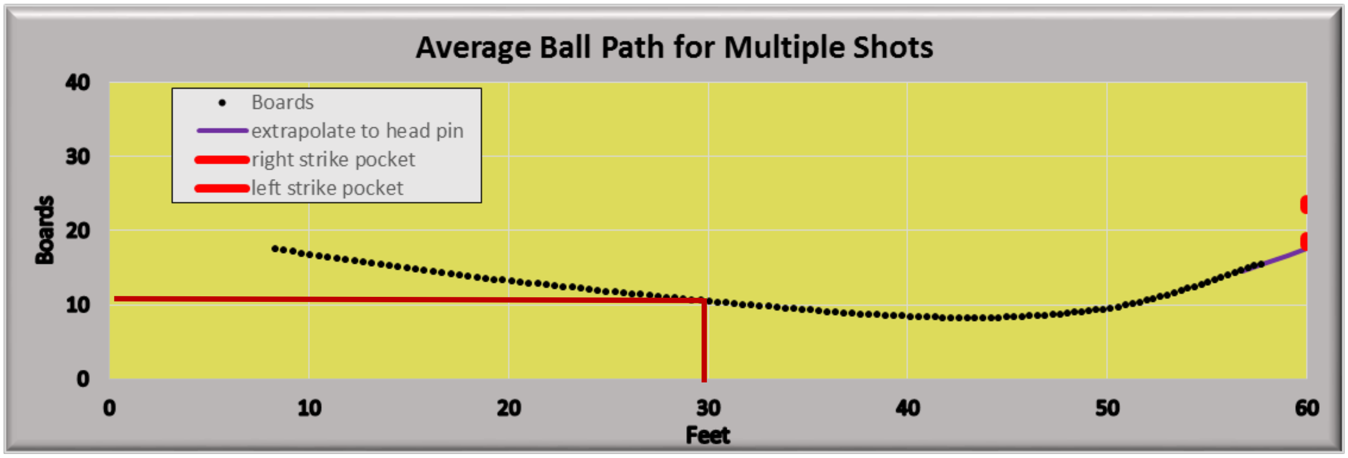
A spreadsheet was developed to calculate the ball RG and total differential RG using various density materials (i.e. steel, ball plug material and hollow spacers) inserted at various depths to achieve the RG and differential RG values. It was determined that we could manipulate the weighted slugs and create differential RG ranging from .000 to .060 and vary the RG from 2.47 to 2.73. The six-hole calculations were not as accurate as the two-hole calculations in the first test, but got us close, and then we made minor weight adjustments to achieve the various RG and total differential RG targets.

Both a 12-pound and 13-pound ball were used for the test, knowing the weights would be added. The final measured ball properties were:

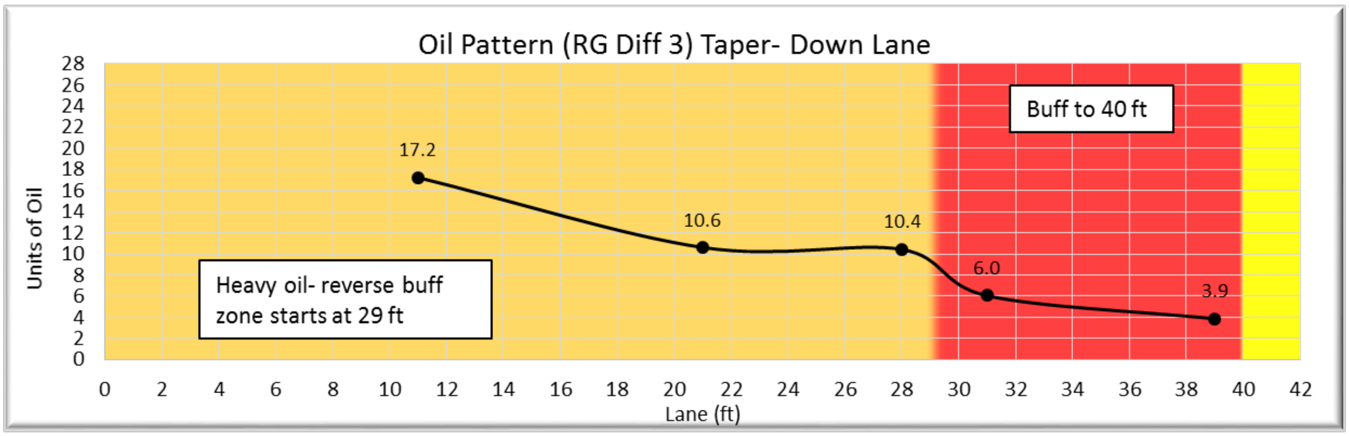


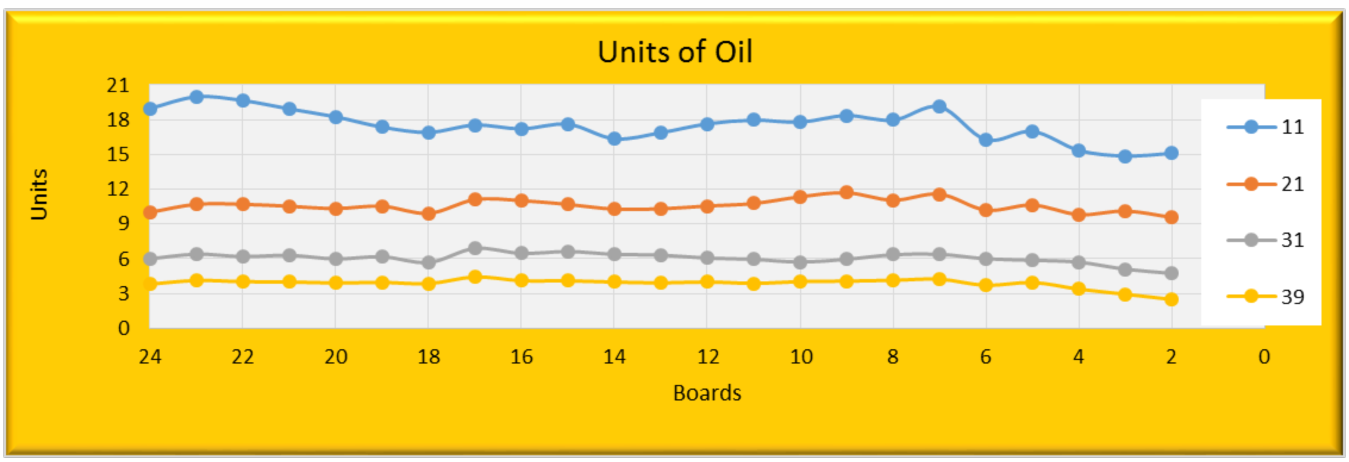
RG & differential RG Combination	Intial Ball Weight	RG Target	Differential Target	Measured RG	Measured differential	Final Ball Weight
High RG / low differential	13.27	2.73	.000	2.728	.007	14.72
High RG / high differential	13.27	2.73	.060	.2.715	.058	14.63
Center point	13.27	2.57	.030	2.577	.035	15.03
Low RG / low differential	12.22	2.47	.000	2.485	.004	16.13
Low RG / high differential	12.22	2.47	.060	2.476	.061	15.83

The oil pattern was changed from the previous differential RG tests. The target was to get a condition that simulated close to a house condition, but with a flat condition. Therefore, the goal was to have approximately 3-5 units at the end of the pattern simulating the three-unit rule. Typical bowling centers apply three units from the 10 board to the gutter. By reviewing the BOLTS data, it was determined that the ball path normally crosses the 10 boards at approximately the 30-foot location.

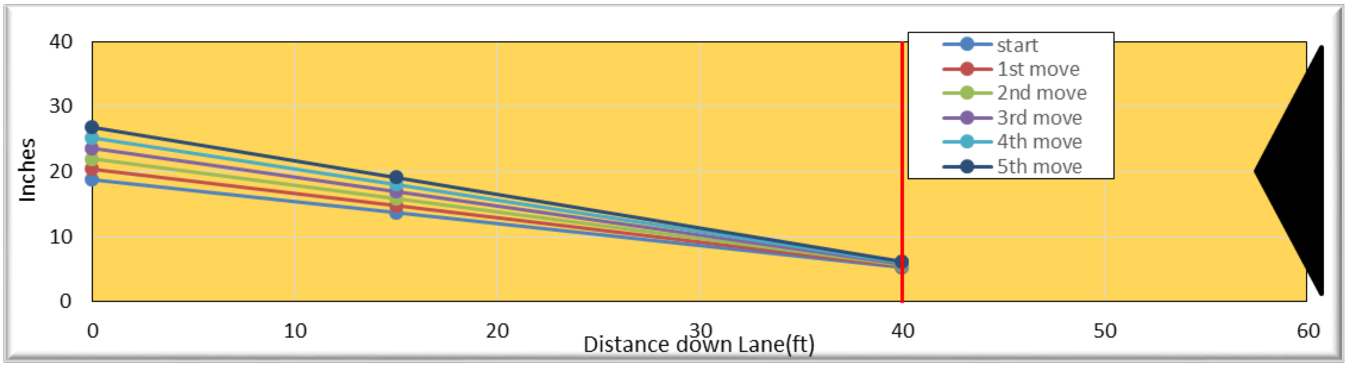


Therfore, the pattern was adjusted to have 6-3 units beyond 30 feet. The lanes were oiled flat from gutter to gutter and tapered from the foul line to the oil line.





The test balls were thrown by E.A.R.L. The same test procedure was followed as used in the differential RG tests. A single ball test consisted of 30 shots with E.A.R.L. being adjusted left after every five shots by 1.5 boards at the foul line and 1 board at the arrows.



This results in targeting approximately the same location at the end of the oil pattern to create maximum oil depletion at the end of the pattern and play the lanes like a bowler would.

BOLTS was used to collect the ball path data for every shot. The results are summarized below.

The following parameters were used for all tests:

- Velocity - 18 MPH
- Axis rotation angle - 60 degrees
- Axis tilt - 13 degrees
- Rotation rate - 275 RPM
- Pin was positioned 3.375” from PAP
- PAP located 5” over from center of grip

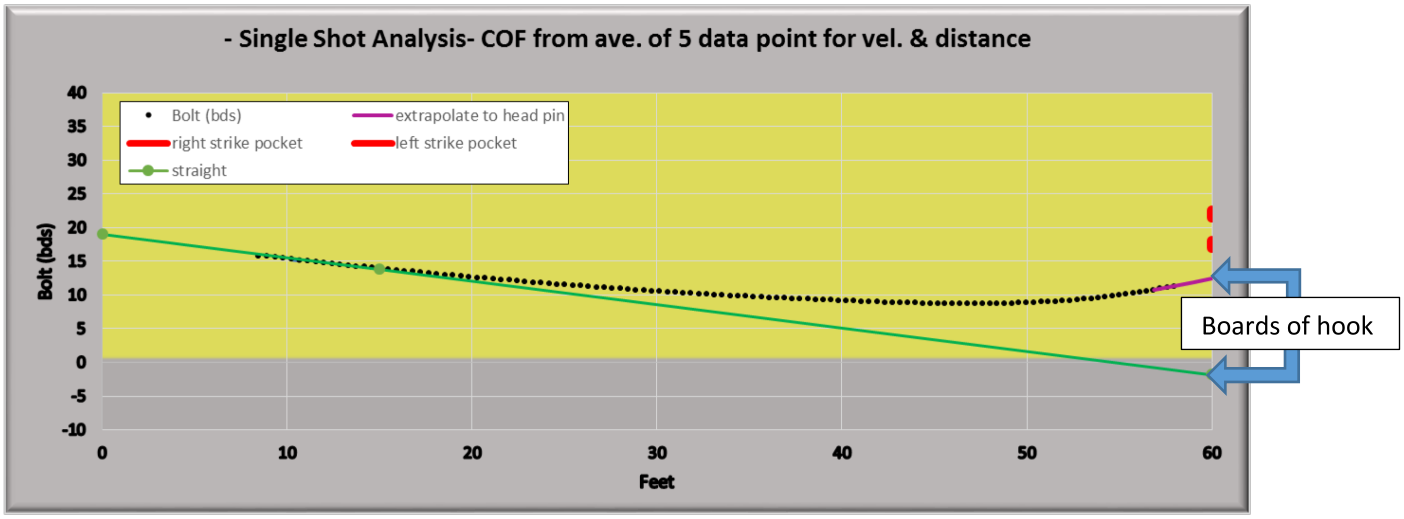
Test results

The following test parameters were monitored:

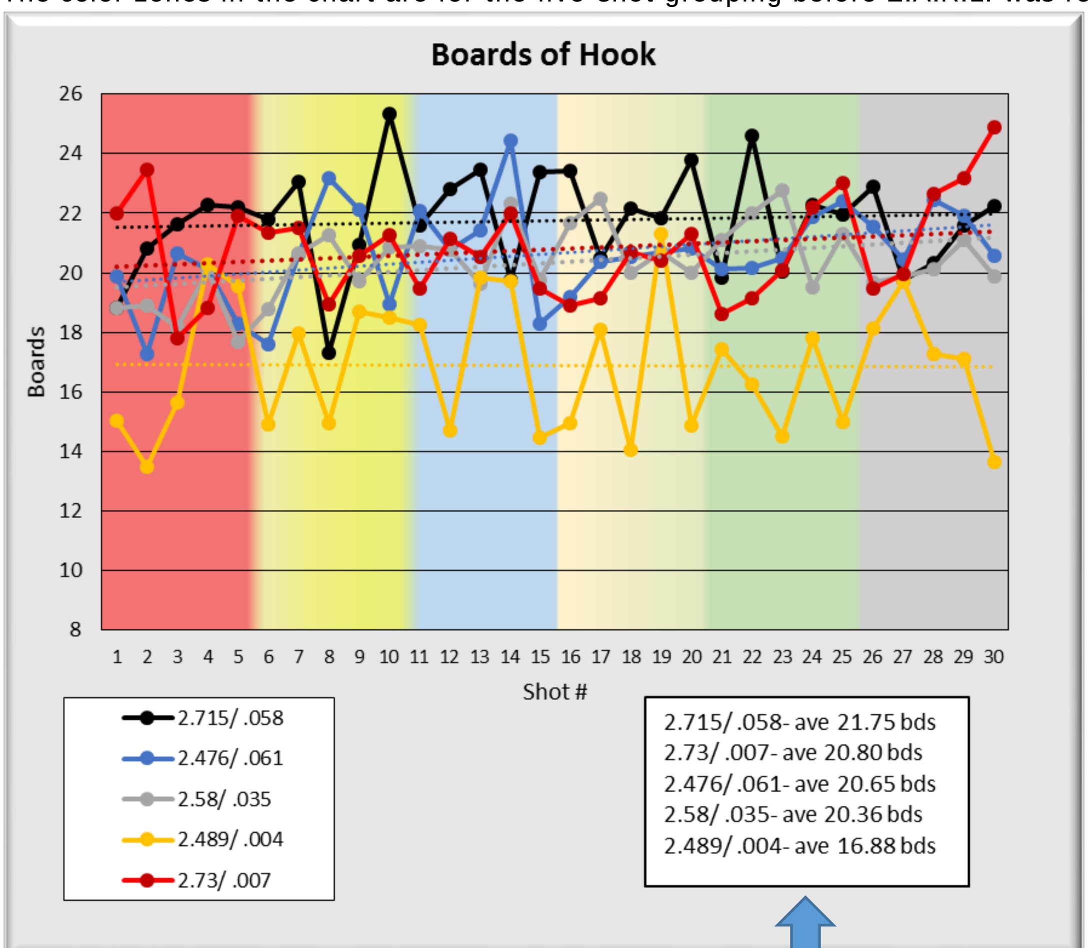
- Total hook
- Entry angle
- Breakpoint
- Track flare

Total hook:

BOLTS was used to measure the total hook. A straight line was extended using E.A.R.L.'s launch settings (lay down board and trajectory) to 60 feet. The number of "boards of hook" was calculated at 60 feet between this straight line and the ball path measured by BOLTS.



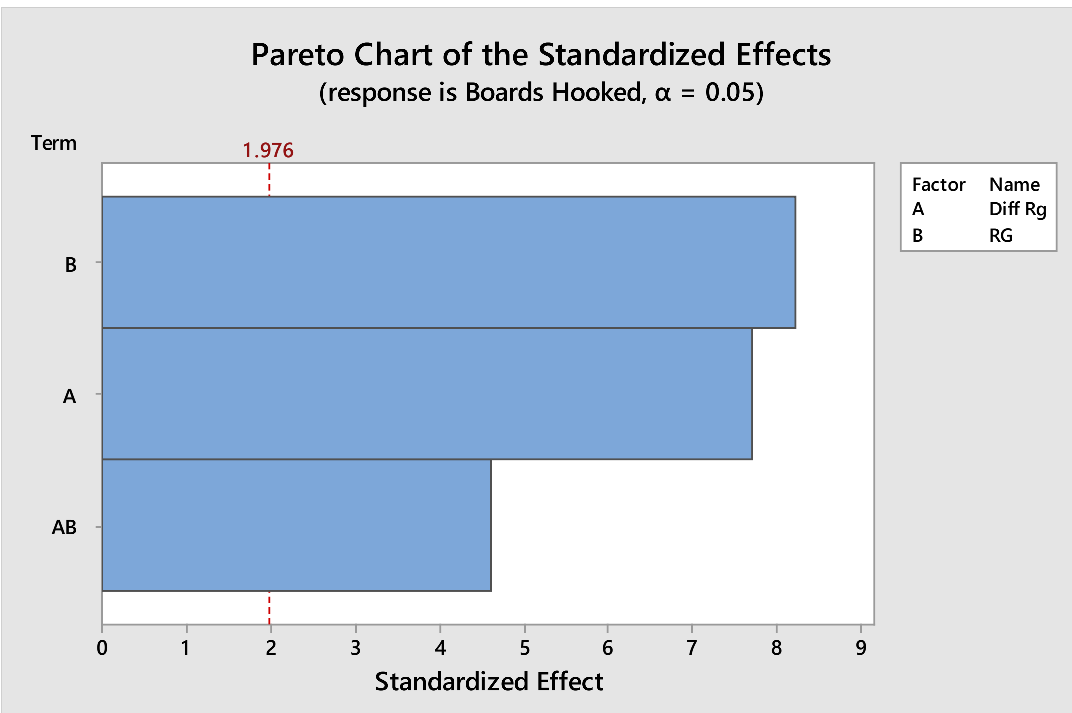
Below is a chart for the "boards of hook" for each shot for the various RG and differential settings. The color zones in the chart are for the five-shot grouping before E.A.R.L. was repositioned.



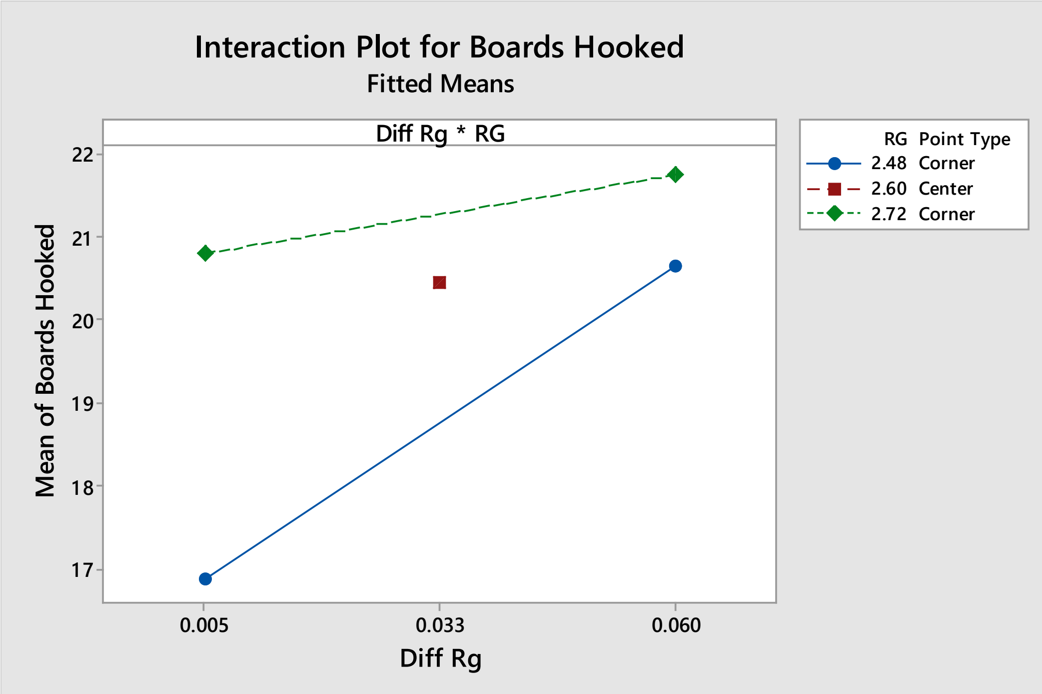
Also, in the text box on the above chart is the average boards of hook for all 30 shots with each test ball. The averages are also listed below.

RG and differential RG	Average boards of hook	Difference from previous RG and differential RG
2.72 / .058	21.75	--
2.73 / .007	20.80	.95
2.48 / .061	20.65	.15
2.58 / .035	20.36	.29
2.49 / .004	16.88	3.48

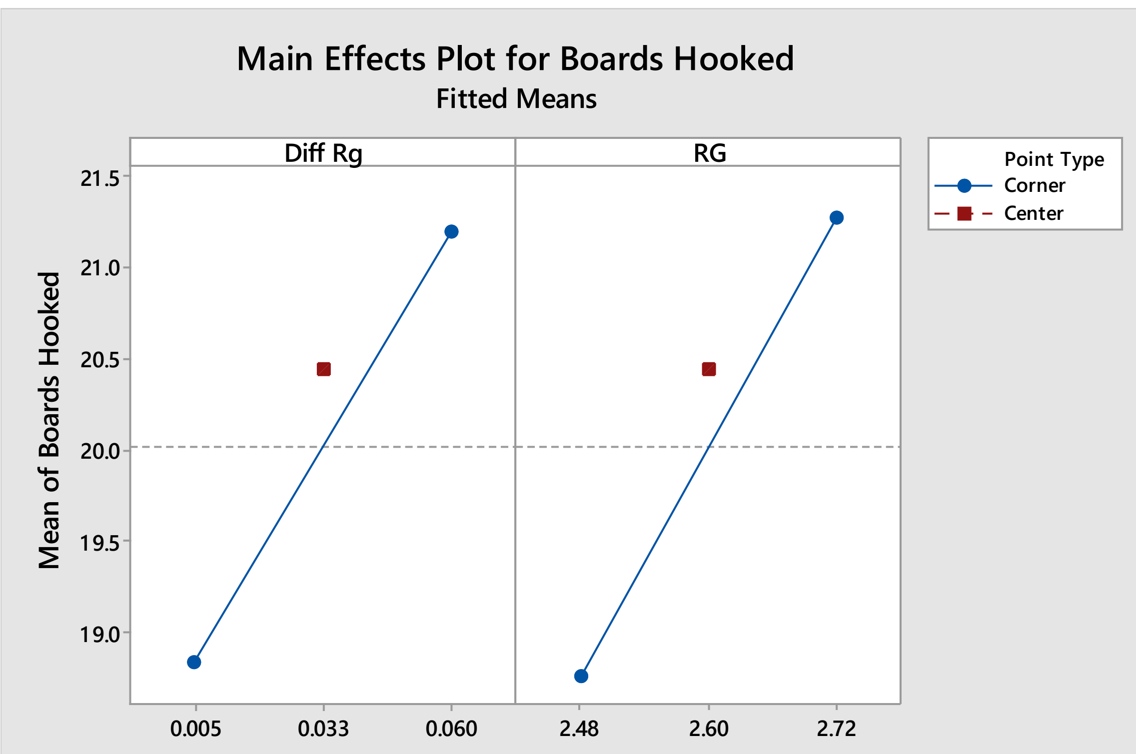
Statistical analysis generated the following Pareto chart, interaction plot and main effects plot:



The Pareto chart above shows that the RG, differential RG and interaction of both significantly affect the board of hook.



This interaction charts shows that the high RG ball with any differential RG value hooked more boards than low RG ball. At the same time, changing the differential RG in a low RG ball creates a larger difference in boards of hook. Therefore, you can create a larger difference in hook with low RG ball by varying their differential RG values. Since the interaction plot shows a significant effect from the interaction, the main effects plot below should be ignored.



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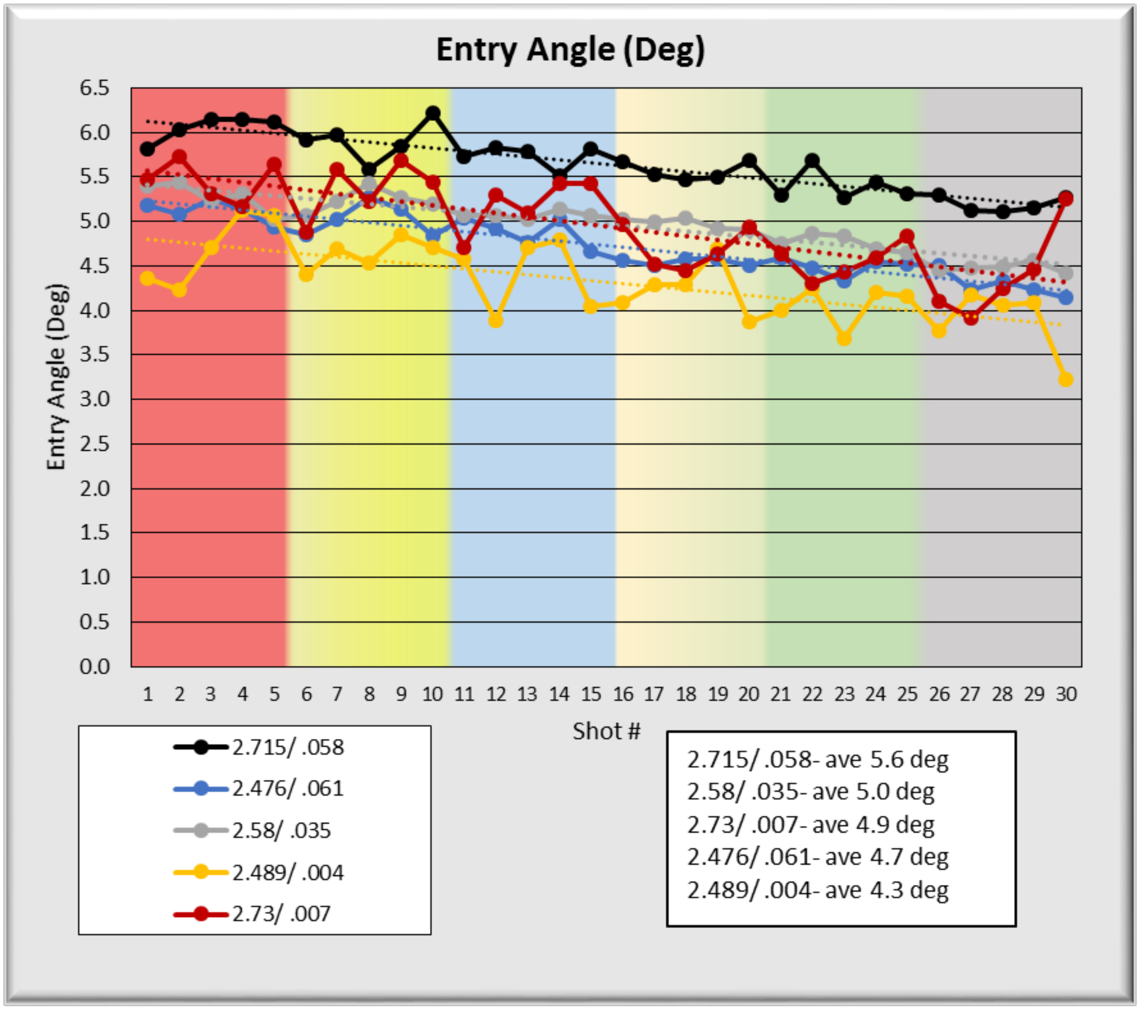
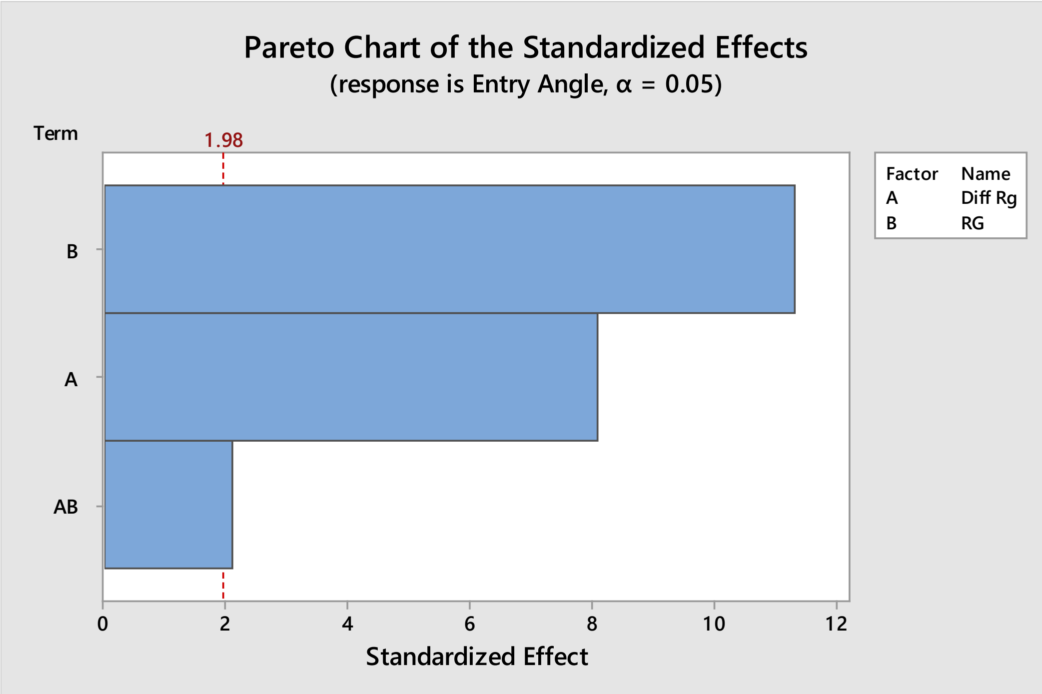
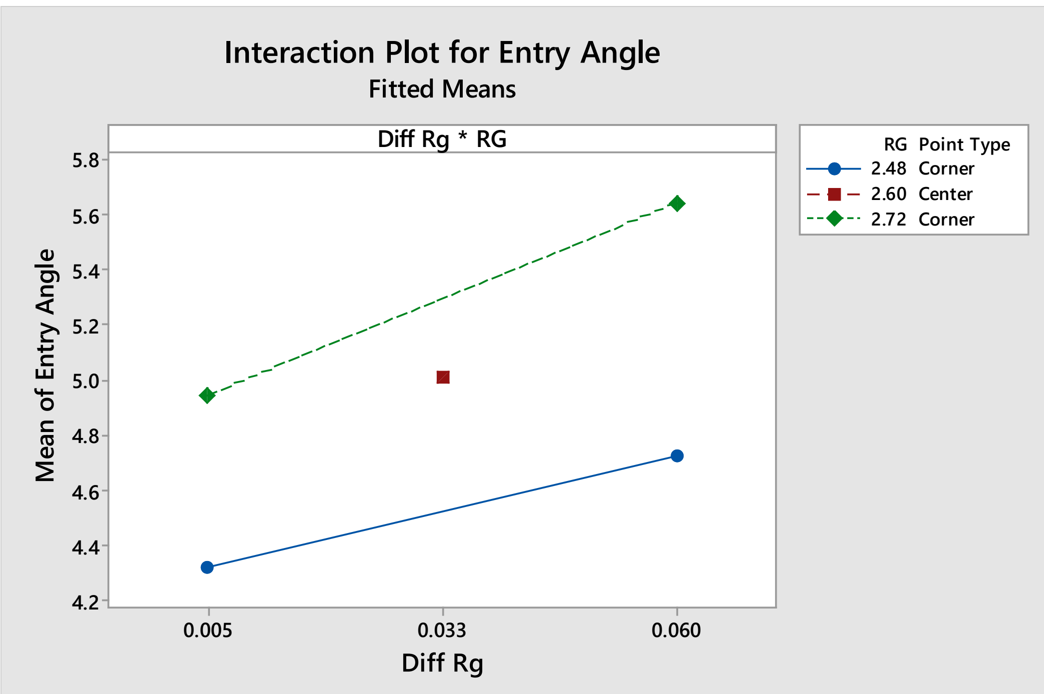
Entry Angle:

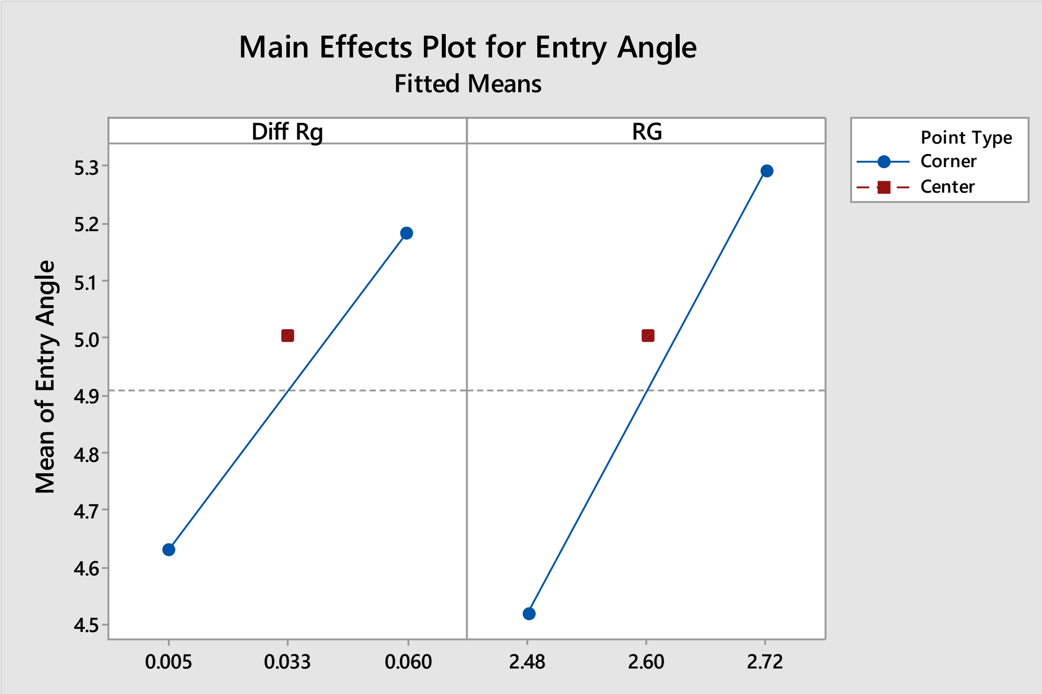


Statistical analysis generated the following Pareto chart, interaction plot and main effects plot:

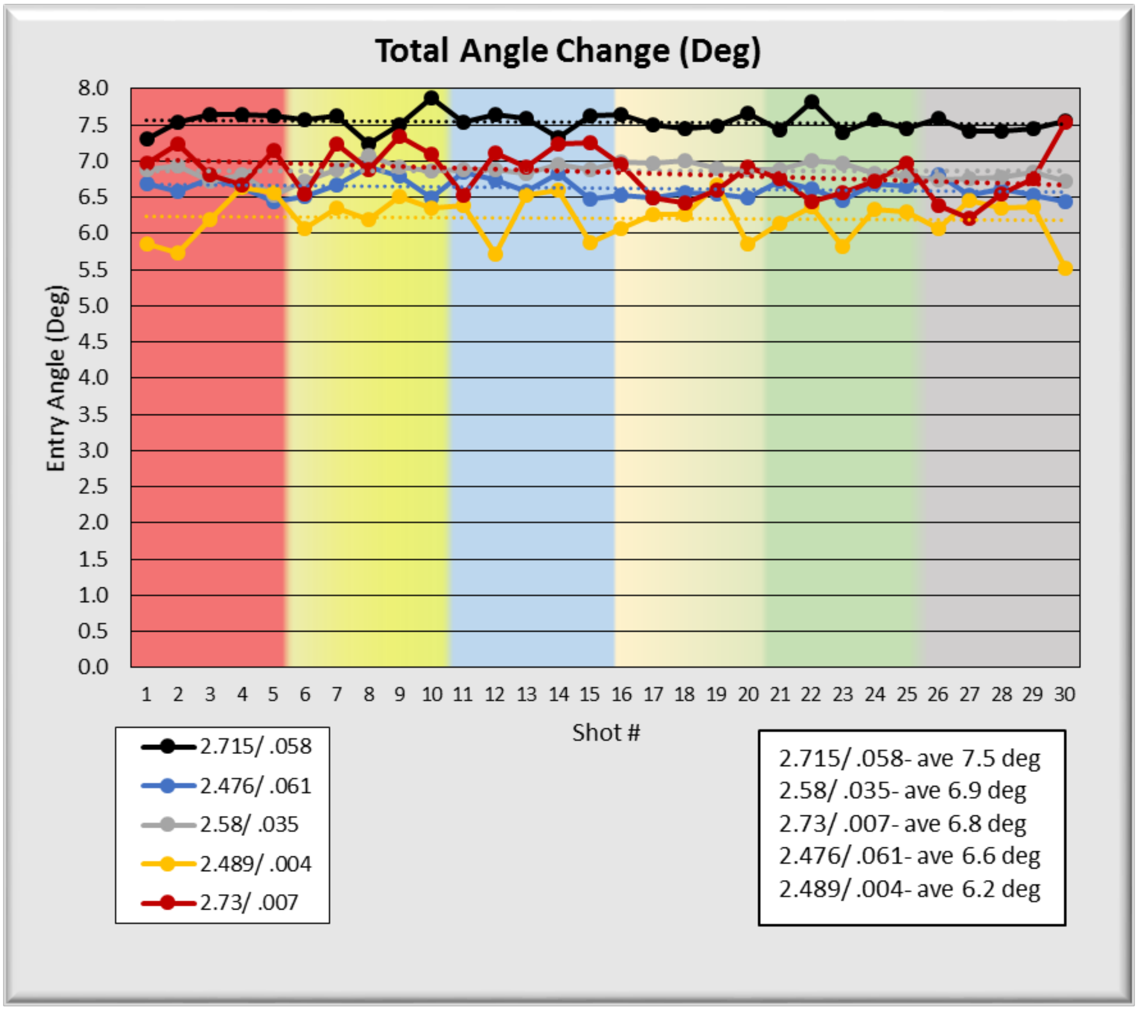




The interaction plot shows almost parallel lines for low and high RG balls as the differential RG is varied. So, the interaction is small. Therefore, the main effects plot below shows that the largest change in the entry angle occurs when the RG was varied (4.5 degrees up to 5.3 degrees). Changing the differential RG had a large influence on the entry angle (4.6 degrees up to 5.2 degrees), but this is slightly smaller than the entry angle change from just the RG.



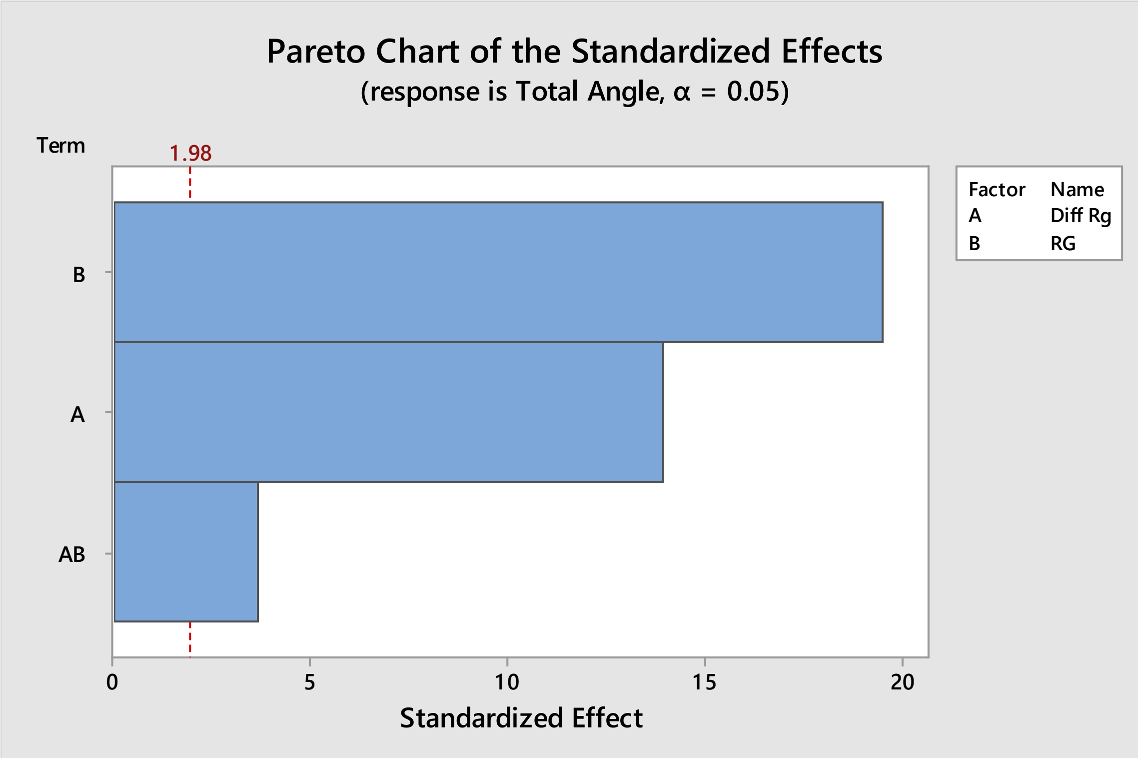
The entry angle slowly decreases from shot 1 to shot 30. This has to do with increasing the launch angle every five shots which should reduce the final entry angle. Therefore, a better indicator of angle change is “Total Angle Change,” which is adding together the Launch Angle and Entry Angle:

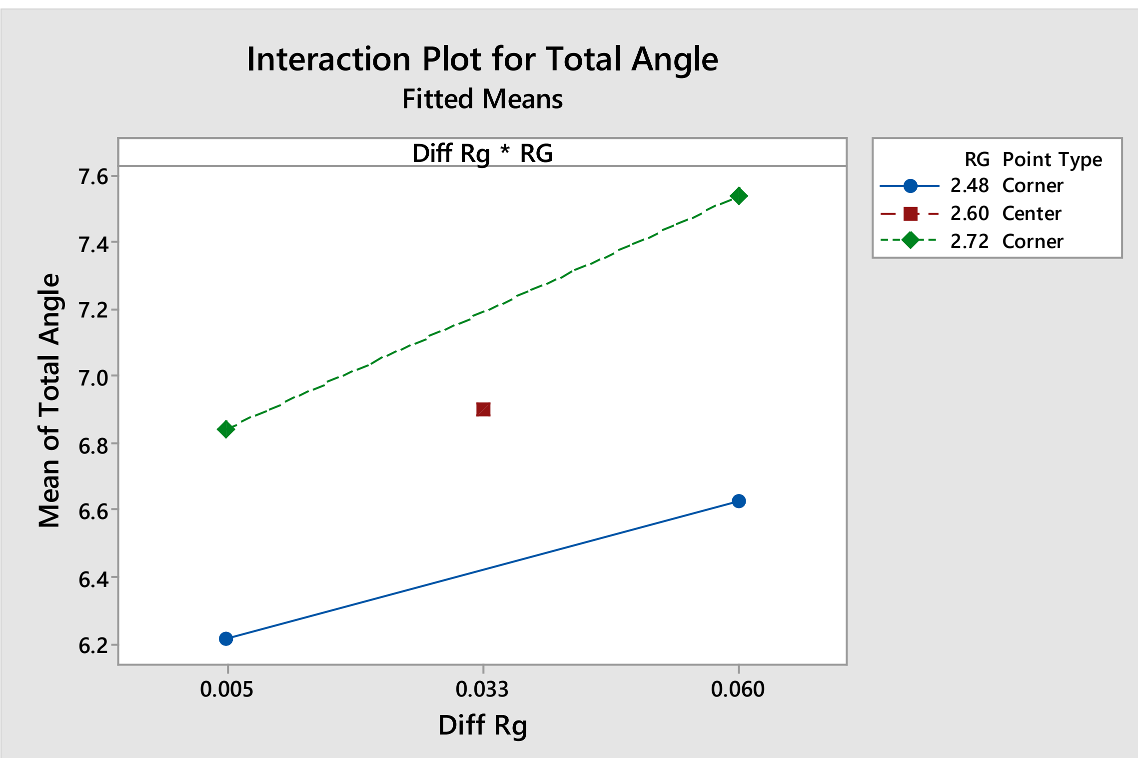


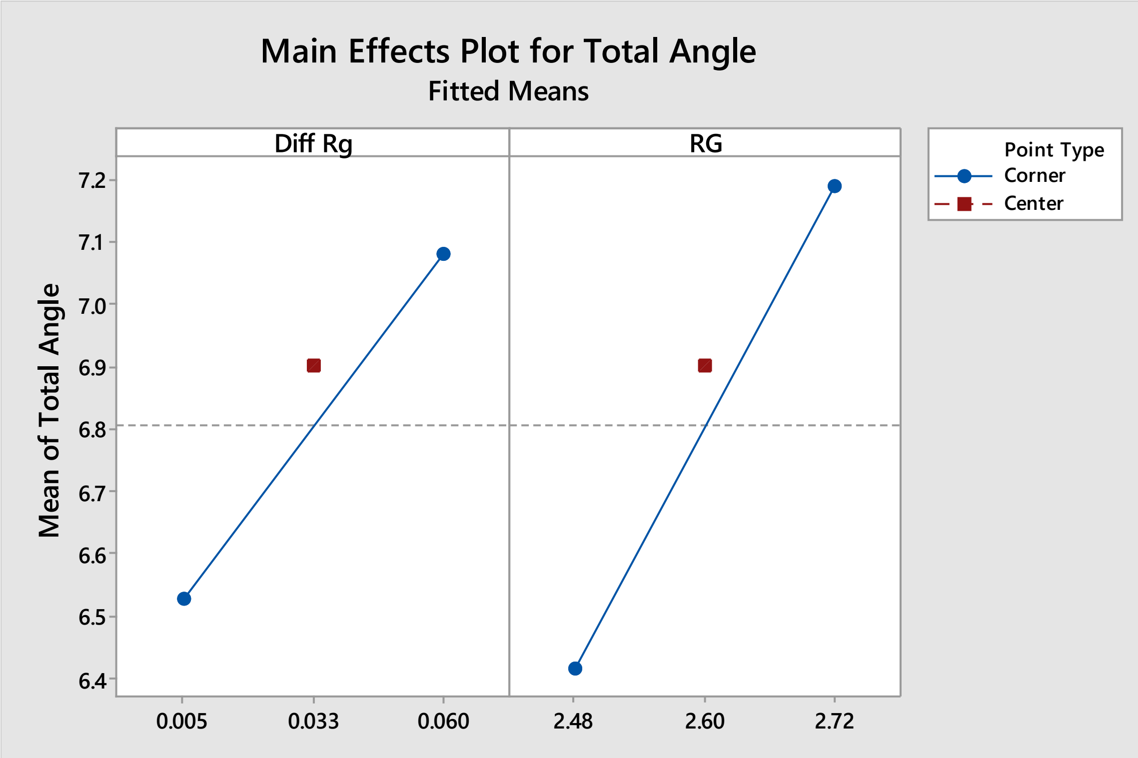
Here, the results are more consistent from shot 1 to shot 30.

Statistical analysis generated the following Pareto chart, interaction plot and main effects plot and show the exact same conclusion as the entry angle analysis:

- Interaction Plot shows almost parallel lines, indicating a small affect from the interaction
- Therefore, need to interpret the main effects plot
  - RG has the most affect (6.4 to 7.2 degrees)
  - Differential RG affects the total angle (6.5 to 7.1 degrees) but slightly less than the RG


Pareto Chart of the Standardized Effects
(response is Total Angle, α = 0.05)
Term
1.98
B
A
AB
0
5
10
15
20
Standardized Effect
Factor Name
A Diff Rg
B RG


Interaction Plot for Total Angle
Fitted Means
Diff Rg * RG
7.6
7.4
7.2
7.0
6.8
6.6
6.4
6.2
Mean of Total Angle
0.005
0.033
0.060
Diff Rg
RG Point Type
2.48 Corner
2.60 Center
2.72 Corner


Main Effects Plot for Total Angle
Fitted Means
Diff Rg
RG
Point Type
Corner
Center
Mean of Total Angle
7.2
7.1
7.0
6.9
6.8
6.7
6.6
6.5
6.4
0.005
0.033
0.060
2.48
2.60
2.72

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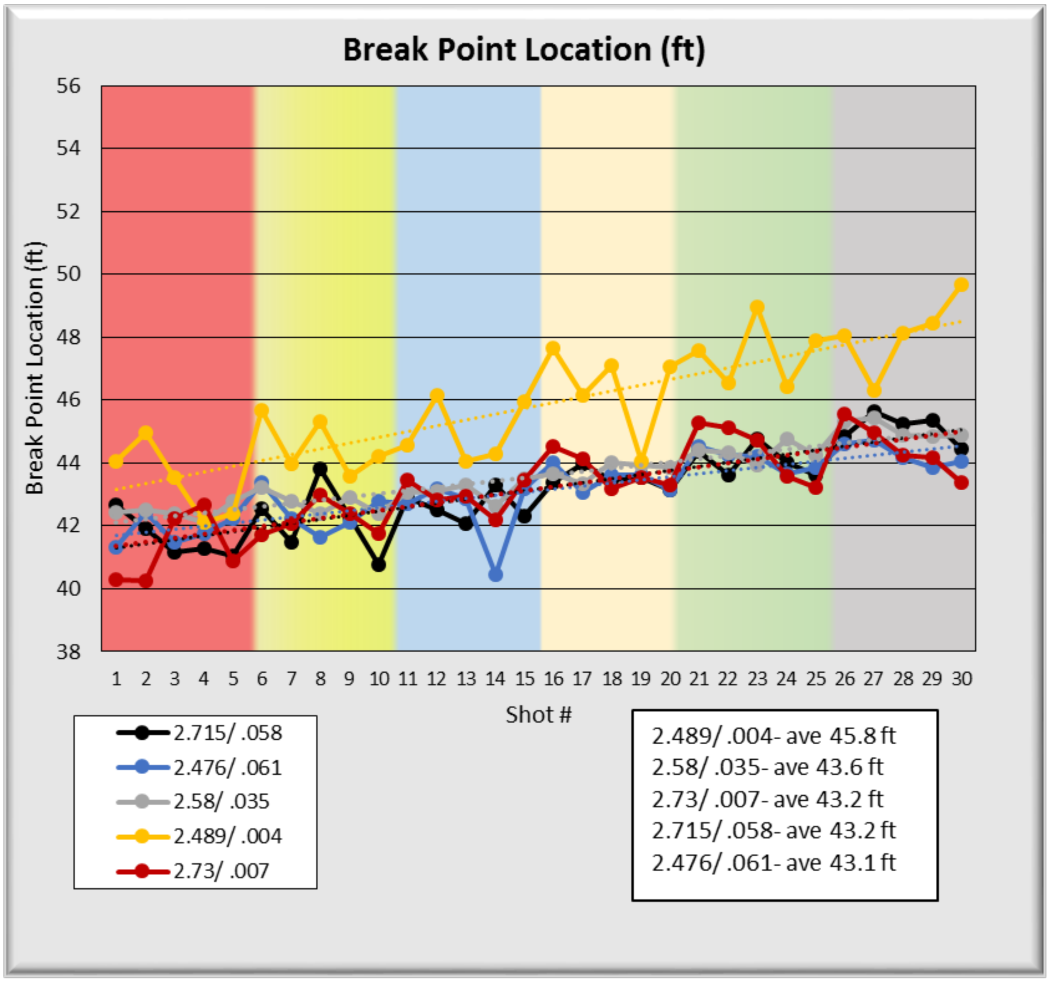
Break Point Location below (ball path location closest to the channel):



The above chart shows that the breakpoint location moved further down the lane between the first shot and the last. But remember, the launch angle was increased every five shots as we moved in 1.5 boards at the foul line and only one board at the arrows. As the launch angle increases, the breakpoint should move farther down the lane. But, all testing was done with the same change in launch angle every five shots, so the movement of the breakpoint due to changing the launch angle is consistent for each test.

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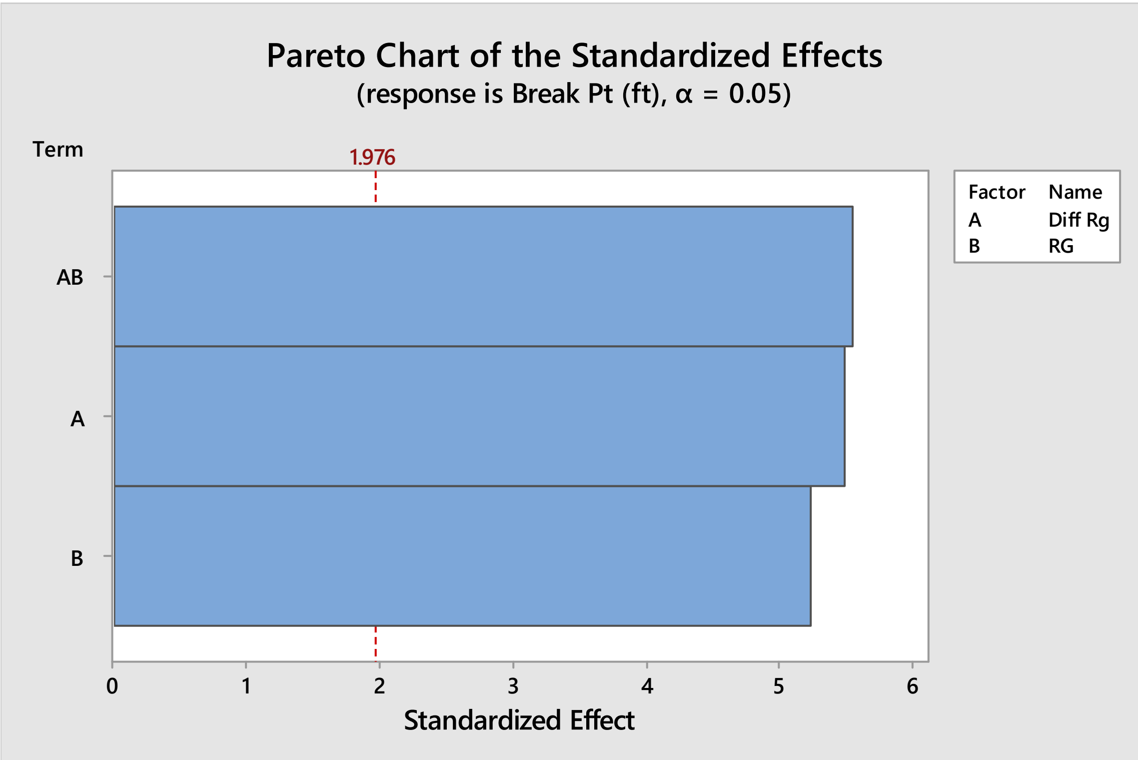
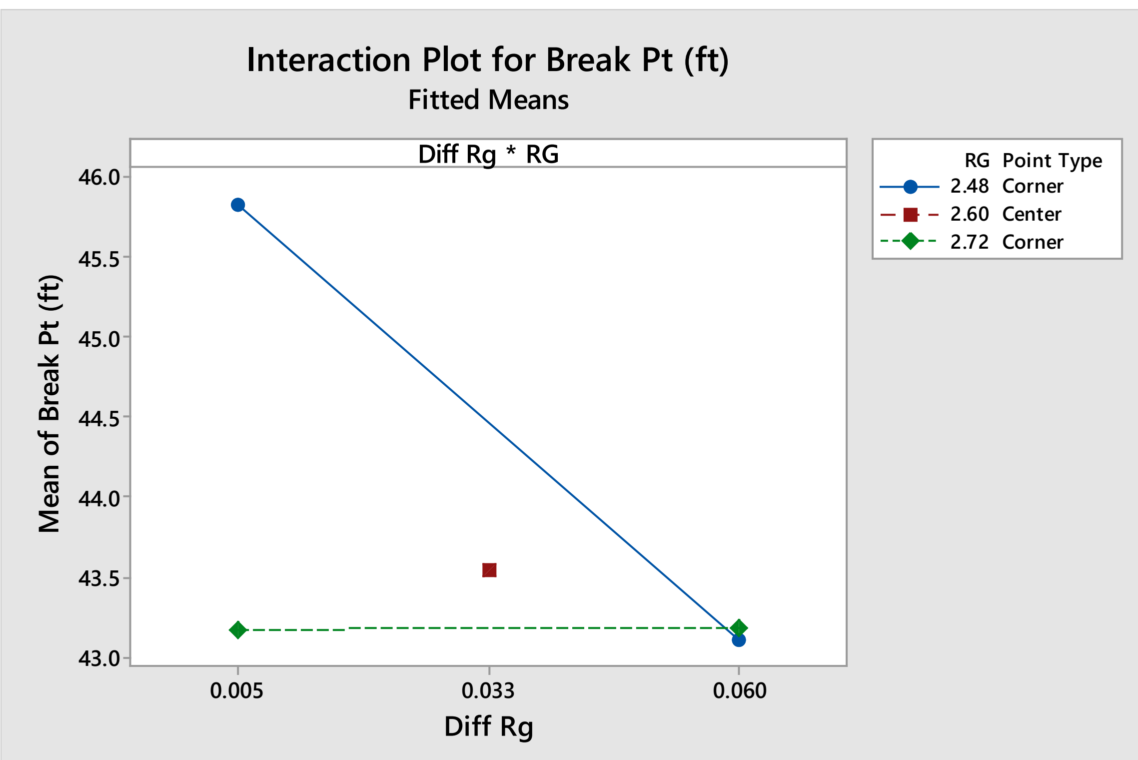
The Pareto chart below shows that the RG, differential RG and interaction significantly affect the breakpoint location.



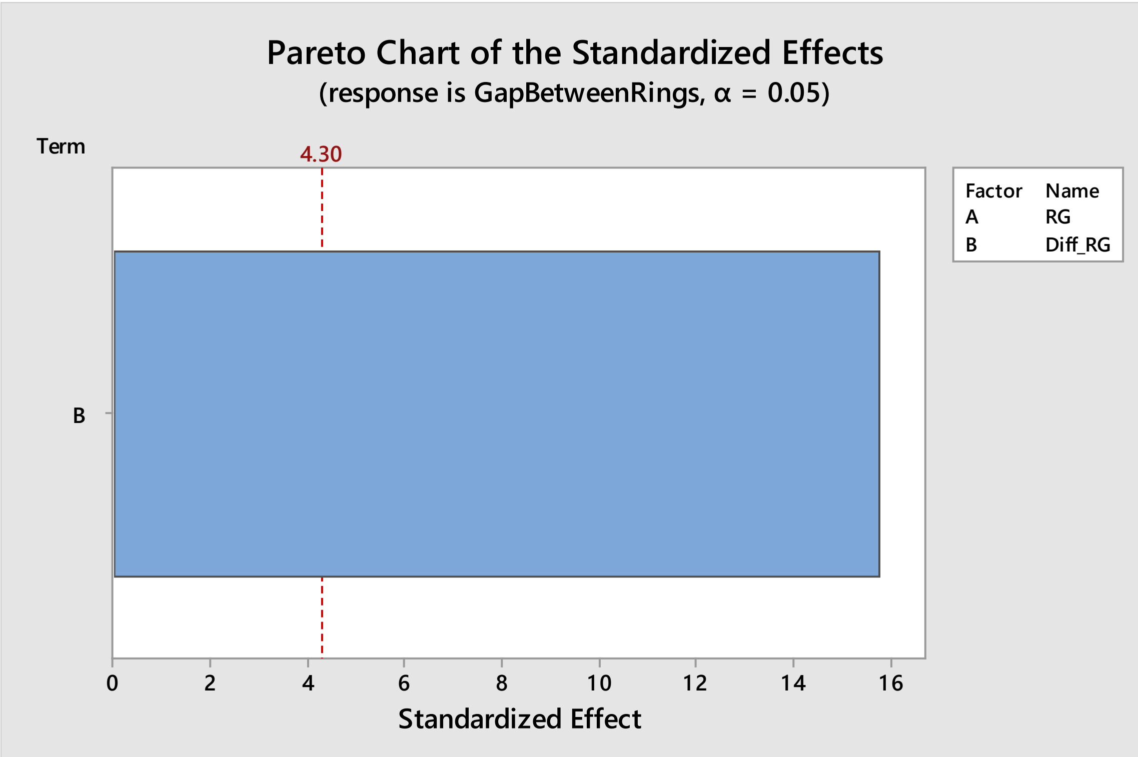


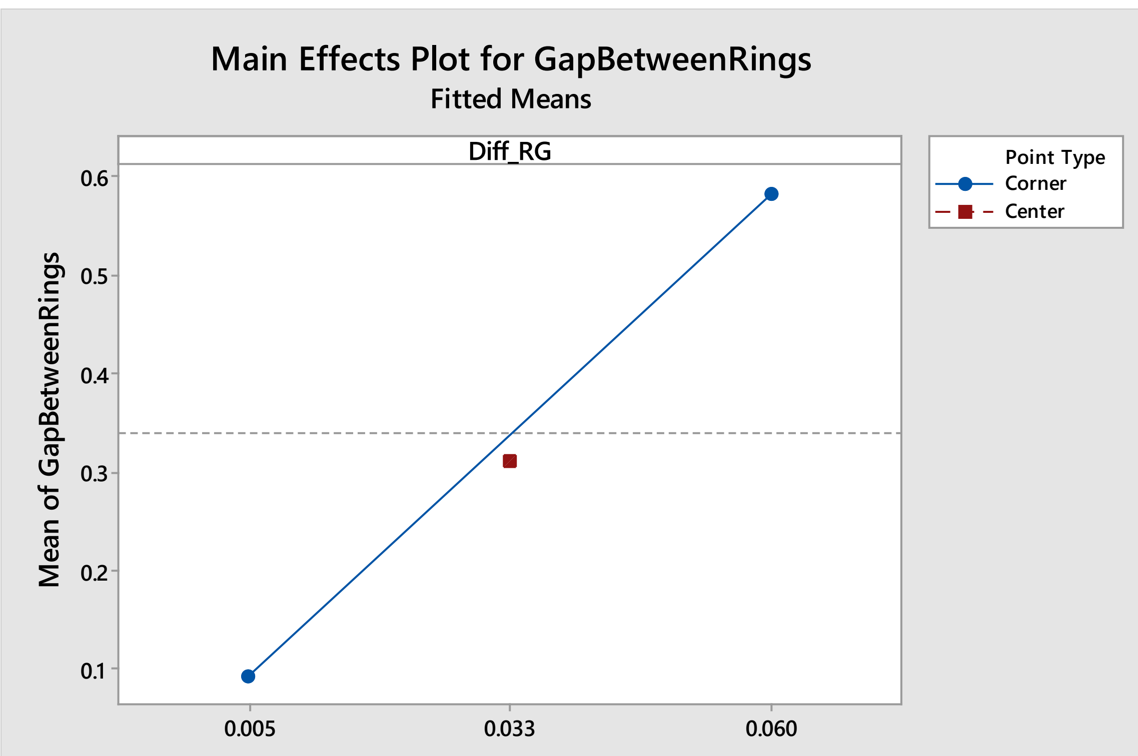
The interaction between the RG and differential RG is significant since the lines intersect. The breakpoint is constant for high RG balls with any differential RG and happens early on the lane. But, the breakpoint changes for low RG balls as the differential RG value changes. Low RG balls with a high differential RG moved the breakpoint closer (43 feet) and to the same location as high RG balls. A low RG ball with low differential RG went much farther (46 feet) before reaching the point on the lane where the ball was closest to the channel. Since the interaction was significant, the main effects plot below is not needed.

Track flare:

Ball	# oil rings	Total track flare width (in)	Gap between oil rings	Comments
2.728 / .007 differential	5	0.5	0.125	ball came back with 4-5 oil rings with no separation between rings
2.49 / .004 differential	4	0.1875	0.063	two oil rings but most times ball returned and could see very little oil on surface
2.58 / .035 differential	4	1	0.333	had 4 oil rings every shot
2.72 / .058 differential	4	1.75	0.583	hooked more than low RG /high flare, had between 4 and 5 oil rings for every shot
2.47 / .060 differential	4	1.75	0.583	

The pareto chart and main effects plots are below:





There is a direct relationship between the differential RG and the gap between each oil ring. When the differential RG increases, the gap between the rings increases. The gap between oil rings is not affected by the RG value.