

ENGINEERING REPORT

Subject: RG and Differential RG Study- Bowler Properties

Date: 9/1/15

Place: International Training & Research Center

Present: Danny Speranza

Purpose:

This is an extension of the RG and differential RG studies. During this test, the bowler properties were added to the test (i.e. RPM, velocity, and axis rotation angle). The goal is to determine which property affects the ball path the most (ball properties or bowler properties).

Summary:

This study shows that the bowler properties have more influence on the boards of hook, entry angle and break point compared to the ball properties of RG and differential RG.

Data:

Test parameters

The basic test is the same as the previous RG and differential RG testing, but now the following bowler properties were adjusted during the test:

- Velocity (17 and 19 MPH)
- Rotation (150 and 400 RPM)
- Axis rotation angle (30 and 90 degrees)
- Ball properties changes
 - RG (2.47 and 2.71)
 - Diff RG (.004 and .060)

A $\frac{1}{2}$ factorial design of experiments was set up using the end points listed above.

This RG and differential RG study is a test to quantify the lane performance from these two ball properties. In this test, bowler properties were also adjusted. Once again, a six-hole ball was used to vary the ball properties. 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).

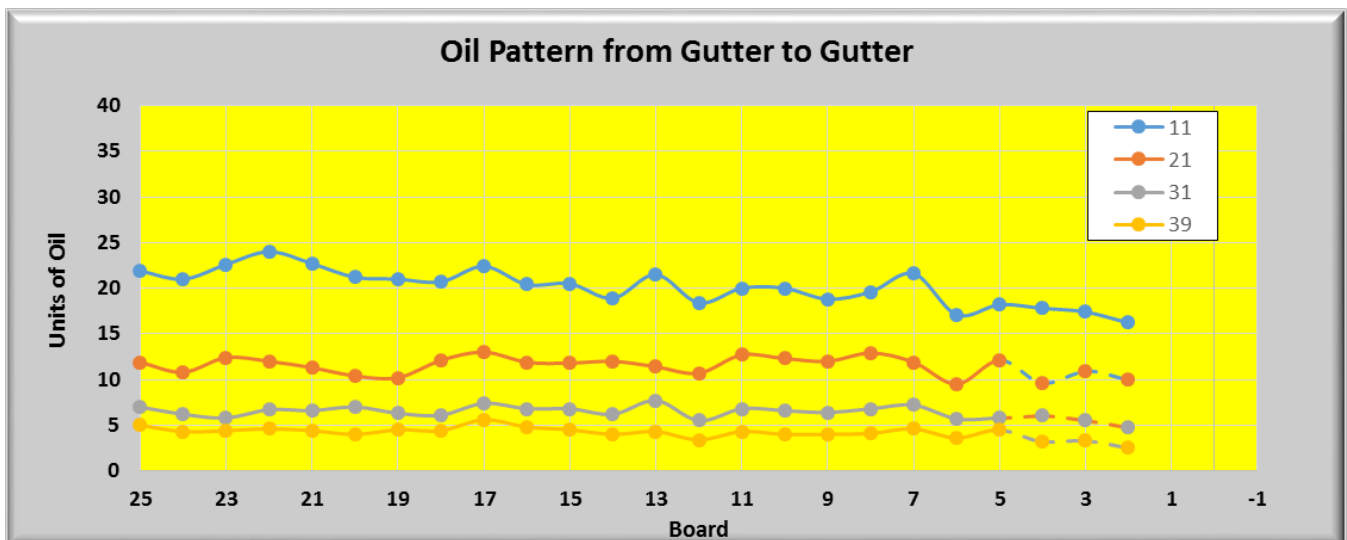
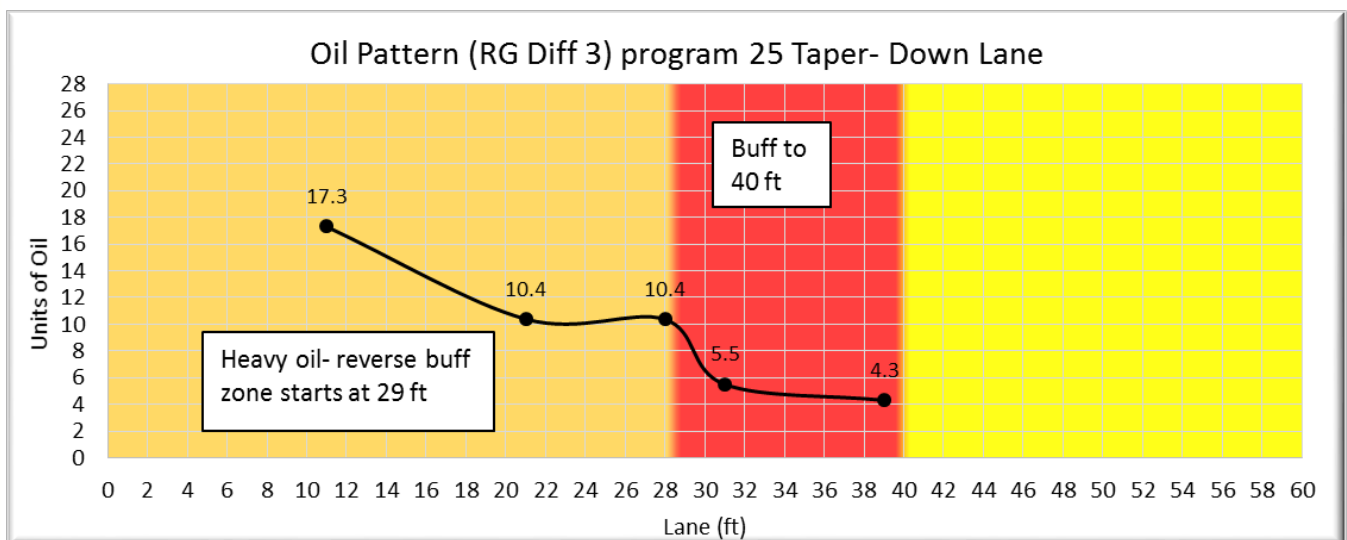
The final measured ball properties were:



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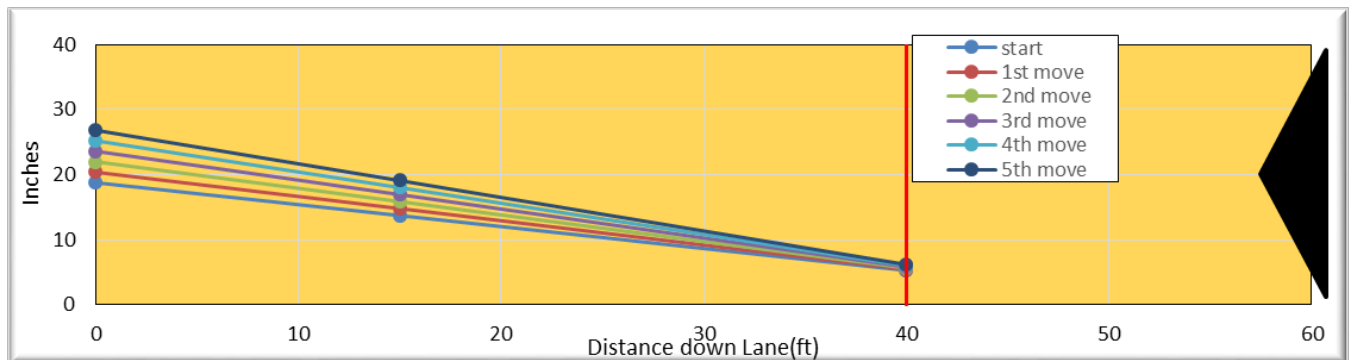
Intial Ball Weight	RG Target	Diff Target	Measured RG	Measured Diff	Final Ball Weight
13.27	2.73	.000	2.728	.007	14.72
13.27	2.73	.060	2.715	.058	14.63
13.27	2.57	.030	2.577	.035	15.03
12.22	2.47	.000	2.485	.004	15.94
12.22	2.47	.060	2.476	.061	15.83

The same oil pattern was used from the prevoius RG and differential RG study. The lane was oiled flat from gutter to gutter and tapered from the foul line to the oil line. The buff zone was to simulate the location down the lane when a ball typically transistions from heavy oil in the center of the lane to very light oil outside of the 10 board. During the original differential RG test, the ball was measured to cross the 10 board at approximately 29 feet down the lane and still target the 8 board as the end of the oil pattern. So heavier oil was applied to 29 feet and minimum oil past that point, like a typical house condition.



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The test balls were thrown by E.A.R.L. The same test procedure was followed as in previous tests except the number of shots was reduced from 30 per test to 20 per test. A single ball test now consisted of 20 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 resulted 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.

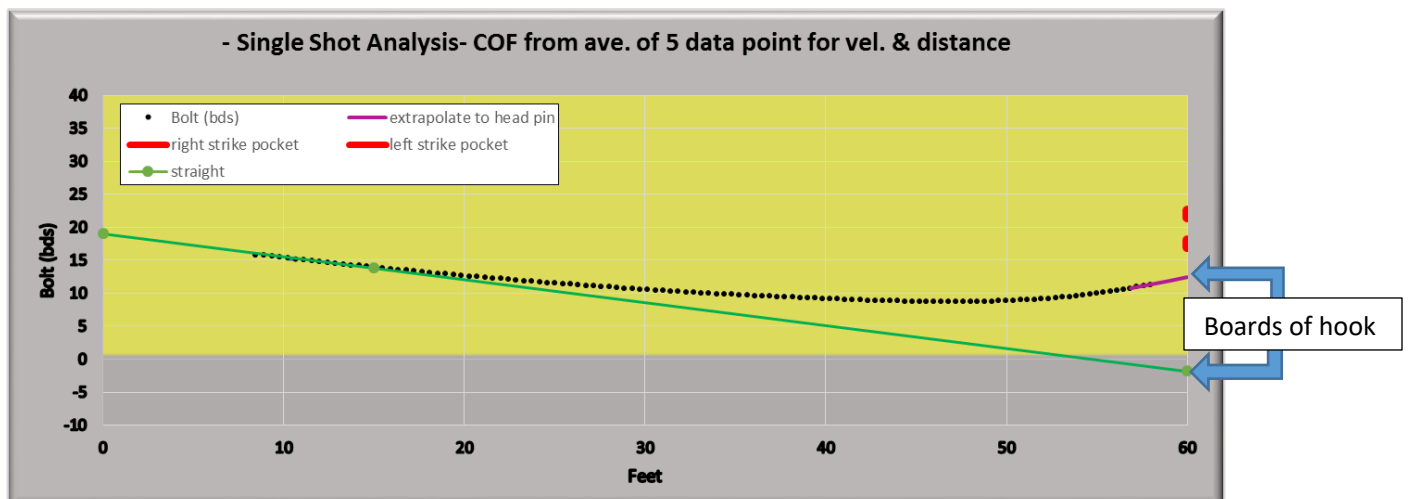
Test results

The following test parameters were monitored:

- Total boards of hook
- Entry angle and total angle change
- Break point location
- Track flare

Total boards of hook:

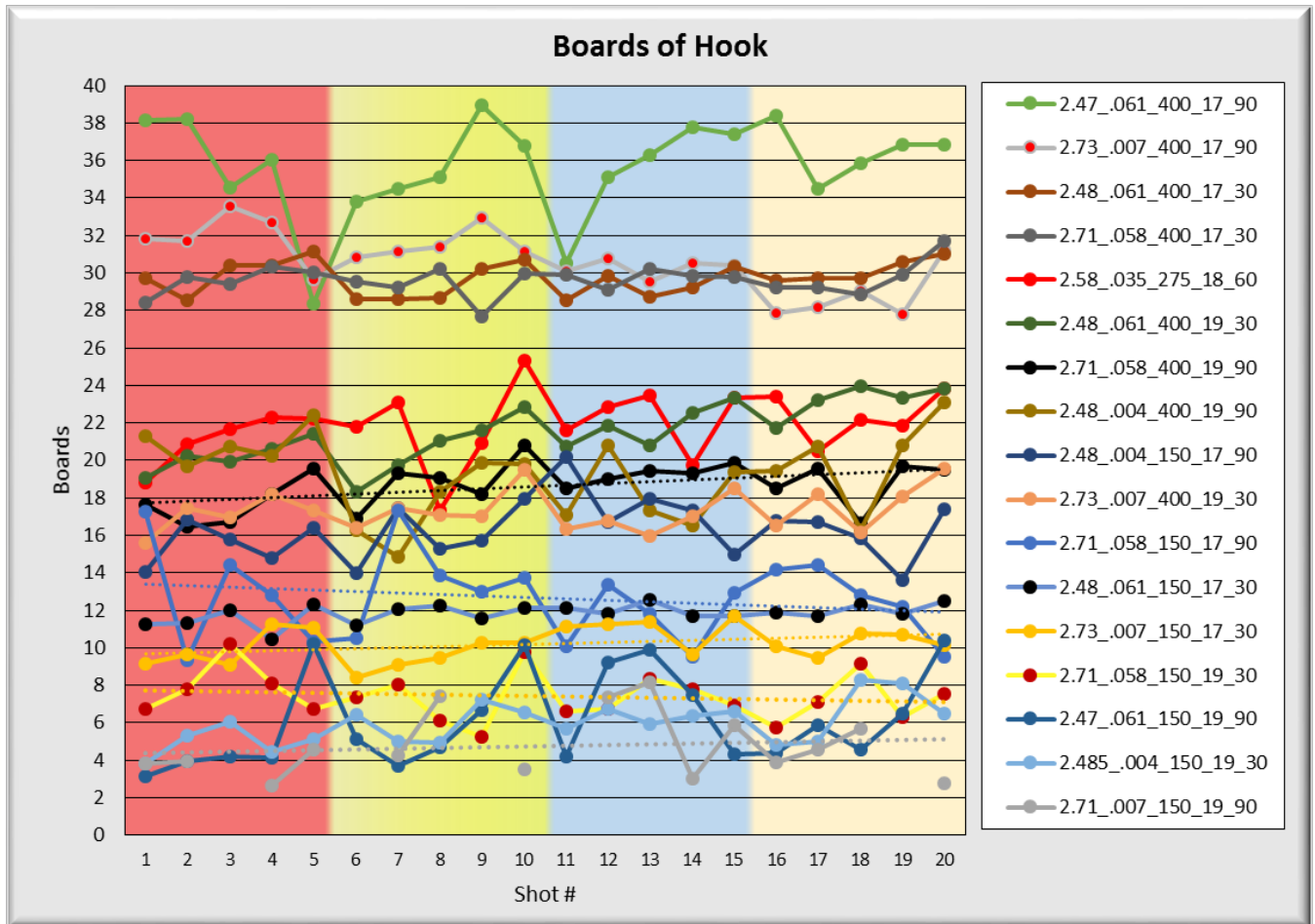
BOLTS was used to measure the total hook. A straight line was extended using E.A.R.L.'s launch settings (lay down board and trajectory) to 60 feet. The number of "boards of hook" was calculated at 60 feet between this straight line and the ball path measured by BOLTS.



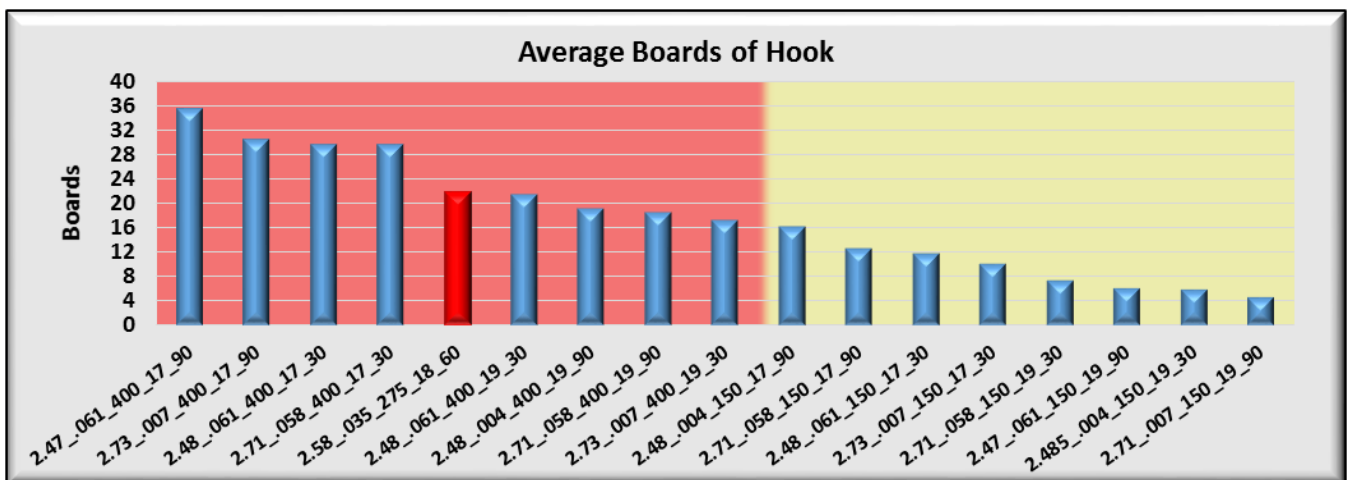
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A design of experiments was set up using a 1/2 factorial design parameters including a center point (2.58 RG_.035 differential RG_275 RPM_18 MPH_60-degree axis rotation).

Below is a chart for the "boards of hook" for each shot for the various test properties. The colored background zones in the chart are for the five-shot grouping before E.A.R.L. was repositioned.



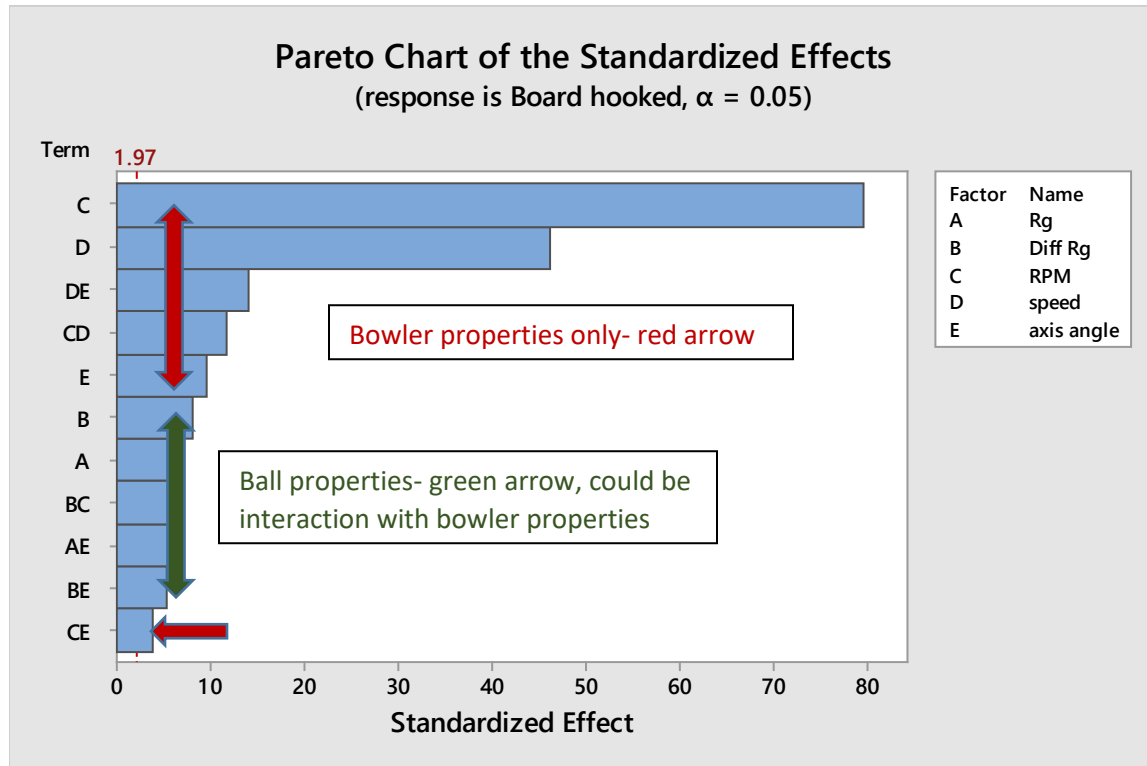
Below is a chart for the average boards of hook for each test (average for all 20 shots):



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The red bar indicates the center point (2.58 RG_.035 diff_275RPM_18MPH_60 axis rotation). The background zone colored in red are all the 400 RPM (and 275 RPM center point) tests. The yellow background zone are all the 150 RPM tests.

Below are the charts for the statistical analysis for the Boards Hooked.



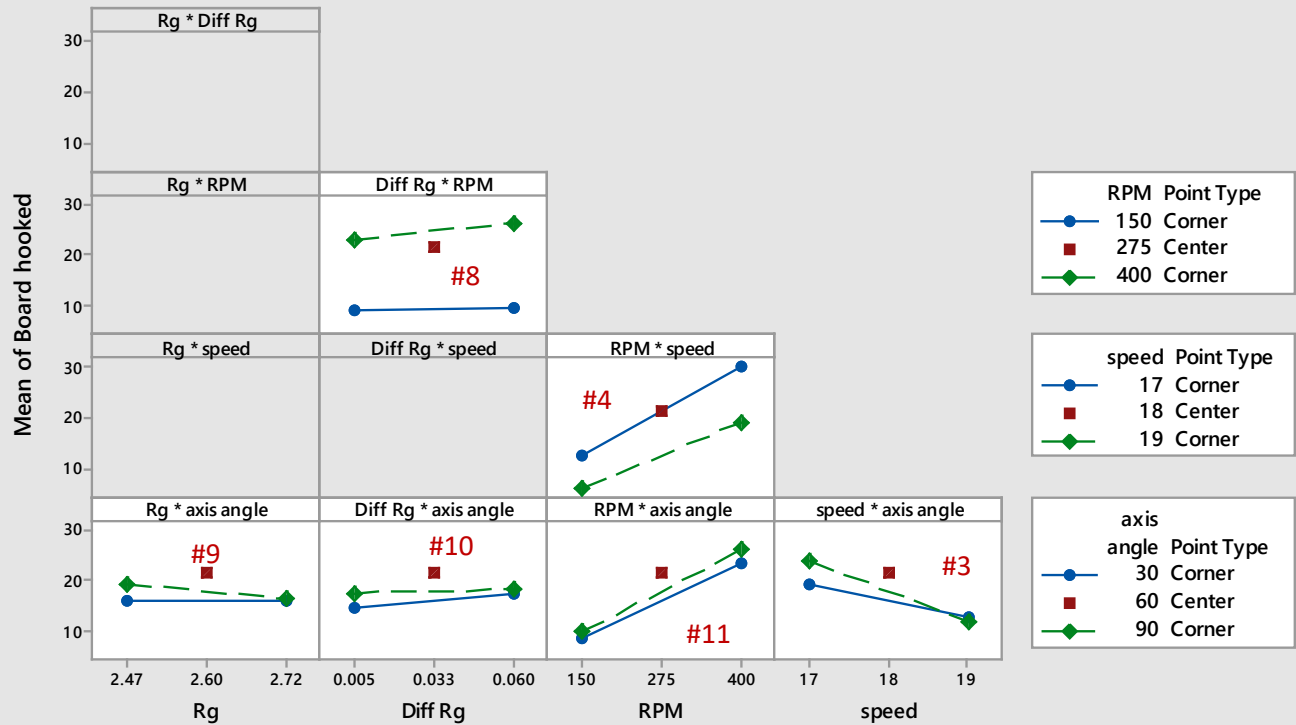
The Pareto chart above shows how important the various factors are which includes interaction of properties. The two properties affecting the results for boards hooked the most are C: RPM and D: speed. The most important ball property is B: differential RG, which is the sixth variable listed. The top-five items affecting the boards hooked are all bowler properties:

1. C: RPM
2. D: Speed
3. DE: Speed and axis angle interaction
4. CD: RPM and speed interaction
5. E: Axis angle

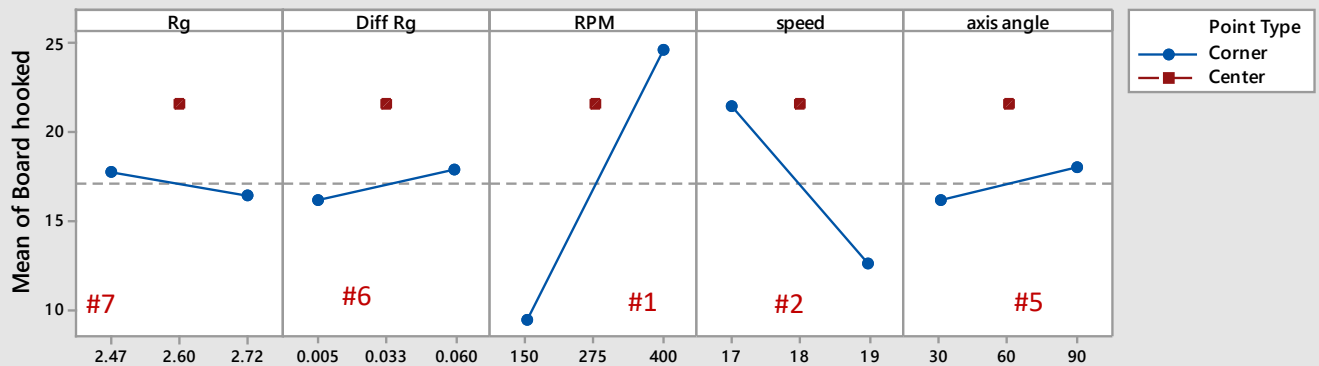
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Below are charts showing the effects of the interaction terms and main effects plot on the boards of hook with the red numbers telling the importance of each (1 = most important, 11 = least important):

Interaction Plot for Boards Hooked Fitted Means

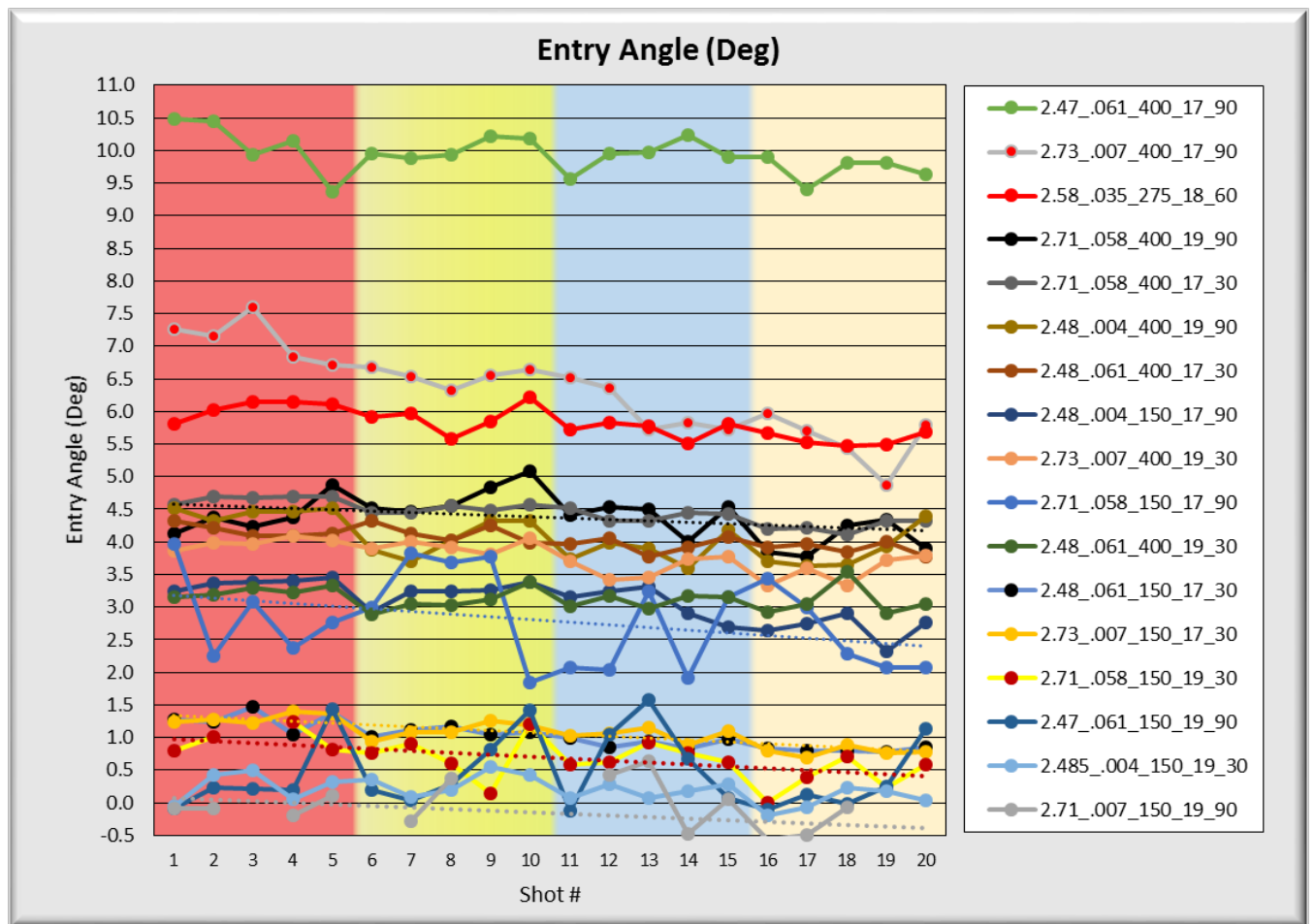


Main Effects Plot for Boards Hooked Fitted Means



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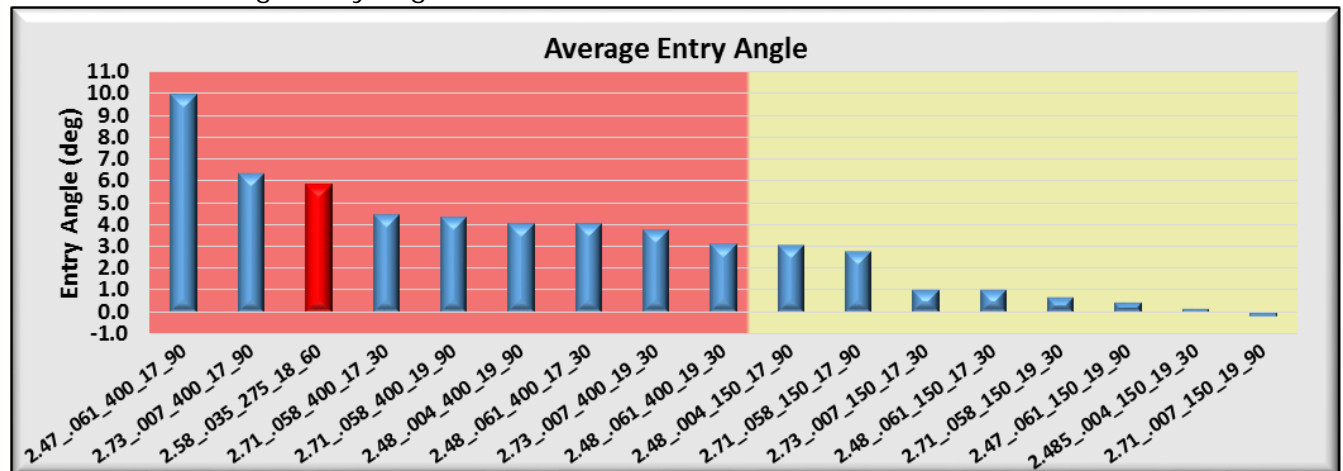
Entry Angle:



There appears to be three groups of entry angles:

- over 5.5 degrees
- 2 to 5 degrees
- below 2 degrees

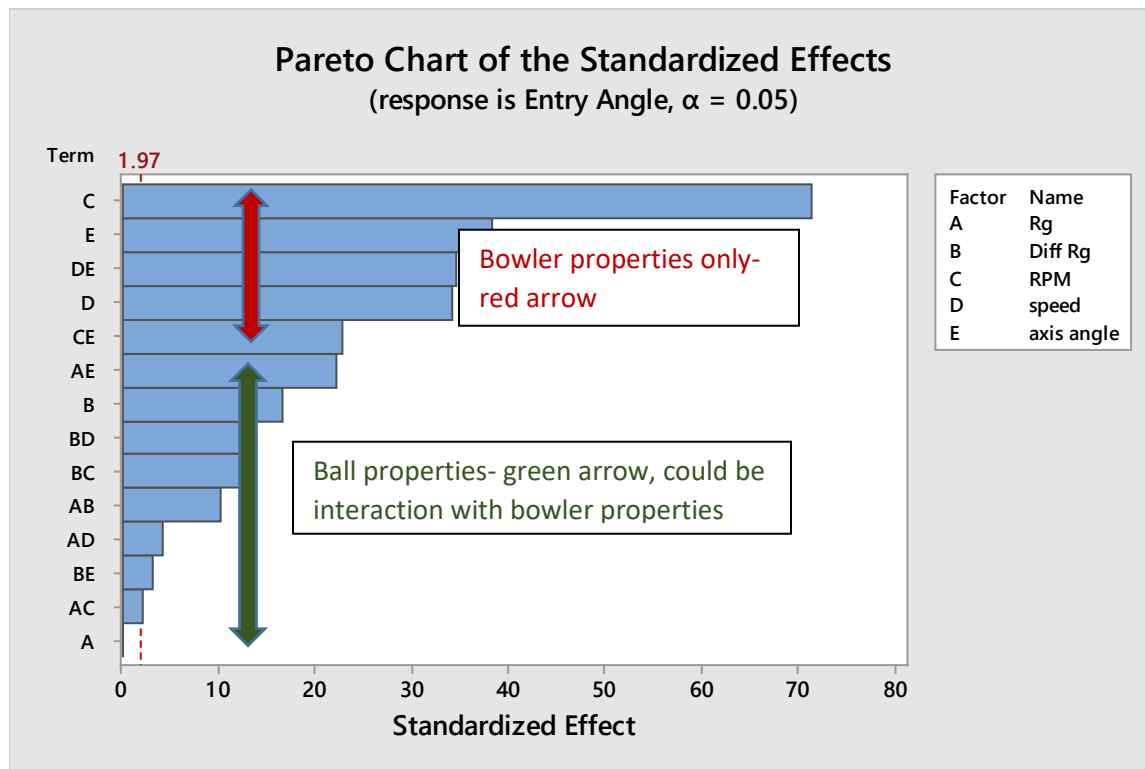
Below is the average entry angle for each test:



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The red background zone shows the higher RPM (400 and 275) results and the yellow background zone shows all the 150 RPM results.

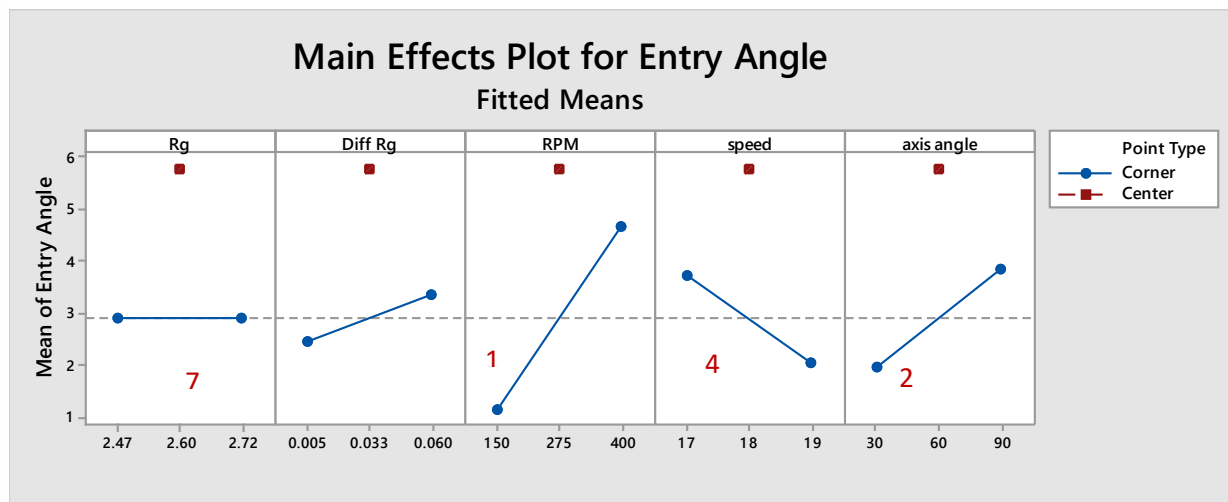
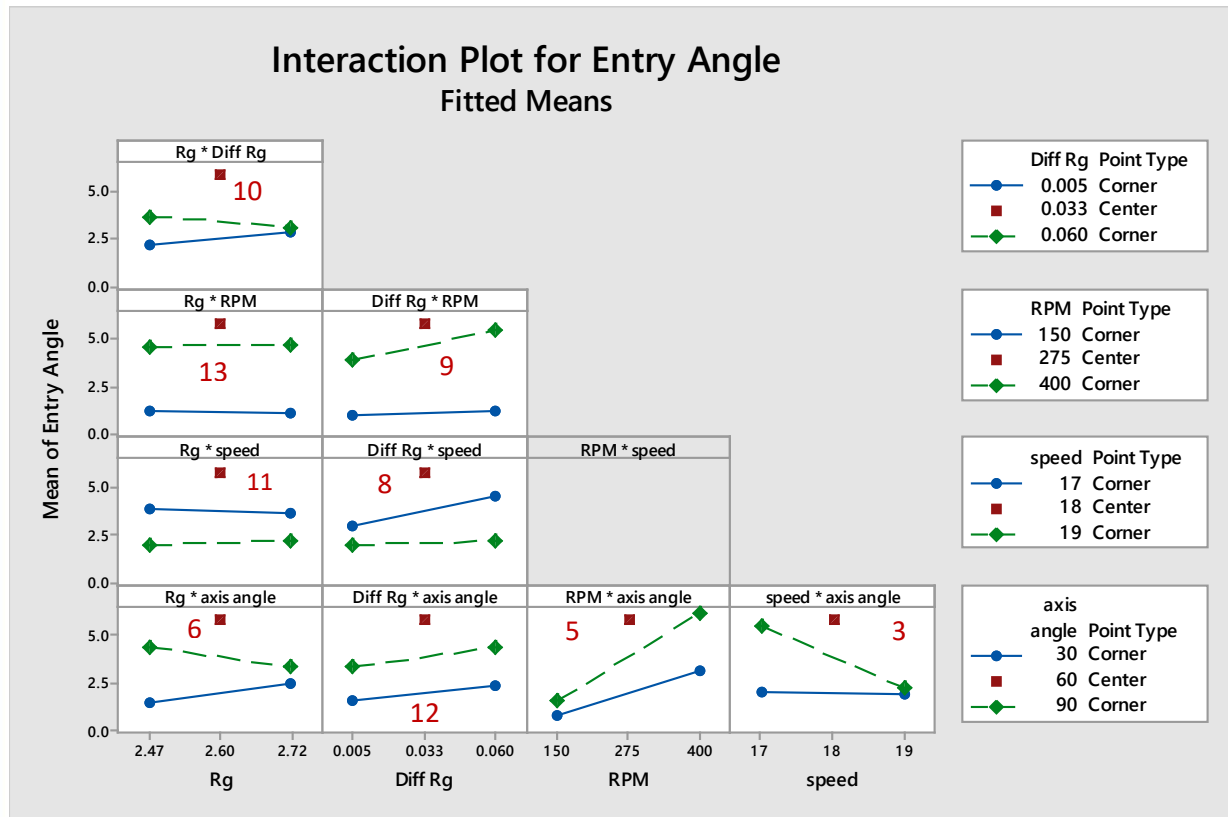
Below is the Pareto chart of the primary variables that affect entry angle:



Once again, the top five properties affecting the entry angle are all bowler properties, with all the ball properties (including ball properties interacting with some bowler properties) also being important but to a smaller effect.

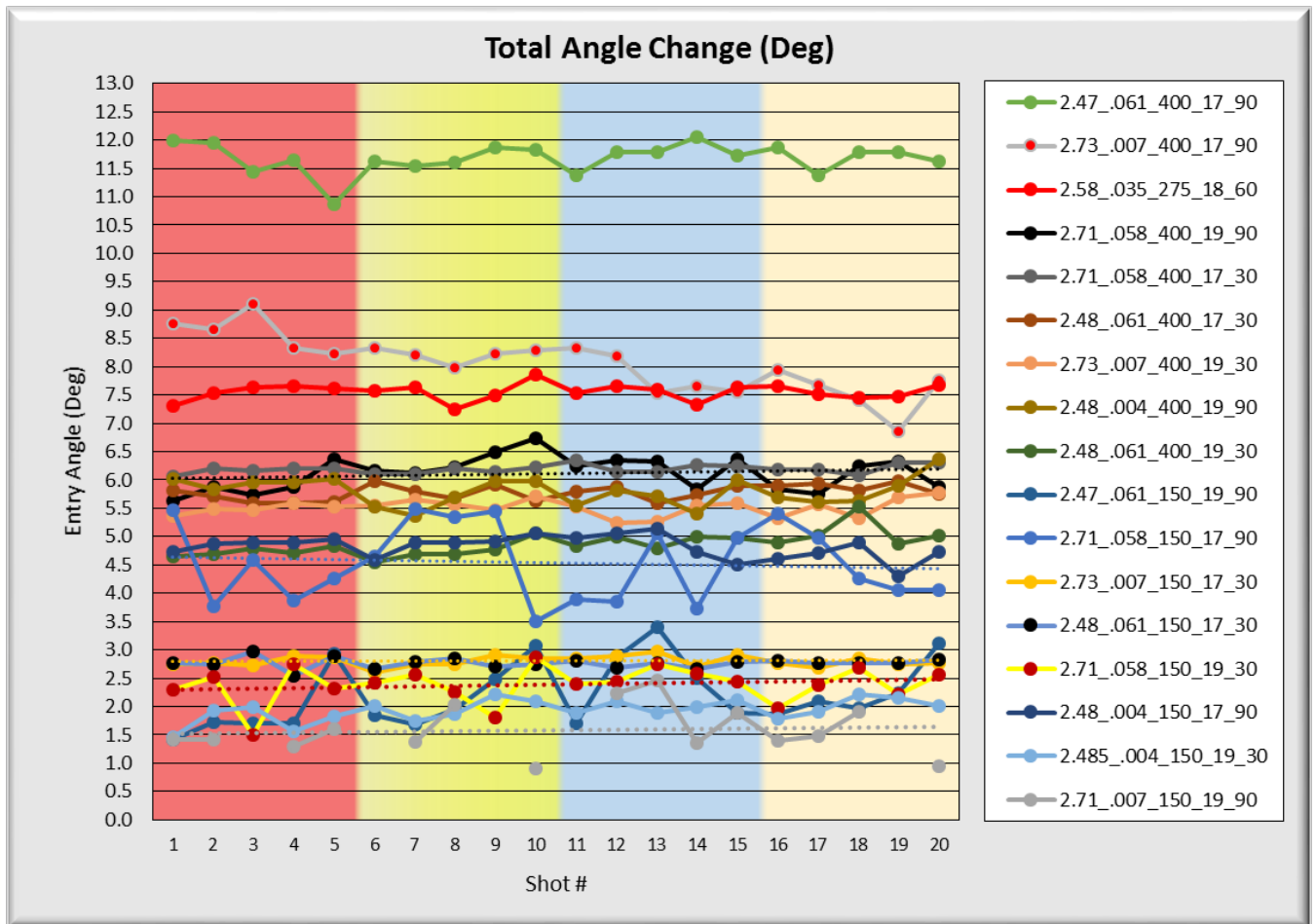
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Below are charts showing the effects of the interaction terms and main effects plot on the entry angle, with the red numbers telling the importance of each (1= most important, 13= least important):

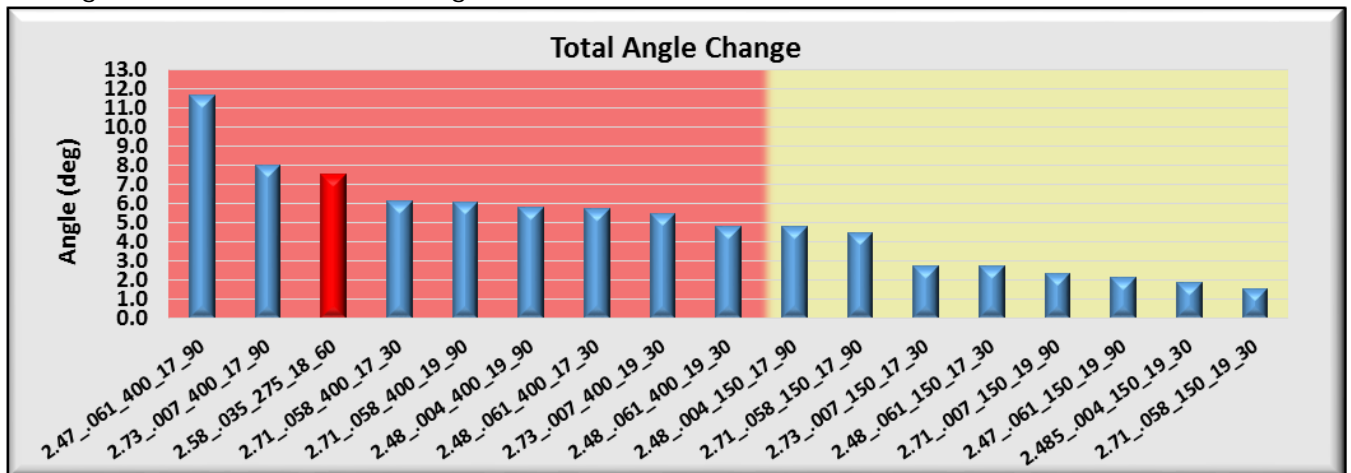


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Total Angle- Adding the launch angle to the entry angle to get the total angle change.



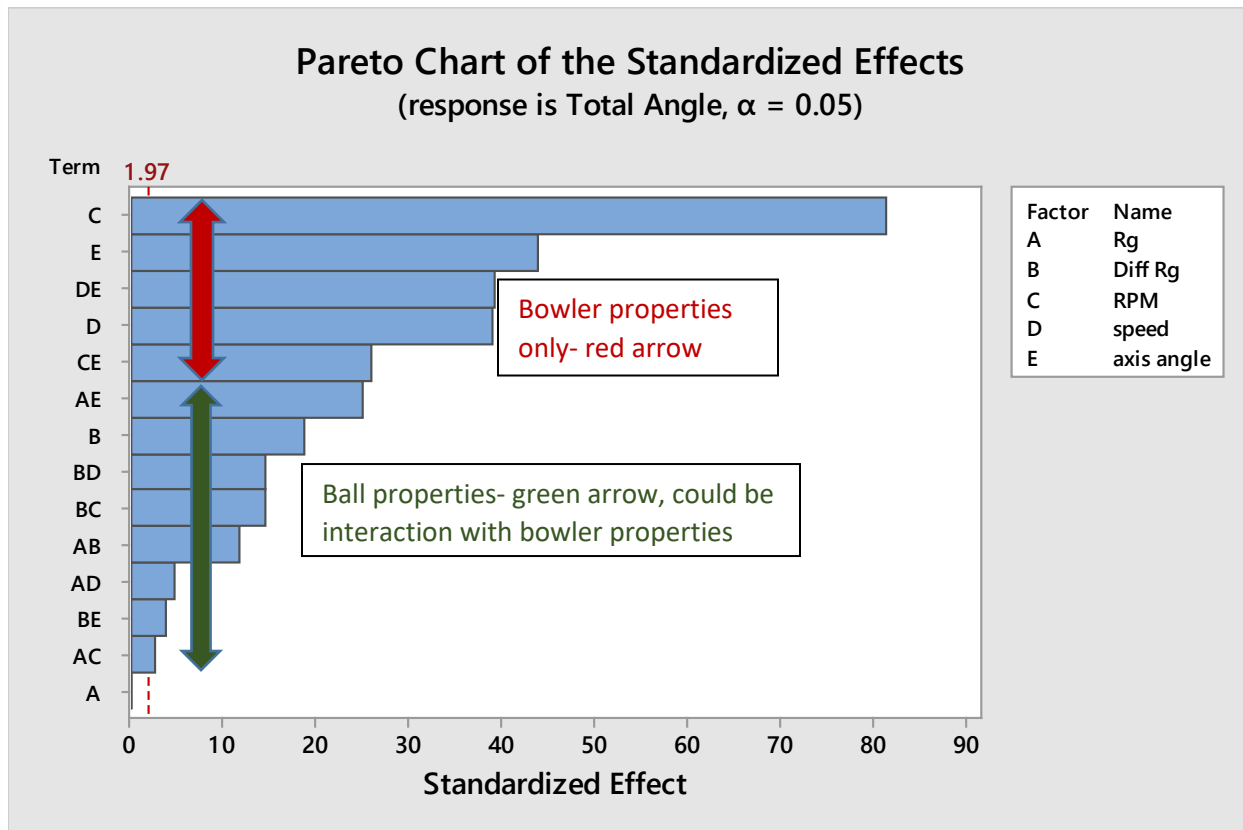
Average for each test for total angle:



Once again, the red background zone are all the tests with higher RPM rates (400 and 275).

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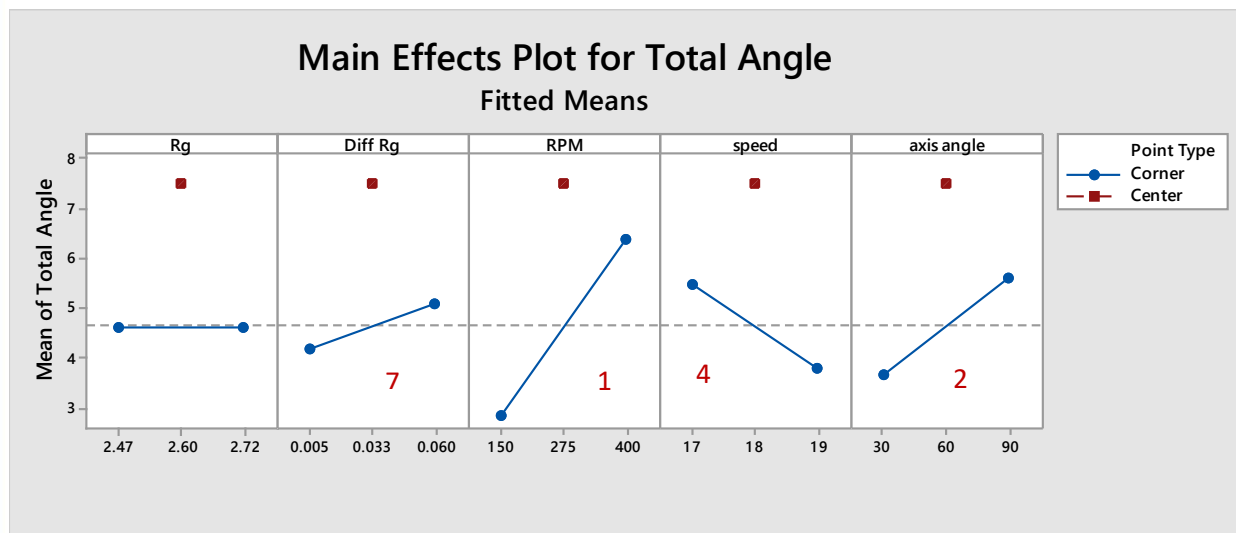
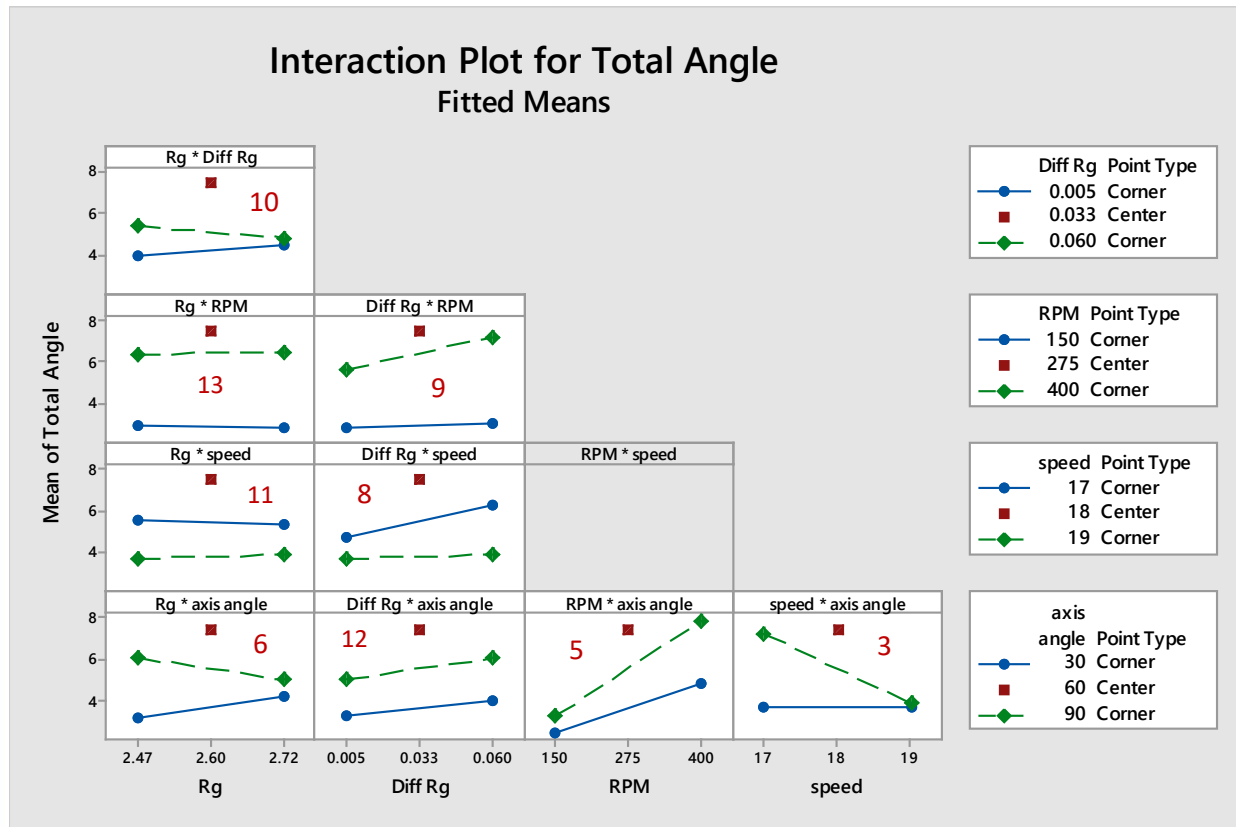
Below is the Pareto chart showing the most important variables affecting the total angle:



Once again, the bowler properties are the top-five factors influencing the total angle, with the rotation rate, axis rotation angle, speed and interaction of these factors dominating the total angle.

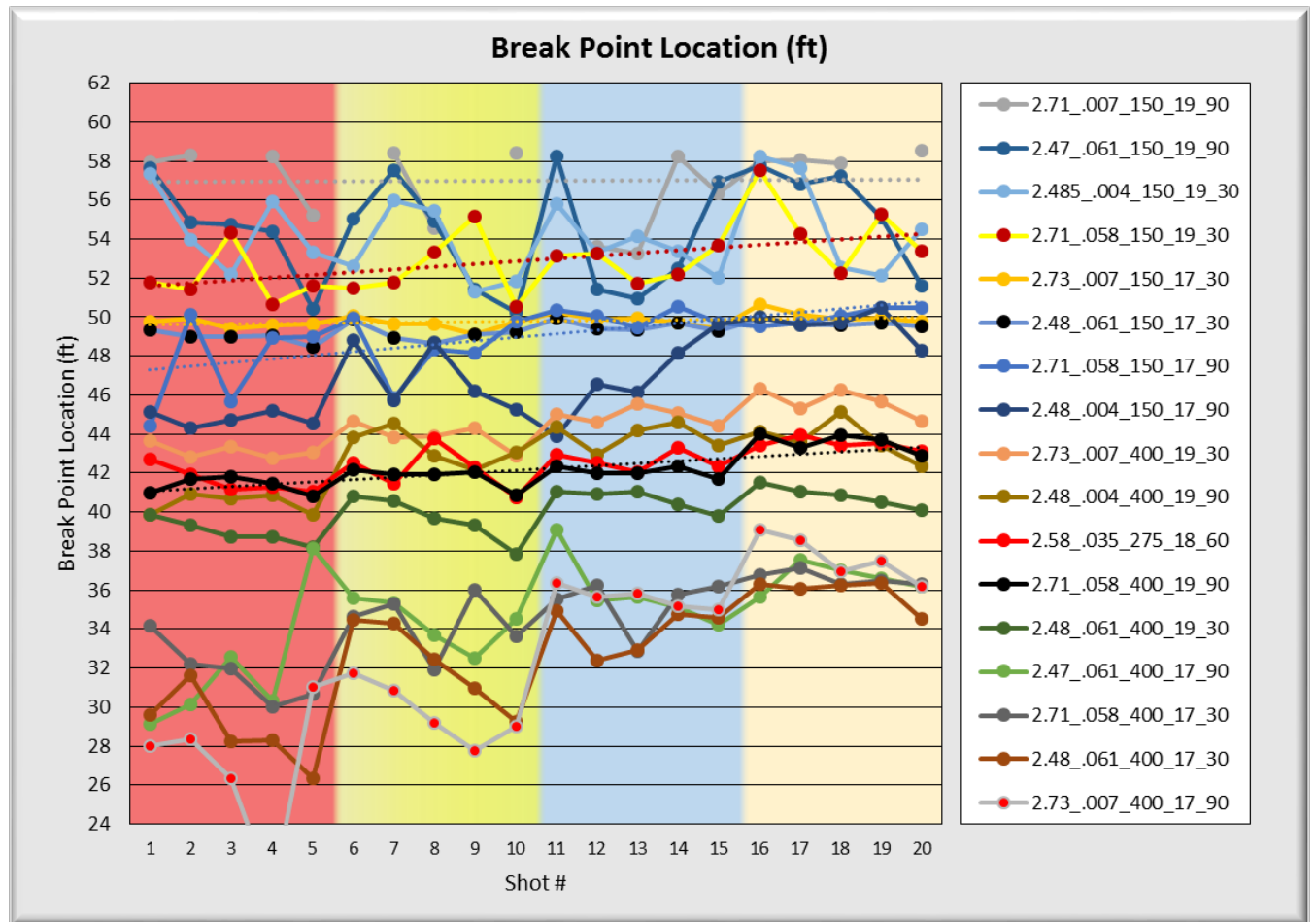
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Below are the interactions and main effects plots for total angle change, with the red numbers listing the importance of each factor or interaction of factors:

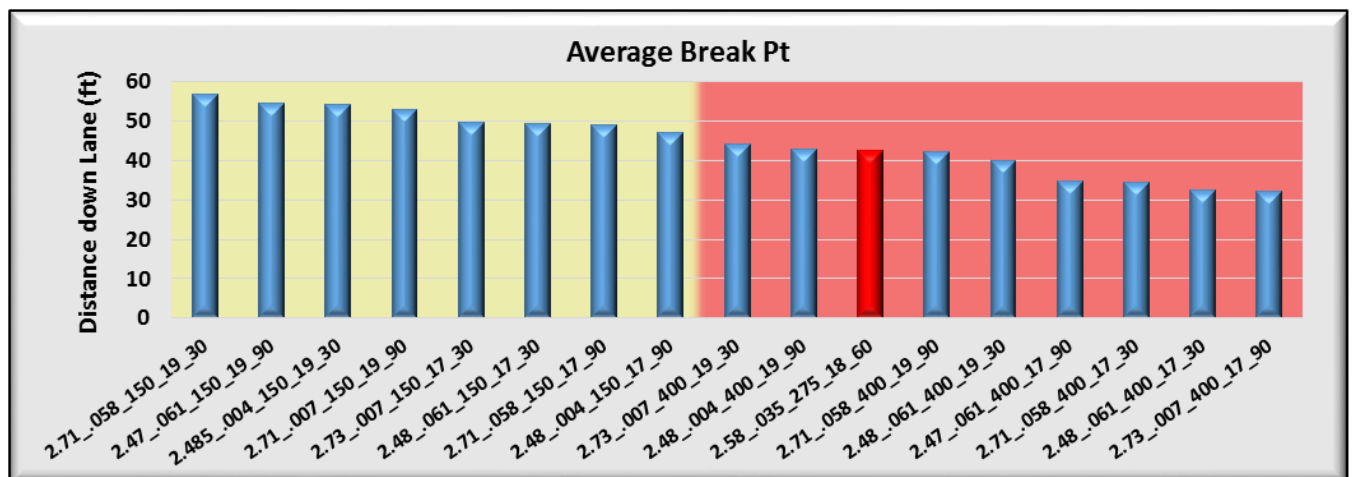


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Break Point Location (ball path location closest to the gutter):



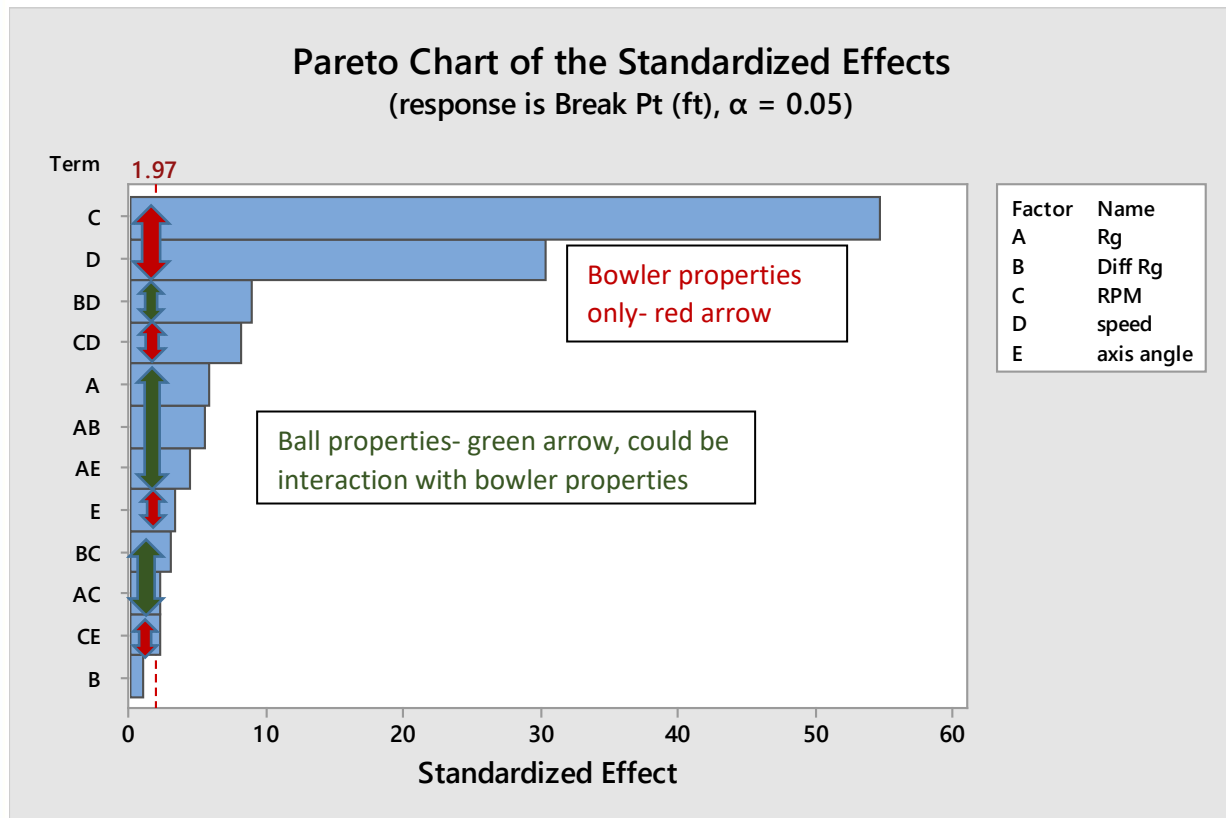
Below is the average break point location for each test:



Once again, the red background shows all the high RPM tests. In this case, high RPM equates to a sooner break point.

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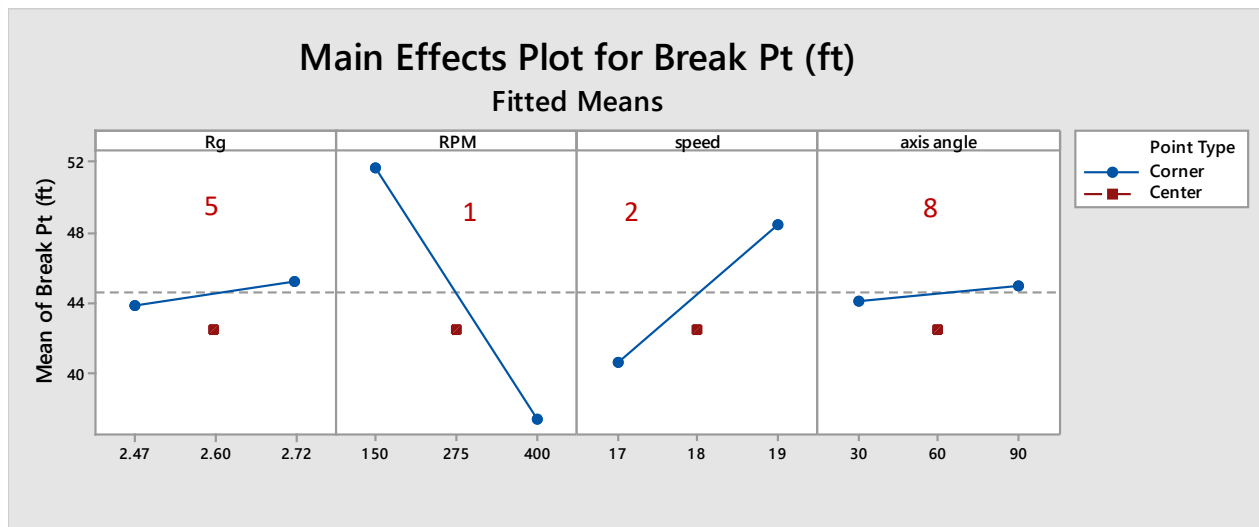
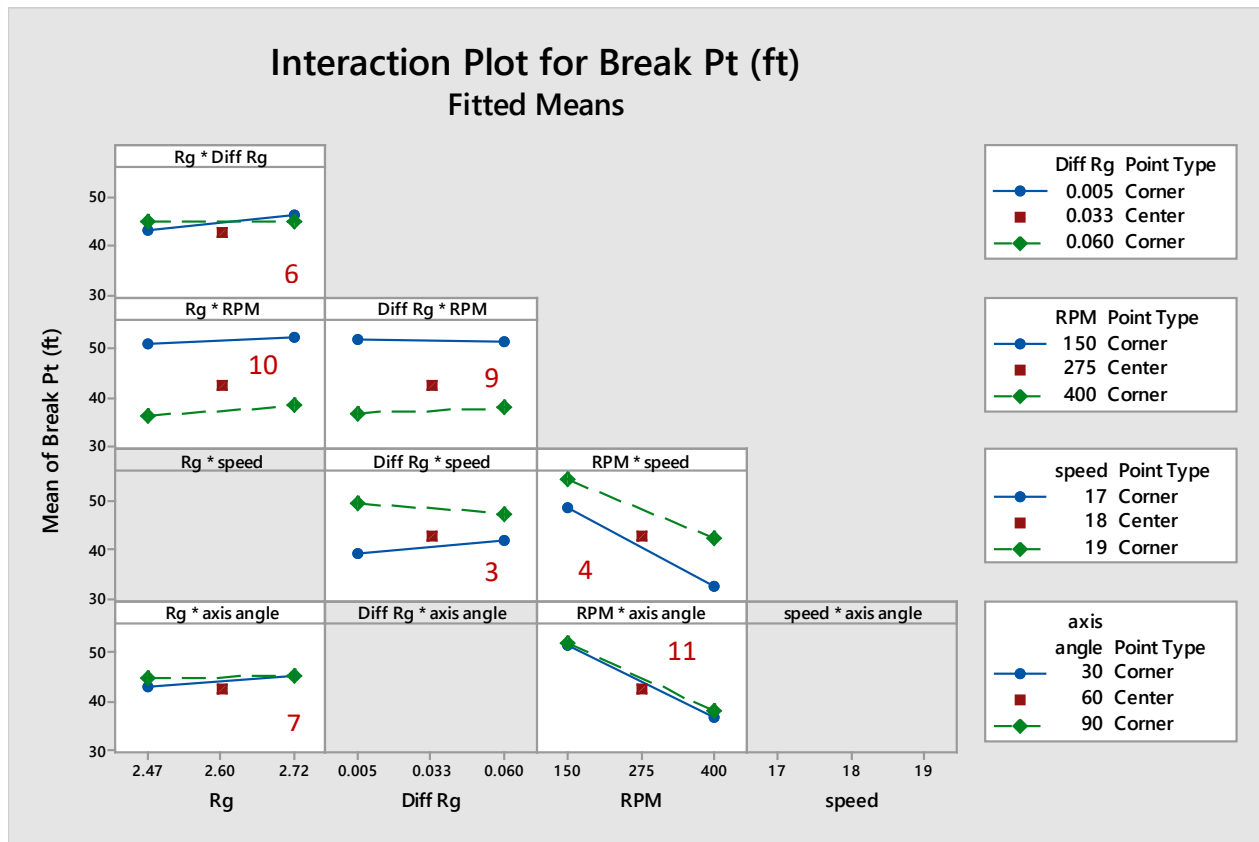
Below is the Pareto chart showing the variables that influence the break point location:



The top two properties having the largest impact on the break point location are bowler properties (RPM and speed), but the interaction of the ball property differential combined with speed moved into third place. This is the highest any ball property reaches in affecting any of the output results measured.

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Below are the interaction and main effects plot for break point location with a numerical rating:



Overall lane performance summary:

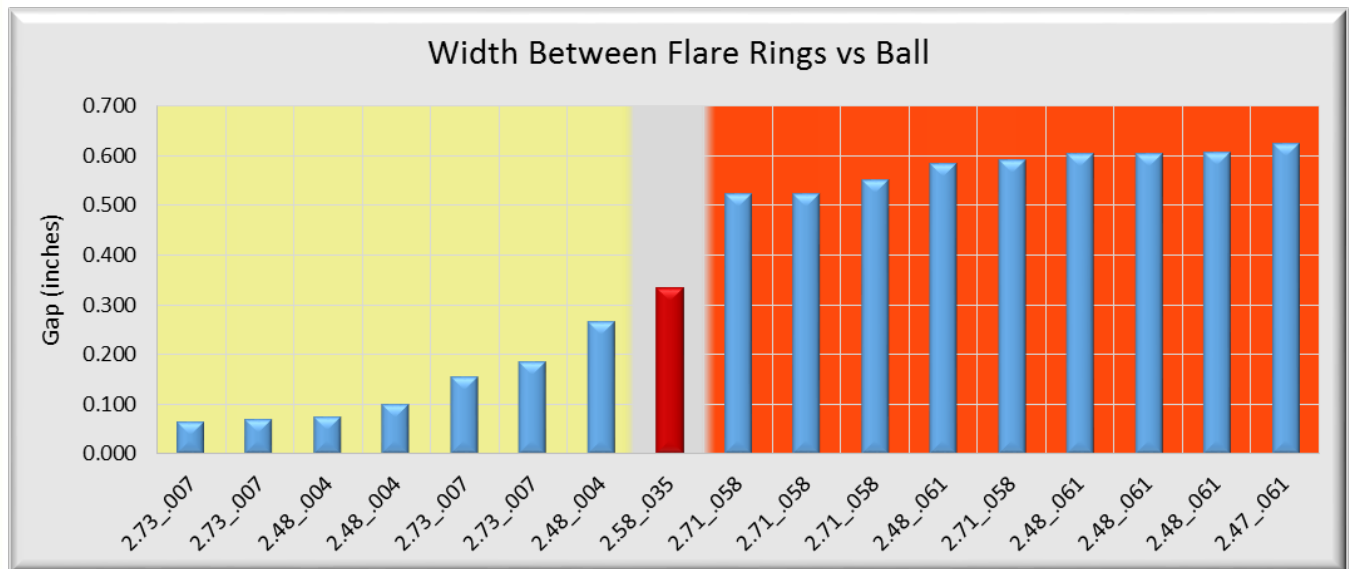
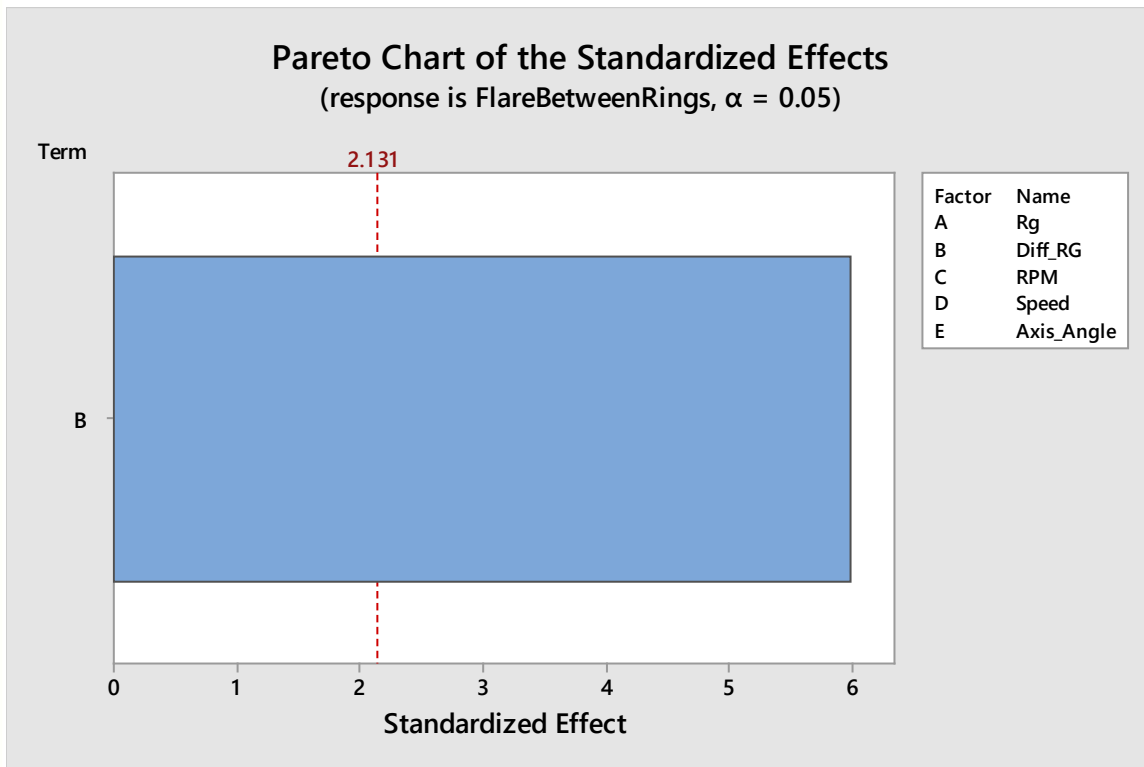
For the performance properties that were measured [(1) boards of hook, (2) entry angle and total angle and (3) break point location], the bowler's RPM rate and ball speed were always in the top three variables affecting the results, and most of the time, they were the top two variables. The ball property of RG and differential RG both influence the results, but to a much smaller degree.

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Track flare and oil movement:

Ball	flare- top of ball			flare- bottom of ball			carrydown comments
	Total flare width top	# oil rings	gap	Total flare width	# oil rings	gap	
2.73_.007_150_17_30	0.1875	4	0.063	0.938	4	0.313	can't see any carrydown, track flare very thin on top & wide on bottom
2.71_.058_150_17_90	2	4	0.667	0.438	2	0.438	see very little carrydown
2.73_.007_150_19_90	0.25	3	0.125	0.188	2	0.188	small dashes of carrydown (no streaks), very little carrydown
2.71_.058_150_19_30	0.875	3	0.438	1.500	3	0.750	
2.71_.058_400_19_90	2.625	6	0.525	2.625	6	0.525	small 1/2" dashes of carrydown in areas from bow tie moving & crossing oil rings
2.48_.061_400_17_90	3.840	7	0.640	3.438	7	0.573	small 1/2" dashes of carrydown in areas from bow tie moving & crossing oil rings
2.47_.061_150_19_90	1.500	3	0.750	0.500	2	0.500	small dashes, very little carrydown
2.48_.061_400_17_30	4.313	8	0.616	3.000	6	0.600	4" dashes of oil but dashes are series of 1/8" oil dashes followed by 3/8" no oil dashes due to crossing moving bow tie
2.71_.058_400_17_30	2.280	5.4	0.518	3.280	7.2	0.529	see item above
2.48_.004_400_19_90	0.203	4	0.068	0.250	4	0.083	hard to determine oil rings- very little oil on ball, never saw any oil on bottom, no separation between oil rings (touching & overlapping each other), oil depletion should be minimal, no visible carrydown past 43 ft with little before 43 ft
2.48_.004_150_17_90	0.406	4.8	0.107	0.188	3	0.094	not much oil on ball, long streaks of carrydown
2.48_.061_400_19_30	3.730	7.375	0.585	4.080	7.5	0.628	6" dashes of oil but dashes are series of 1/8" oil dashes then 3/8" no oil dashes, crossing moving bow tie
2.485_.004_150_19_30	0.390	2.75	0.223	0.625	3	0.313	very little oil on ball, little carrydown
2.73_.007_400_19_30	0.243	4.75	0.065	0.475	8.2	0.066	very little oil on ball, more oil at end with very thin oil rings touching each other, long streaks of carrydown
2.73_.007_400_17_90	0.296	4.83	0.077	0.219	4.500	0.063	very thin oil rings with no separation between rings, not much oil on ball especially bottom side, 8" streak of carrydown in areas
2.48_.061_150_17_30	0.718	3	0.359	2.430	4.000	0.810	lot of oil on ball, not much carrydown
2.58_.035_275_18_60			0.000			0.000	

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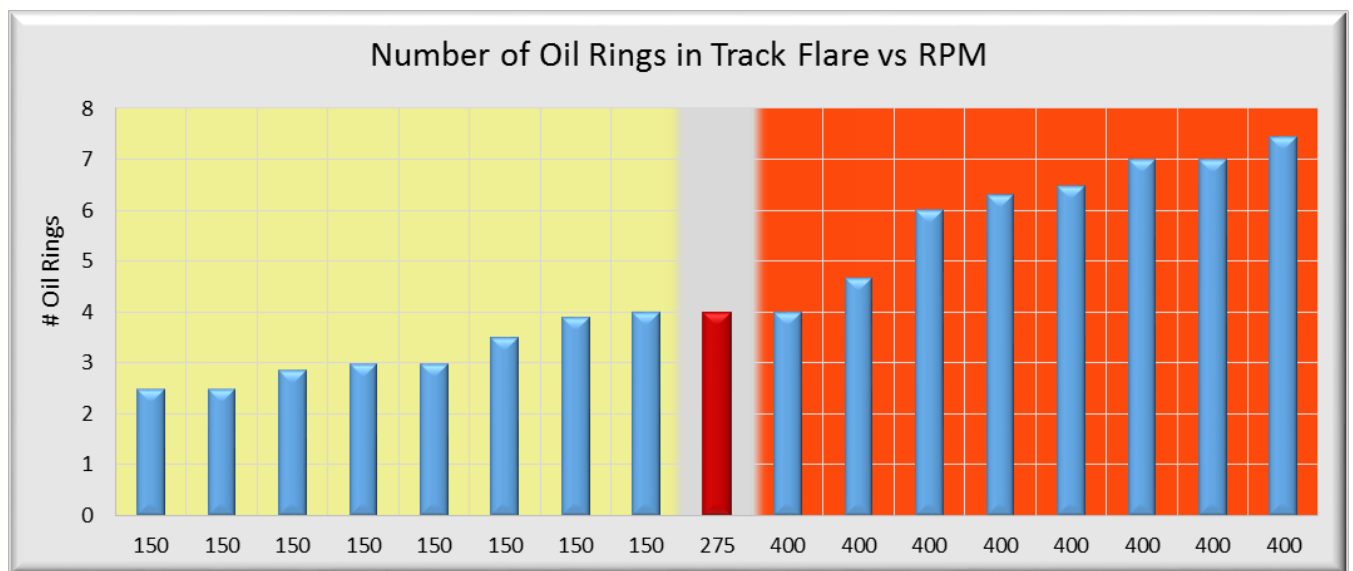
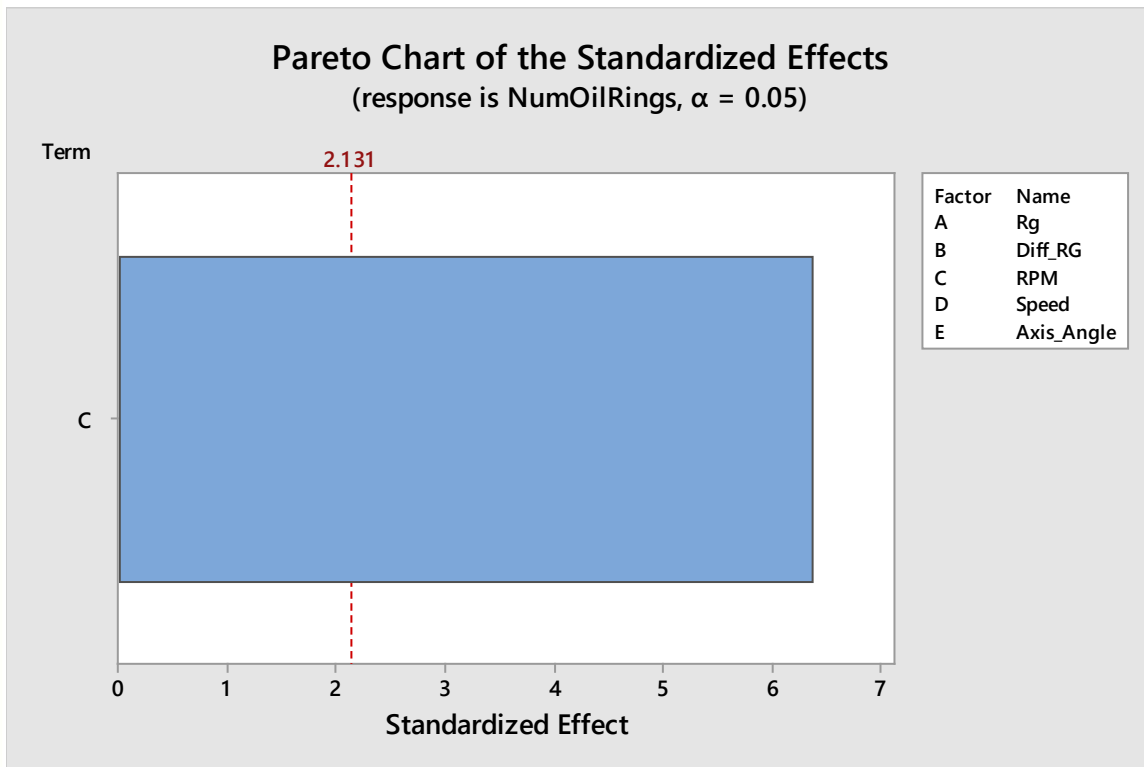


Track flare summary:

The gap between oil rings on the ball is related to the differential RG of the ball and independent of RG or any bowler property.

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Number of oil rings in ball flare:



The number of oil rings on the ball was directly related to the RPM rate and no other property.