# ENGINEERING REPORT

**Subject**: Vary RPM vs. Ball MOI on House Pattern

**Date**: 12/31/15

**Place**: International Training & Research Center

**Present**: Danny Speranza

**Purpose**: Test the RG and Differential RG study varying rotation rate to maintain the same rotational energy for each ball. For this test, it will be conducted on a house oil pattern. The last test was on a flat oil pattern.

**Summary**:

We have documented that bowlers rotate balls with different RPM rates based on the moment of inertia of the ball (MOI). The previous test changed the RPM to match the MOI for each ball and was tested on a flat oil pattern. For this test, we will run the same test on a house pattern. The rotation rate was, again, adjusted for the moment of inertia of the ball. The results got closer together then the previous test on a flat oil pattern due to bowling on a house condition and adjusting the launch location to hit the pocket. Balls that went straighter were thrown closer to the channel which had less oil and therefore the ball hooked more resulting in some properties appearing greater with the less hooking balls due to the oil pattern (and not the ball). Average for 20-shot test:

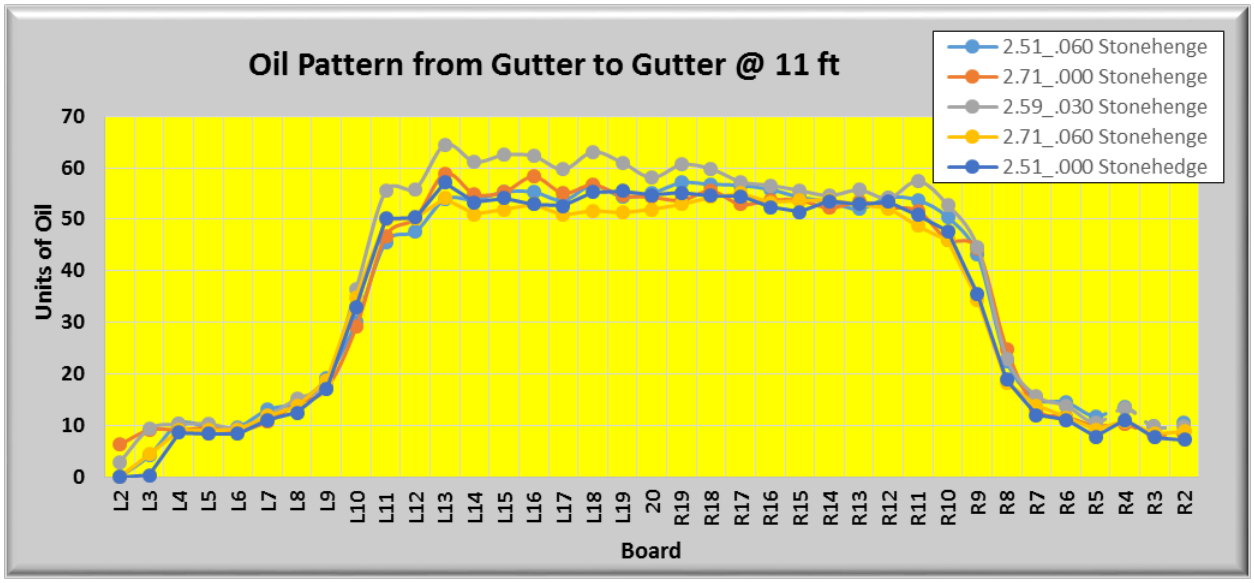
- Average Total Boards of hook (most to least)
  - Low RG, high differential RG ball hooked the most boards - 12.71 boards
  - Low RG, low differential RG hooked second-most - 12.51 boards
  - Med RG, med differential RG hooked third-most - 12.19 boards
  - High RG, high differential RG hooked fourth-most - 11.37 boards
  - High RG, low differential RG hooked the least - 11.30 boards
- Average Entry Angle (most to least)
  - Low RG, low differential RG ball had the most entry angle - 5.12 degrees
  - Low RG, high differential RG ball had the second-most entry angle - 4.47 degrees
  - High RG, high differential RG ball had the third-most entry angle - 4.32 degrees
  - Med RG, med differential RG ball had the fourth-most entry angle - 4.26 degrees
  - High RG, low differential RG ball had the least entry angle - 4.09 degrees
- Average Total Angle (most to least)
  - Low RG, low differential RG ball had the most total angle - 5.50 degrees
  - Low RG, high differential RG ball had the second-most total angle - 5.35 degrees
  - Med RG, med differential RG ball had the third-most total angle - 5.04 degrees
  - High RG, high differential RG ball had the fourth-most total angle - 5.00 degrees
  - High RG, low differential RG ball had the least total angle - 4.37 degrees
- Break point location (feet down the lane where ball is closest to channel)
  - Ball paths were adjusted to hit the pocket, so the break point was greatly influenced by how soon the ball reached the lighter concentration of oil on the outside boards
    - High RG, low differential RG ball had the earliest break point - 21.83 ft
    - Low RG, low differential RG ball had the second-earliest break point - 29.89 ft
    - High RG, high differential RG ball had the third-earliest break point - 40.82 ft
    - Med RG, med differential RG ball had the fourth-earliest break point - 41.27 ft
    - Low RG, high differential RG ball had the latest break point - 41.95 ft
  - The break point directly correlates to starting location
    - Playing further outside reached lighter oil sooner and break point was sooner
    - Playing further inside reached lighter oil later and break point was later

**Data:**

**Test parameters**

The basic test this time is the same as outlined during the previous test. The only difference is that the test was conducted on a house oil pattern.

This RG and differential RG study is a series of different tests to quantify the lane performance from these two ball properties. During the last test, the RG and differential RG of a ball was varied by drilling six holes and adding weights to achieve the desired RG and differential RG. The main purpose for this study was to test on a typical house oil pattern.




The heavy oil is from 10 to 10 and has a fast taper from 7 to 10 to approximately 3-4 units on the outside boards at the end of the pattern. The high differential RG ball (.060) and medium differential RG ball (.030) each started its ball path in the heavy oil (inside 10 board) and targeted the 8 board at 40 feet. The low differential RG ball (.000) started its ball path at the 8-9 board and had a very small launch angle to hit the 8 board at 40 feet. So, the low differential RG balls were basically playing on much less oil for the first 30-35 feet of their ball path until all ball paths got close to the the 8 board at 40 feet. This had a big impact on the results.

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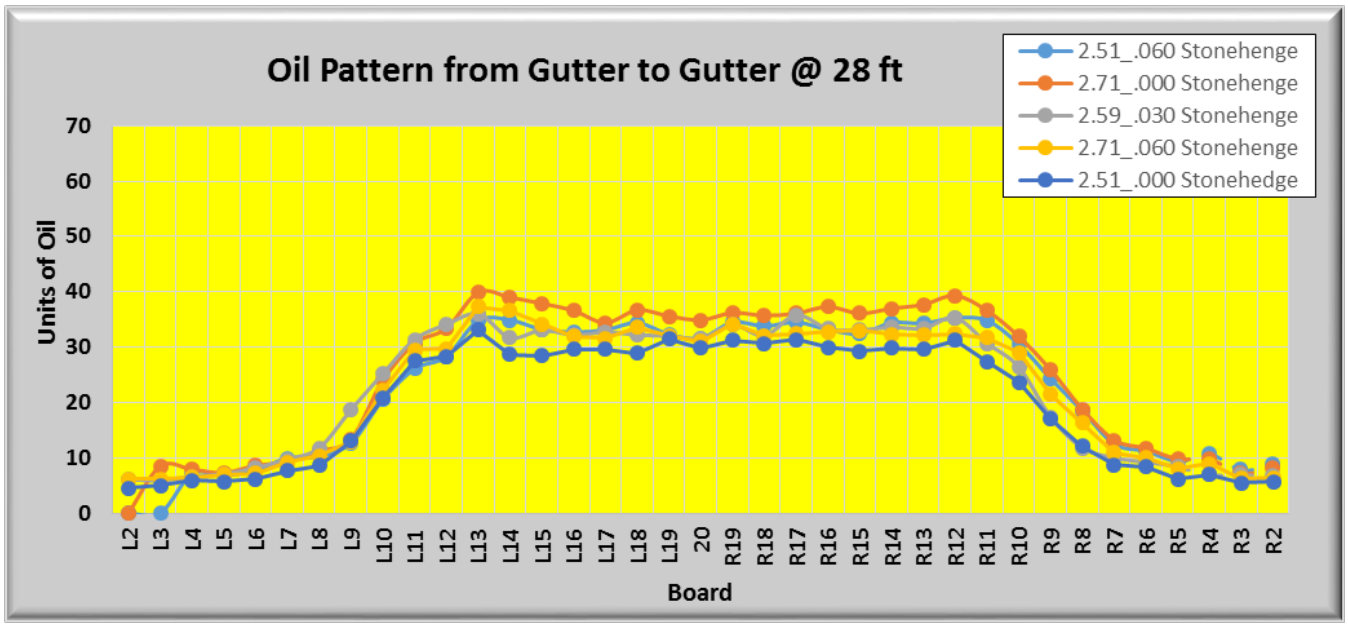


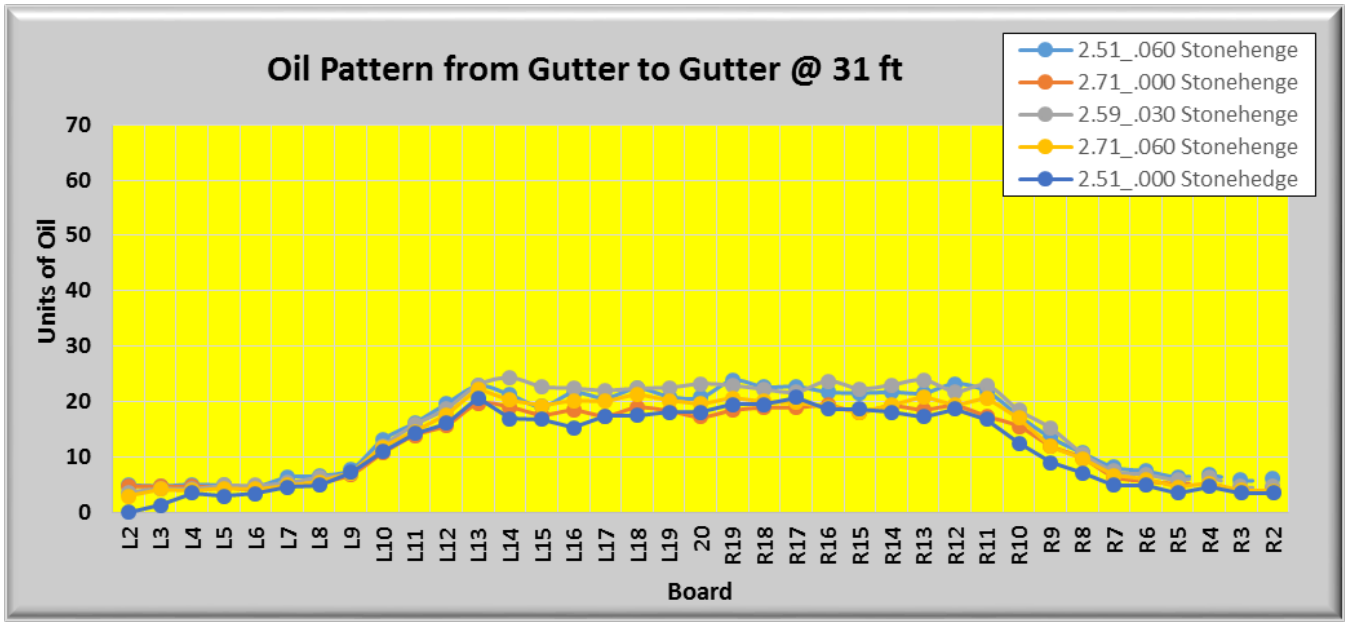

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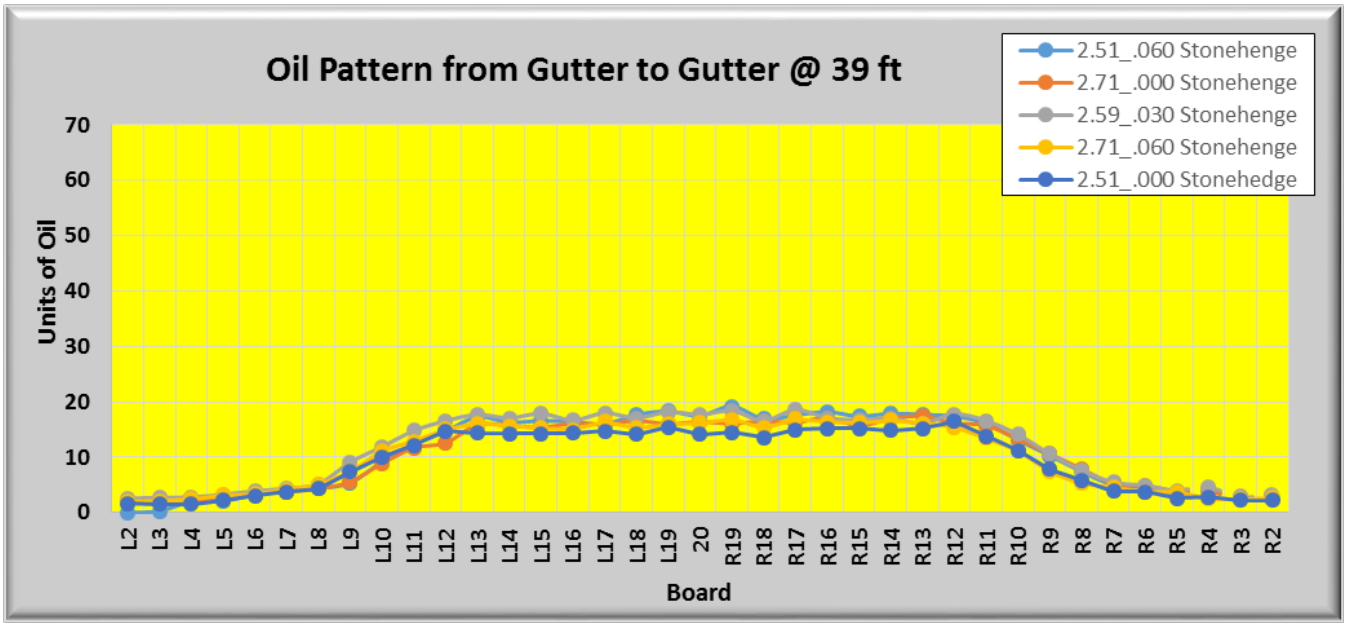



Based on bowlers' results, we discovered that the RPM rate imparted to the ball changes when the moment of inertia of the ball varies. Therefore, this test is to repeat the previous test but on a house pattern. The RPM rate will be adjusted based on the moment of inertia of the ball about the PAP location. The table below calculates the RPM rate for each ball.

| Ball | Wt. | RG min | RG max | RG @ PAP | MOI @ PAP | RPM | RPM setting for EARL | comment |
|---|---|---|---|---|---|---|---|---|
| 2.51 / .000 | 15.9 | 2.51 | 2.506 | 2.51 | 100.17 | 282 | 297 | |
| 2.48 / .060 | 15.9 | 2.481 | 2.543 | 2.512 | 100.39 | 282 | 297 | |
| **2.57 / .030** | **15.8** | | | **2.585** | **105.58** | **275** | **290** | **base line for 275 RPM** |
| 2.593 / .031 | 16.1 | 2.594 | 2.625 | 2.609 | 109.25 | 270 | 285 | |
| 2.713 / .000 | 15.8 | 2.713 | 2.712 | 2.714 | 116.34 | 262 | 277 | |
| 2.72 / .060 | 15.8 | 2.68 | 2.74 | 2.710 | 116 | 262 | 277 | |

It should be noted that the MOI about the PAP can be very different from the RG value for a ball when it has a high differential RG values. The 2.481 ball with .060 differential RG is actually 2.512 RG about the PAP. And the 2.68 RG ball with .060 differential RG is actually 2.71 RG about the PAP. So, in this test we have:

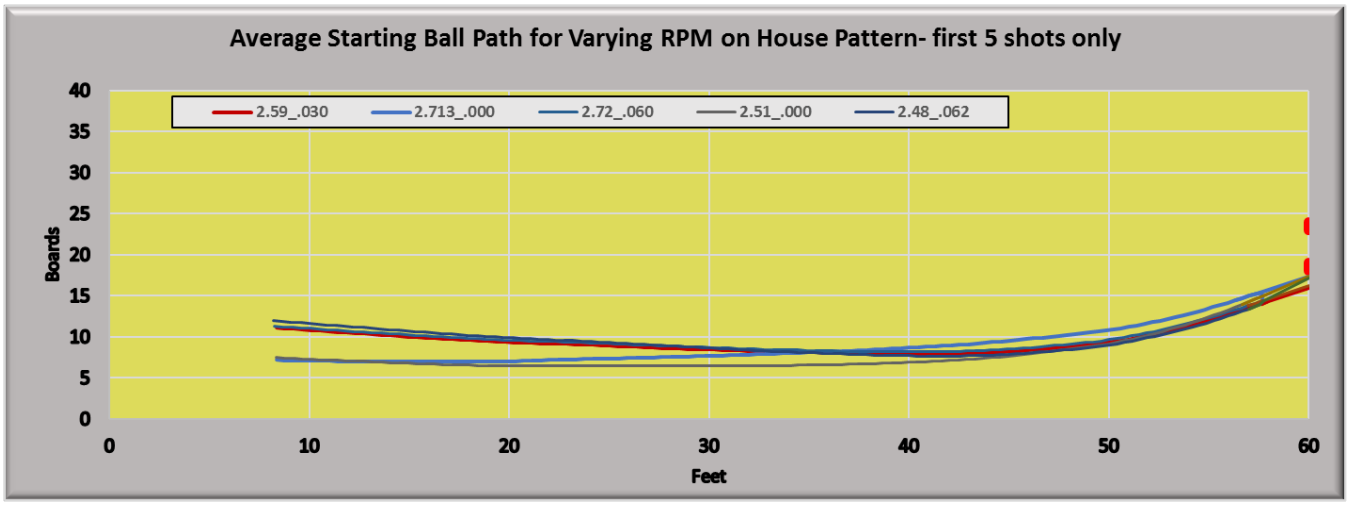
- Low RG= 2.51 (PAP value for .000 and .060 differential RG)
- Medium RG= 2.61 (PAP value for .030 differential RG)
- High RG= 2.71 (PAP value for .000 and .060 differential RG)

The total change in the RPM rate was 20 RPM for this test. Typically, a bowler can expect to see a 20 RPM difference if they were to throw a 2.51 RG ball versus a 2.71 RG ball.

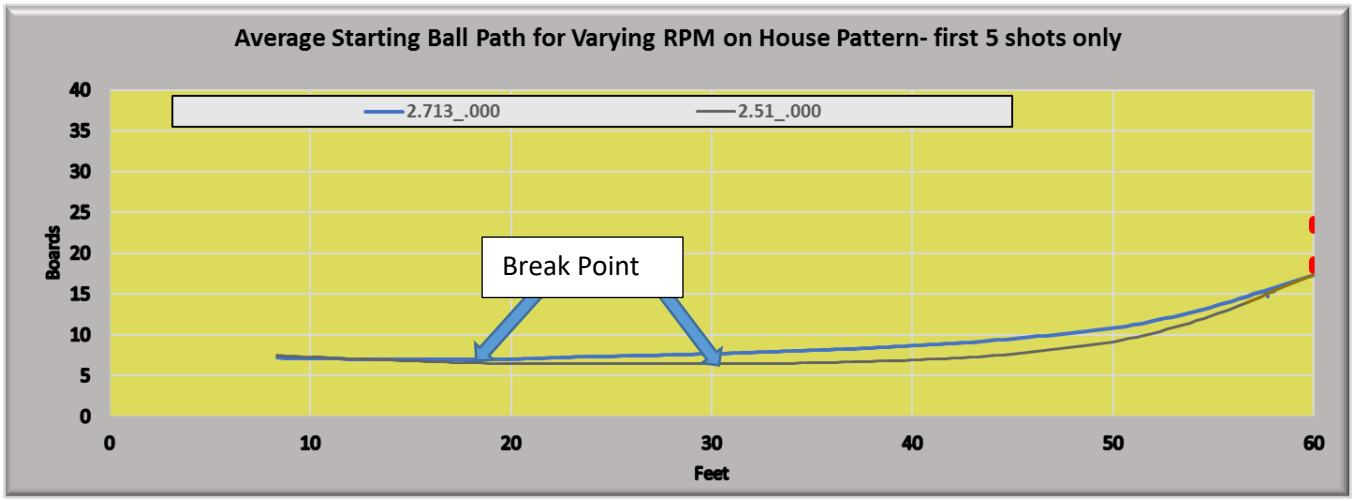
New test balls were drilled for this test in an attempt to maintain the same total weight for each test ball since the weight is one of the moment of inertia variables.

The test balls were thrown by E.A.R.L. with a similar test procedure as used in the previous test. There were two differences:

- The ball path was adjusted so that each ball began the test by hitting around the strike pocket (see chart below).
- The ball starting position was adjusted to the left after every 10 shots (was five shots) by 1.5 boards at the foul line and 1 board at the arrows. This was the same adjustment as in previous tests but moved after 10 shots and not five shots.



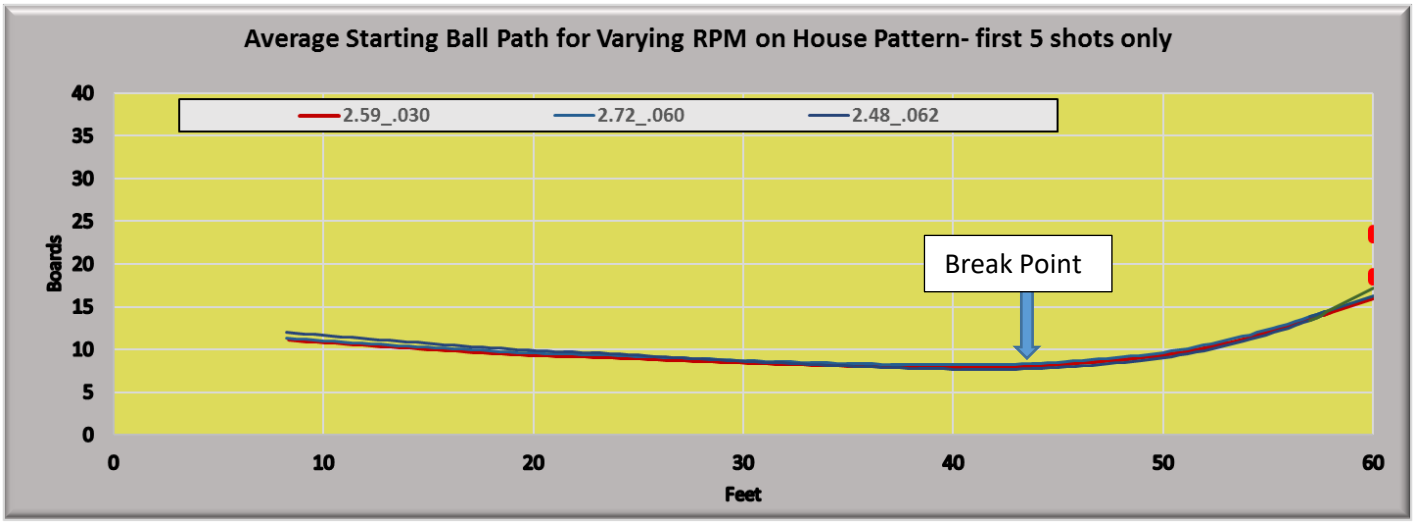

All ball paths were adjusted to hit around the 8 board at 40 feet (next to the down-lane, dark board target) and hit the pocket to start. The balls with .000 differential RG started further outside with small launch angles of -0.2 to -0.3 degree. Therefore, as soon as the direction changes by this small angle, the ball had reached its break point and the path was no longer going towards the channel. This had a large impact on the break point location.



The three test balls with the medium differential RG (.030) and high differential RG (.060) started with the following launch conditions:

- High RG, high differential RG (2.71_.060)- lay down board 13 and -0.6-degree launch angle
- Medium RG, medium differential RG (2.59_.030)- lay down board 13 and -0.7-degree launch angle
- High RG, high differential RG (2.51_.060)- lay down board 14 and -0.8-degree launch angle

The initial ball paths are charted below:




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 - varied based on MOI of ball
- Pin was positioned 3.375” from PAP
- PAP located 5” over from center of grip

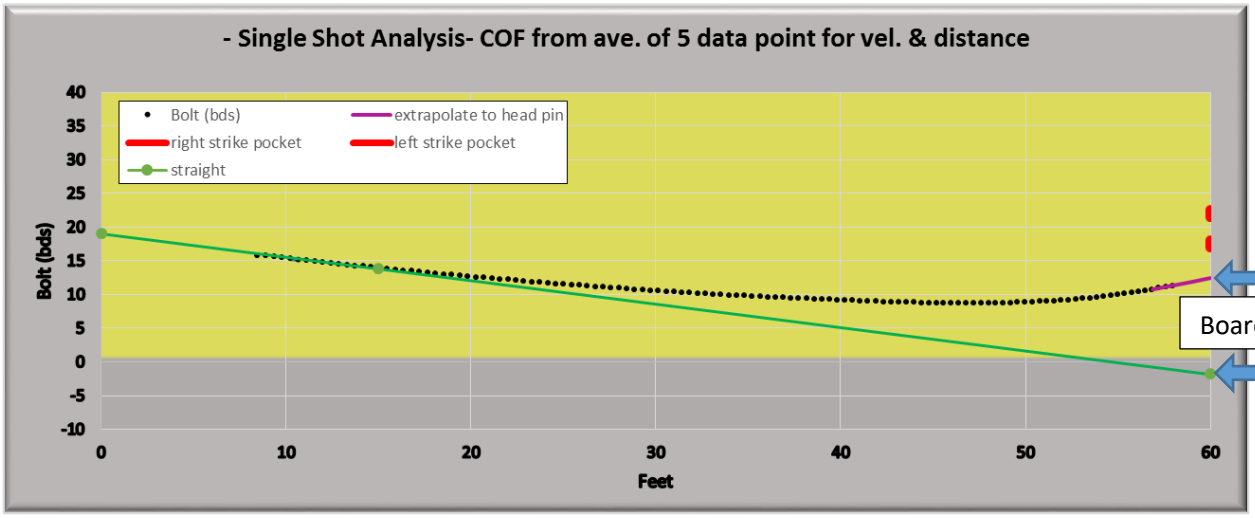
**Test results**

The following test parameters were monitored:

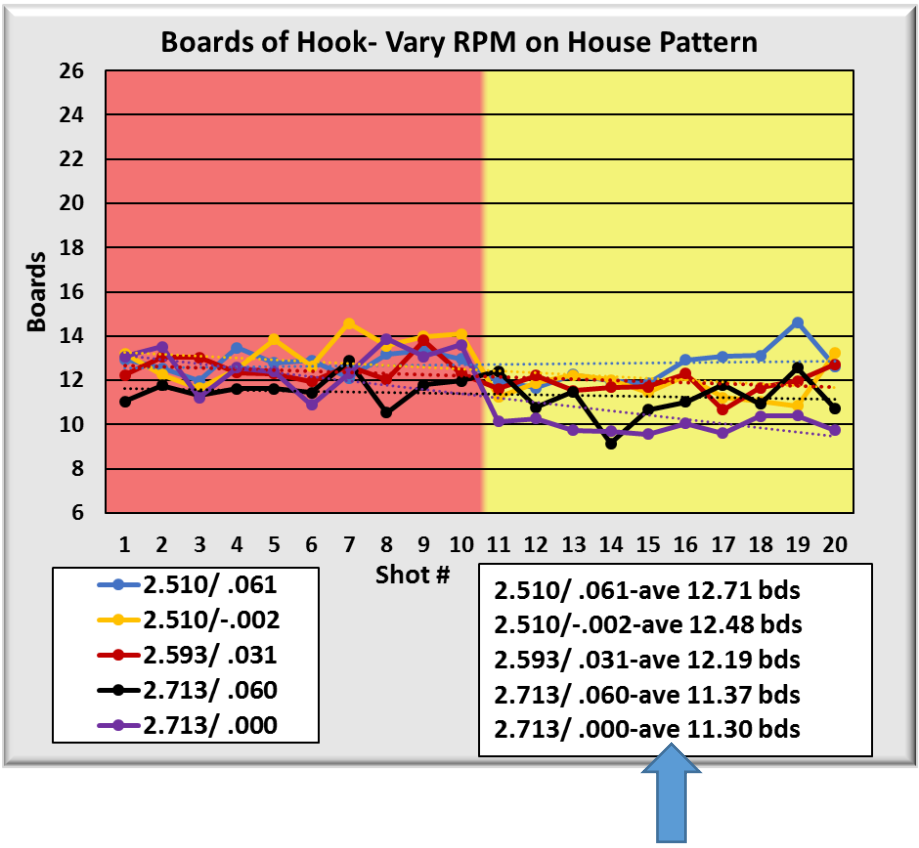
- Total hook
- Entry angle
- Break point

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.

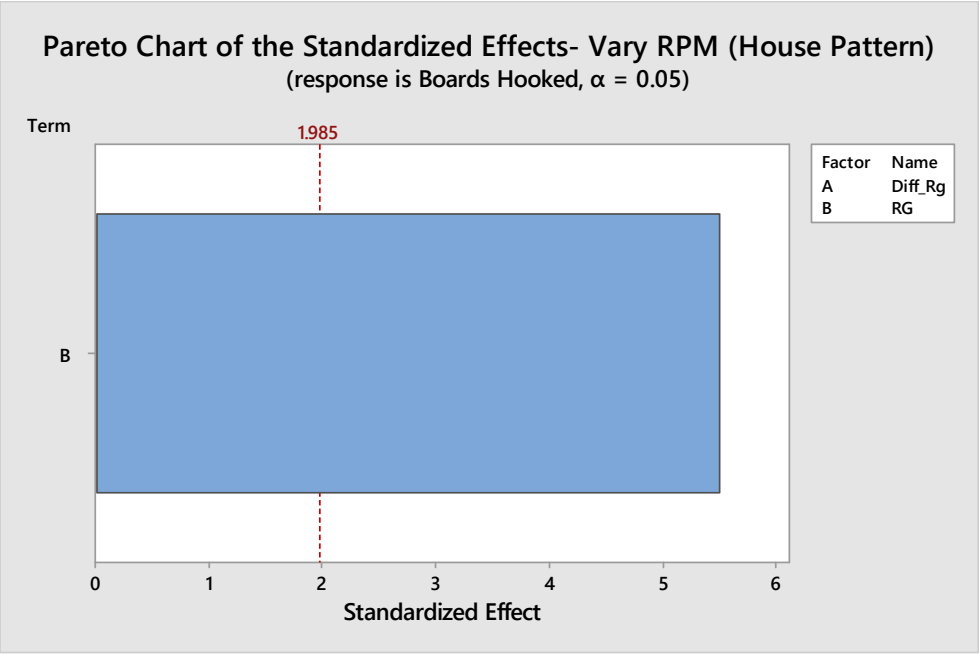



Below is a chart for the boards of hook for each shot for the various RG and differential RG settings. The colored background zones in the chart are for the 10-shot grouping before E.A.R.L. was repositioned. After moving 1.5 boards in at the foul line and 1 board at the arrows after shot 10, all balls hooked less. The big flaring balls gradually increased their boards of hook at they approached shot 20.

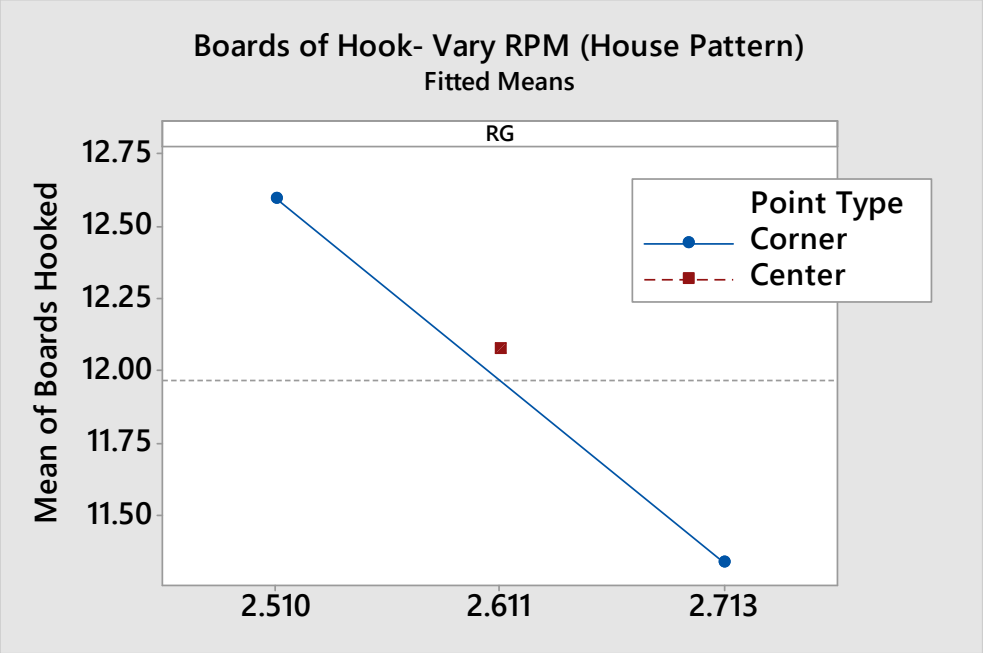



Also, in the text box on the above chart, is the average boards of hook for all 20 shots with each test ball. Remember that the low differential RG ball path started closer to the gutter in less oil which increased their boards of hook.

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

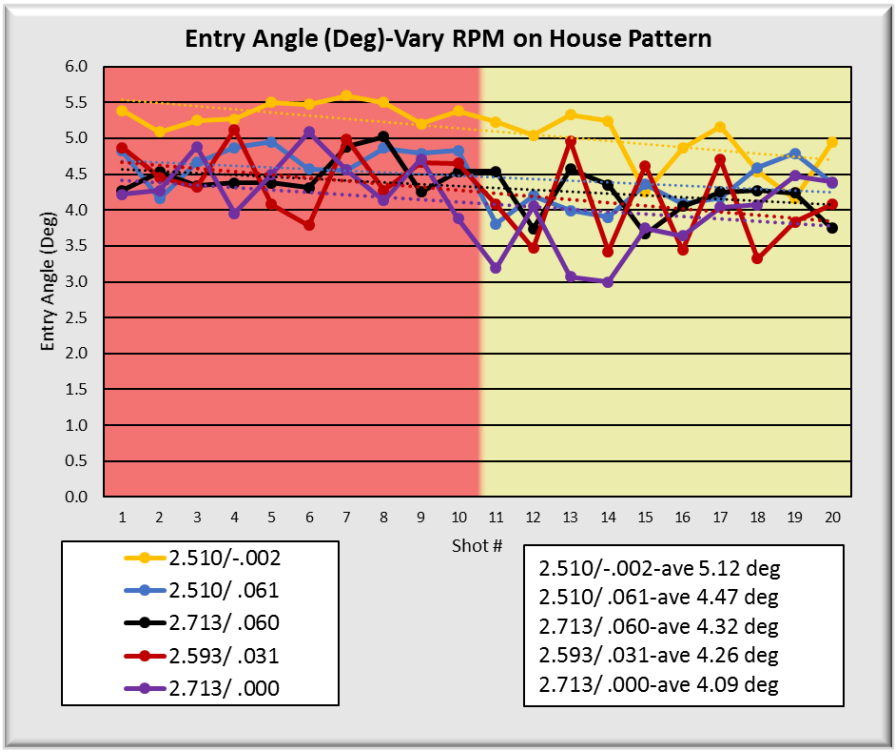



The Pareto chart above shows that only the RG affected the boards of hook.



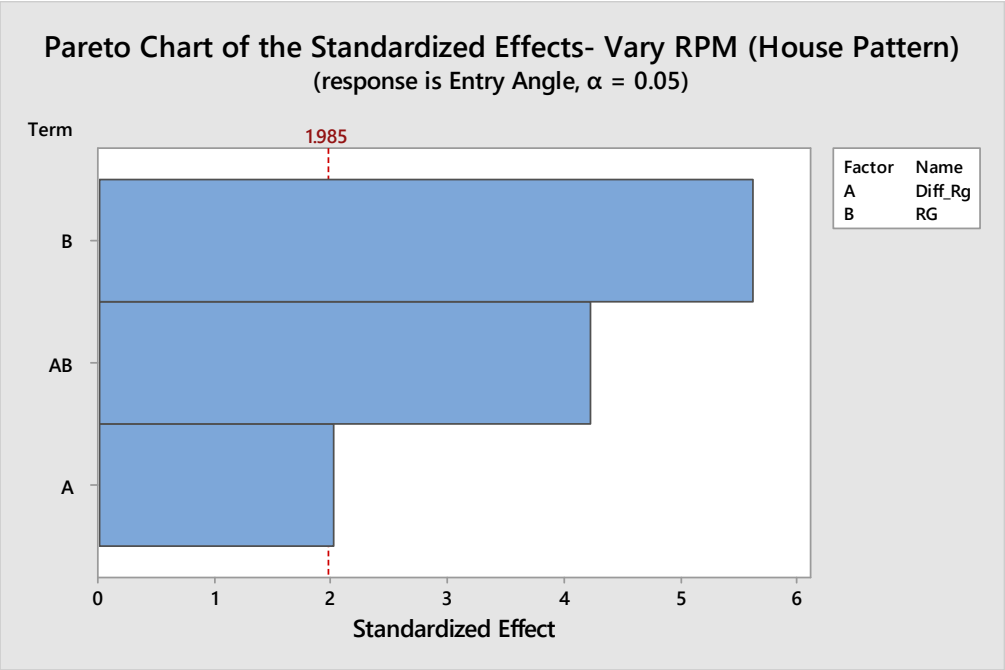

This main effect plot shows that the ball RG value directly affected the boards of hook with the medium RG being close to the center of the boards of hook. The low RG balls (2.51) hooked on average 12.59 boards and the high RG balls (2.71) hooked 11.33 boards. The medium RG ball hooked 12.07 boards.

Entry Angle:

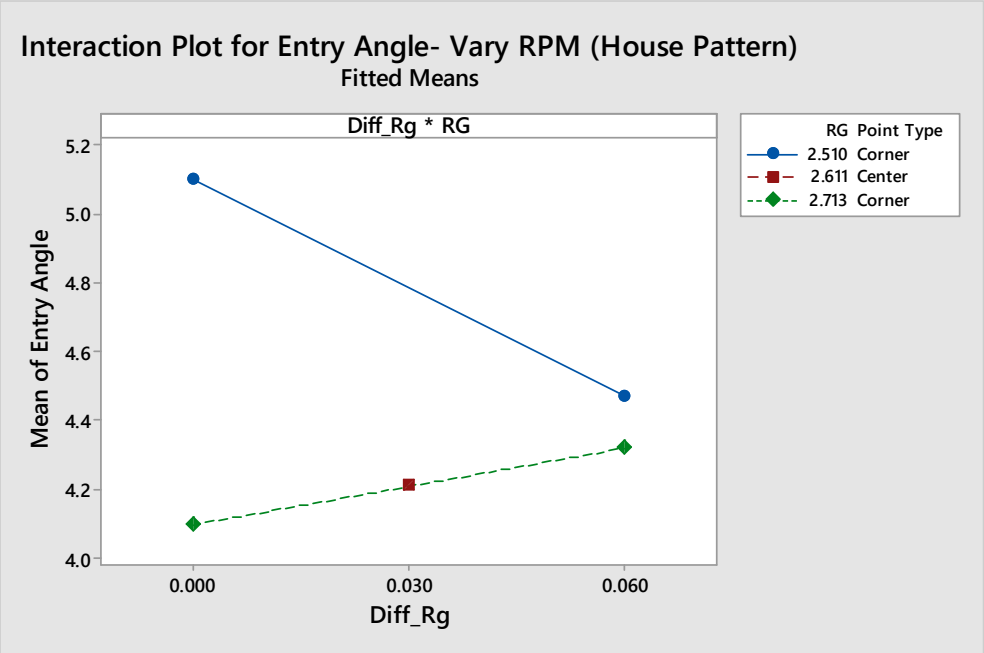



The low RG, low differential RG (2.51 / -.002) had the largest entry angle. This also is influenced by the ball path starting closer to the gutter with less launch angle. But, the high RG, low differential RG (2.71 / .000) had the same trajectory but the least entry angle.

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

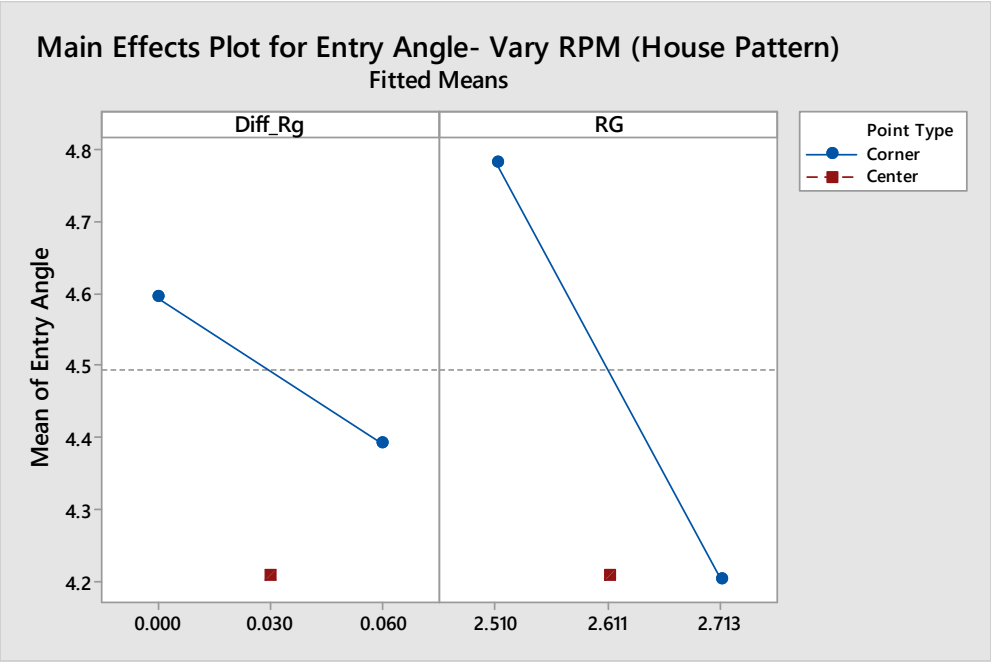



The Pareto chart above shows that the RG, differential RG and interaction between the RG and differential RG have a significant effect on the entry angle with the differential RG being the least significant (just barely above the threshold red line).

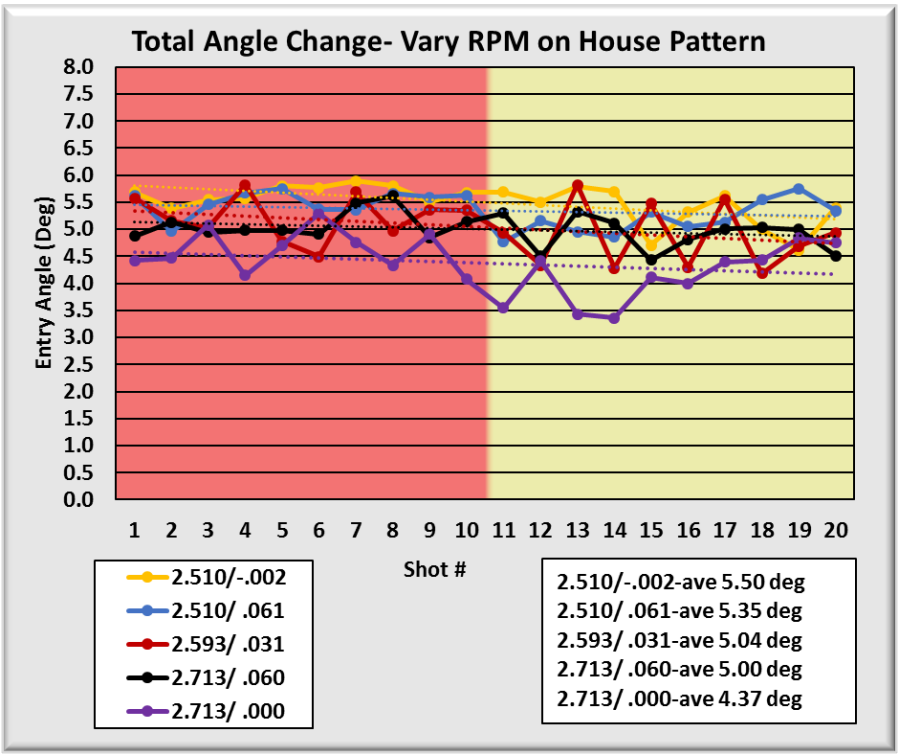



The lines in the interaction chart intersect showing that both the RG and differential RG affect the entry angle. The low RG ball (blue line) has a larger entry angle regardless of the differential RG. The

high RG ball had less entry angle regardless of the differential RG with the medium RG (2.61) in the center of the high RG line (green line). Since there is a large interaction, the main effects plot below can be ignored.



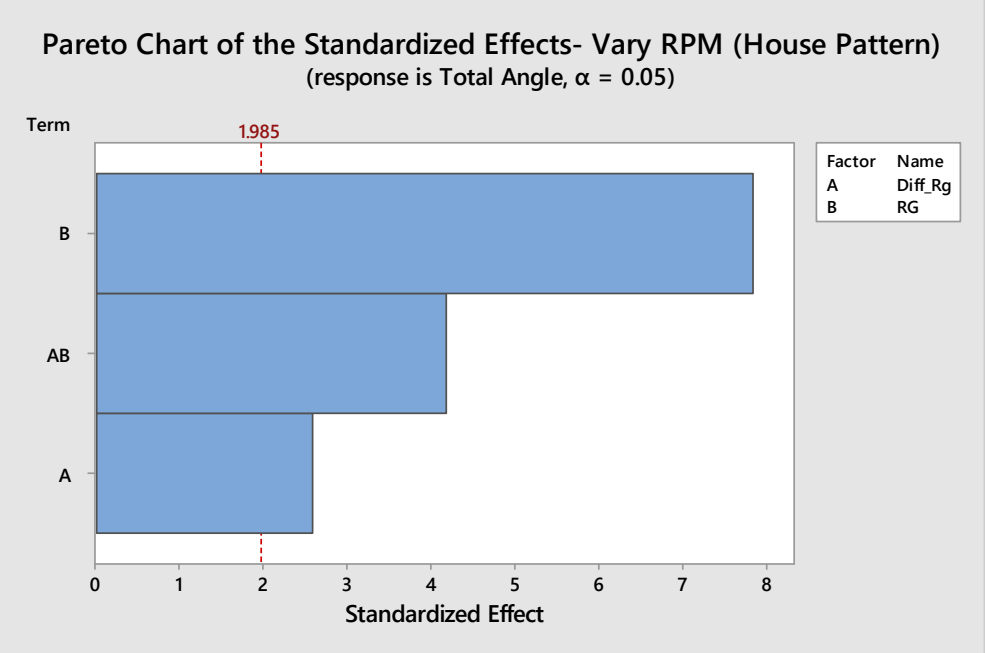

The entry angle drops off immediately after shot 10 due to the increased launch angle. Therefore, a better indicator of angle change is total angle change, which adds together the launch angle and entry angle:

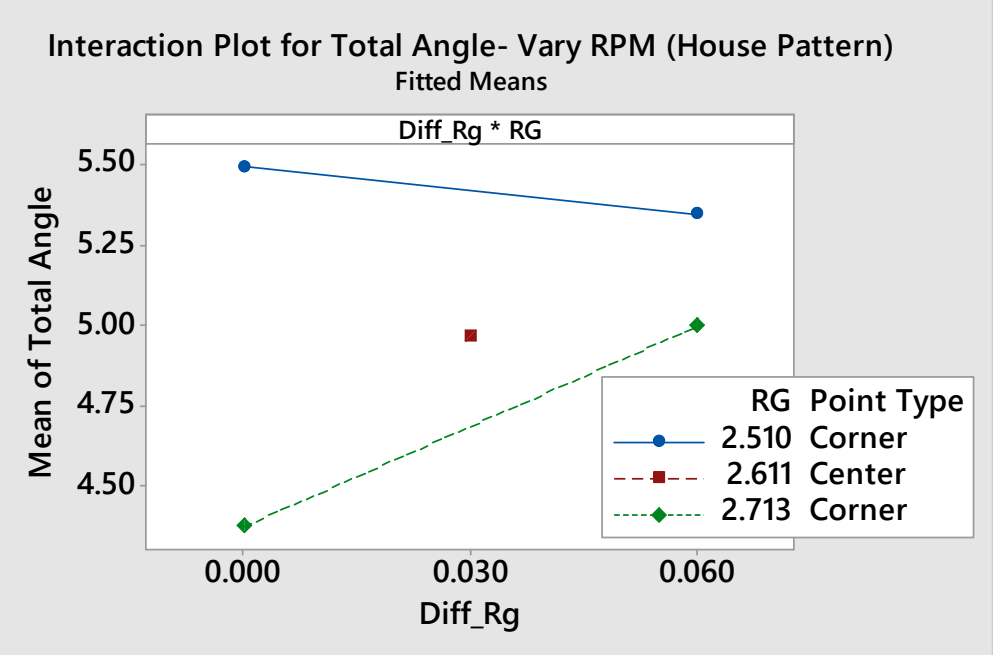


Here the results are more consistent from shot 1 to shot 20.

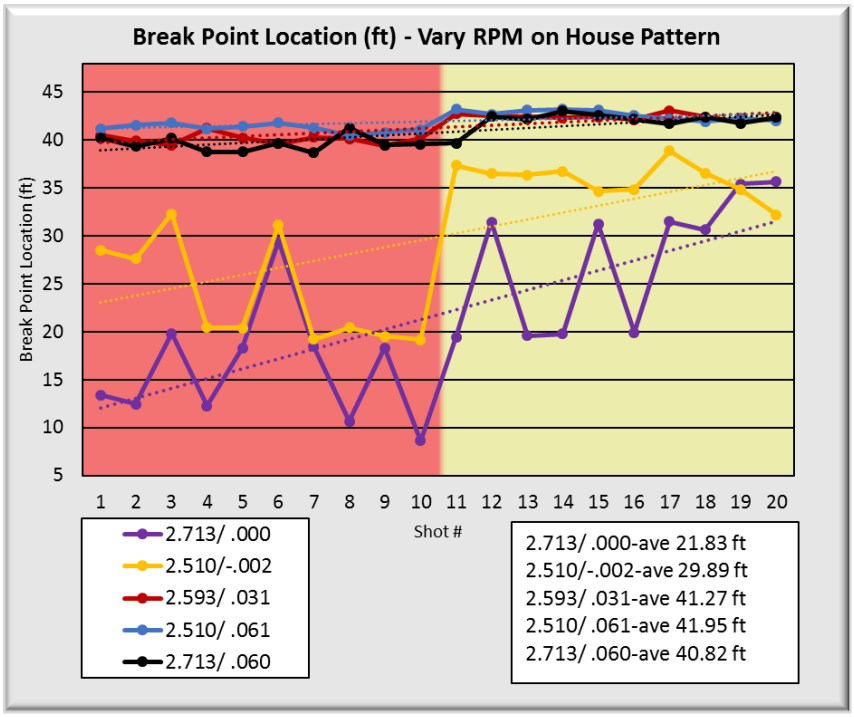
Statistical analysis generated the following Pareto chart, interaction plot and main effects plot and show the very similar conclusion as the entry angle analysis:

- Pareto shows significant influence from RG, differential RG and the interaction of both properties
- Interaction plot cross
  - Low RG ball has the most total angle regardless of differential RG
  - Medium RG has a medium amount of total angle change
  - High RG ball has less total angle regardless of differential RG
- Can ignore the main effects plot since the interaction chart shows a significant change

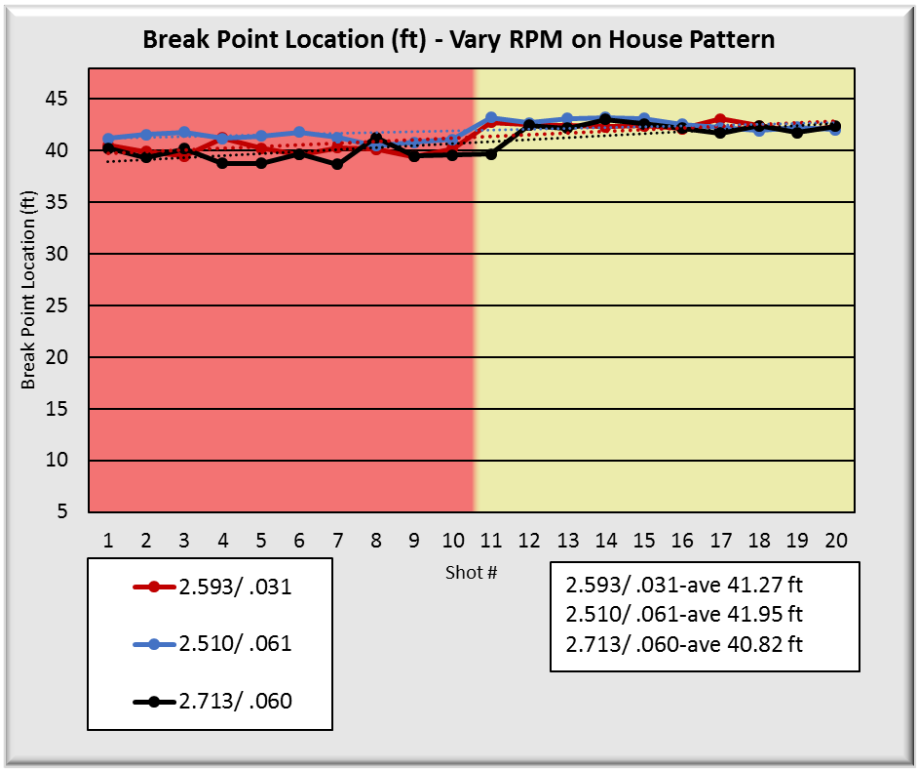


Break point location below (ball path location closest to the channel):




The break point is the location of the ball path when it is closest to the channel. All ball paths were adjusted to start the test by hitting the pocket. The low differential RG balls did not hook very much. Therefore, their launch angles were very small (-.2 and -.3 degrees). Therefore, they were almost parallel to the boards at the start of the test, resulting in a very early break point. So, the break point chart is divided into two charts below:



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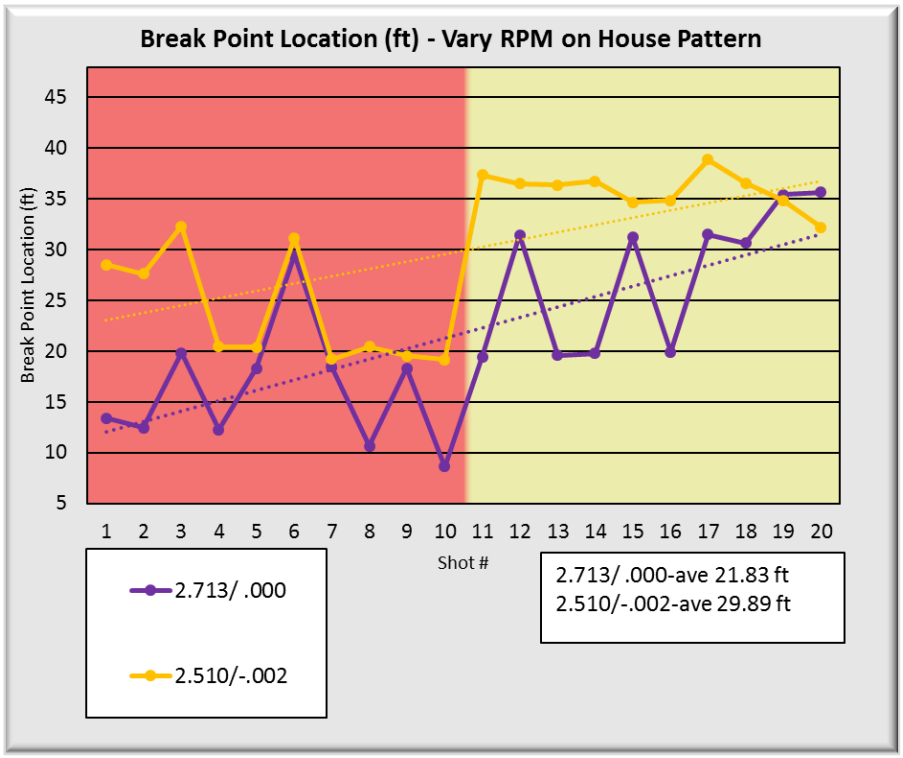
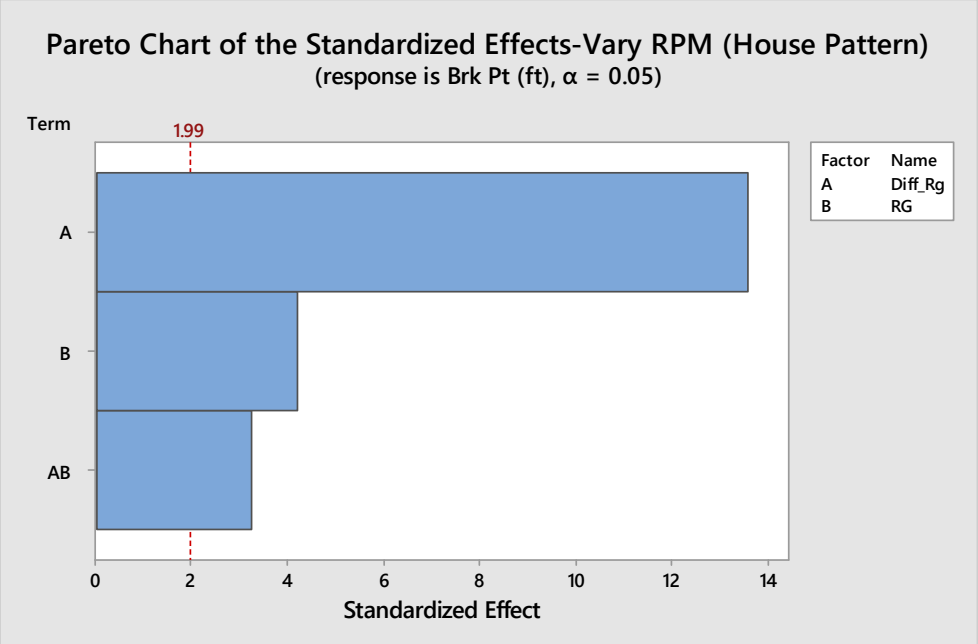
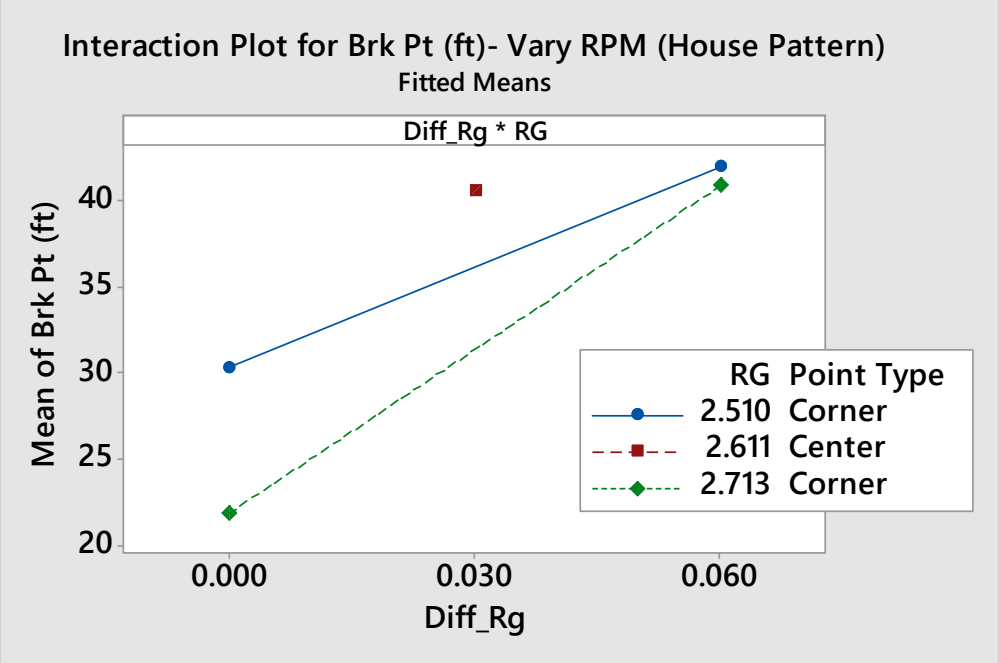
The high differential RG and medium differential RG test balls were all thrown with a similar launch angle (-0.6 to -0.8 degrees) and lay down point (13 to 14 board). Here, the high RG ball had a little sooner break point (40.82 feet), and the low RG and medium RG balls were at about the same distance (41.27 and 41.95 feet). All three break point locations were within 1.1 feet of each other and almost exactly the same distance from shot 11-20.




The above chart shows that the break point location moved much closer for the .000 differential RG balls, but this was due to small launch angles. After shot 10, the launch angle was increased, making the balls go much further down the lane before they reached their location closest to the channel.






The break point was earliest for the low differential RG balls, but this is greatly affected by its small launch angle required to hit the pocket. Plus, the low differential RG balls were thrown closer to the gutter, which had lighter oil. Therefore, these results are misleading. But, the high RG balls did have a sooner break point then the equivalent low RG balls with the same differential RG but, again, the higher RG ball was thrown with a slightly smaller launch angle:

- High RG, high differential RG had -0.6 launch angle vs. -0.8 for low RG, low differential RG
- High RG, low differential RG had -0.2 launch angle vs. -0.3 for low RG, low differential RG