

# Bowling Ball Track Flare Explained: An Analytical Study of Core Dynamics and Modern Layout Methods and Their Combined Effect on Track Flare

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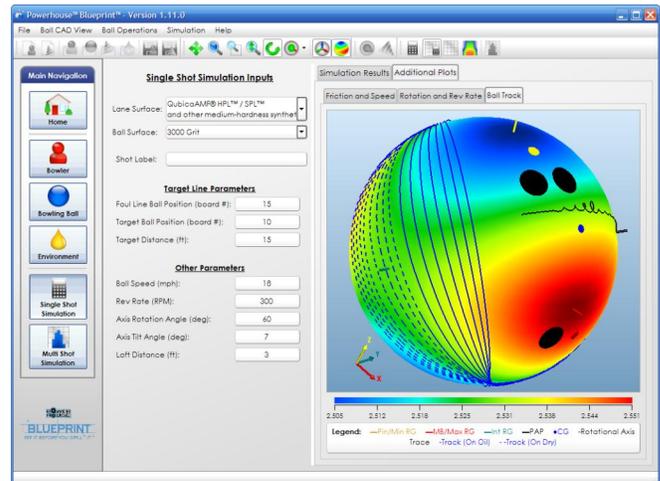
## I. INTRODUCTION

In the 20+ years since the introduction of high performance bowling ball cores, great progress has been made in understanding how ball drillers and bowlers can best take advantage of core dynamics to achieve optimal on-lane reaction. But, significant confusion remains for many bowlers and industry professionals as they try to better their understanding of how core shapes, undrilled / drilled mass properties, and modern drilling techniques combine to make the ball behave as it does on-lane.

In today's modern game, it is well established and widely agreed upon that friction is the most important factor in determining a ball's on-lane performance. The coverstock's composition and surface finish play the largest roles in determining the amount of friction the ball experiences during its trip down a given lane dressed with a given oil pattern. However, on-lane friction levels can also be influenced by core dynamics, thanks to track flare (also known as axis of rotation migration). Different amounts of track flare can cause different amounts of fresh ball surface to contact the lane on each revolution, which can result in significant change in the friction level between the ball and the lane. In fact, for most modern reactive resin balls, the total hook difference between balls drilled with minimum flare and maximum flare can be on the order of five to 10 boards, making track flare management a critical aspect of effective modern ball drilling.

**Track flare and better explaining the factors that impact track flare are the sole topics of this paper.** This will be done by examining a wide variety of drilling configurations in three different real-world bowling balls using the **Powerhouse™ Blueprint™** software package for virtual ball drilling and on-lane motion simulation.

Powerhouse Blueprint combines advanced CAD modeling capabilities with a physics-based rigid-body motion equation solver that simulates the on-lane motion of a drilled ball. Blueprint's modeling and simulation algorithms have been tested and verified thoroughly using C.A.T.S.®-instrumented lanes, Digitrax™ analysis, and high-speed video analysis. A Blueprint simulation provides a very accurate prediction of what happens to the ball in the real world. This makes it a



**Figure 1. Powerhouse Blueprint software screenshot, showing a drilled ball with predicted track flare.**

highly valuable tool for a study such as this. Without physically putting a single hole into a bowling ball, Blueprint allows us to rapidly explore the critical factors that impact track flare, providing valuable new insights into the ball selection and ball drilling process.

## A. ANALYSIS OVERVIEW

Modern asymmetrical bowling balls generally require three parameters to describe the orientation of the core relative to the grip center and positive axis point (PAP). While numerous layout systems are currently popular among bowlers and pro shop professionals, this paper will describe layouts using the parameters of the Dual Angle Layout Technique™. In Dual Angle Layout nomenclature, the parameters used to describe the core's orientation are:

- **Pin-to-PAP distance:** The distance along the ball's surface between the pin and the bowler's PAP, measured in inches.
- **Drilling angle:** The angle between the mass bias / pin line and the pin / PAP line, measured in degrees (note that "mass bias", "PSA", and "high RG axis" are interchangeable terms having equivalent meaning; also, for symmetrical balls, the convention is to substitute the center of gravity for the mass bias when specifying drillings in Dual Angle Layout form).
- **VAL angle:** The angle between the vertical axis line (VAL) and the pin / PAP line, measured in degrees.

Three separate ball drilling studies are summarized in this paper. Each study aims to explore the role of one of the three above parameters by drilling and simulating the on-lane track flare of various layouts. In each study, we will repeat the exact same set of layouts on three different real-world bowling balls (detailed below). The three drilling studies are as follows:

- **Study #1:** Explores the impact of pin-to-PAP distance. We will drill all three bowling balls with five different pin-to-PAP distances using two different mass bias angles, for a total of 10 different drillings for each ball.
- **Study #2:** Explores the impact of VAL angle. Here, we will drill all three bowling balls using five different VAL angles using two different pin-to-PAP distances, for a total of 10 drillings for each ball.
- **Study #3:** Explores the impact of the drilling angle. Again, we will drill all three bowling balls with five different drilling angles using two different VAL angles, for a total of 10 drillings for each ball.

In total, this paper utilizes the simulated on-lane track flare of 90 drilled bowling balls.

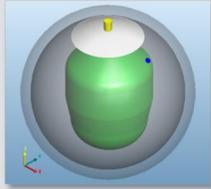
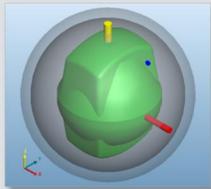
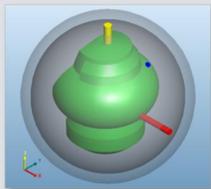
### B. INPUT DATA SUMMARY

The bowling balls used in this study are the Columbia 300® Omen™, Track® 508A™, and Track® 919C™. Respectively, the cores in these balls represent a symmetrical, a mild asymmetrical, and a strong asymmetrical, all with relatively high total differentials. The reason for selecting three balls with a wide range of intermediate differentials is to draw specific attention to the differences that exist in drilling strategies and on-lane behavior for bowling balls with different levels of undrilled asymmetry. The core shape and mass properties of these three bowling balls are summarized in figure 2.

All of the simulations performed in this study use the same right-handed bowler, with the following style:

- **Ball speed (at release):** 18 mph
- **Rev rate (at release):** 300 RPM
- **Axis rotation angle (at release):** 60 degrees
- **Axis tilt angle (at release):** 20 degrees
- **Loff distance:** 3 feet
- **PAP (at release):** 5 inches over x ½ inch up

The intent of using these bowler parameters is to utilize a typical "tweener" style. With these delivery specifications, this bowler is relatively matched with respect to ball speed and rev rate, with fairly typical release rotation angles (axis rotation and axis tilt) and PAP coordinates.

Bowling Ball	Core Geometry	Mass Properties
Columbia 300 Omen		Low RG (in): 2.47 Total Diff. (in): 0.054 <b>Int. Diff. (in): 0.000</b>
Track 508A		Low RG (in): 2.52 Total Diff. (in): 0.049 <b>Int. Diff. (in): 0.007</b>
Track 919C		Low RG (in): 2.53 Total Diff. (in): 0.050 <b>Int. Diff. (in): 0.019</b>

**Figure 2. Bowling ball core geometry and undrilled mass properties summary.**

In addition to using the same bowler for all simulations, we have also used the same lane surface and oil pattern throughout. The lane surface used is that of a high-hardness synthetic, such as Brunswick® Pro Lane™. The oil pattern used is the PBA® Scorpion pattern®, with an oiled length of 41 feet.

### C. AN EXAMPLE: CALCULATING THE ON-LANE TRACK FLARE FOR ONE SIMULATED DRILLING

To provide some background on the process that is used to calculate the results shown in this paper, we will start with an example, walking through the entire simulation process for one drilled bowling ball. For this example, we will drill and simulate the track flare of the Track 919C with a 60 x 4 x 30 drilling (note that in this standard layout nomenclature, the first number represents the drilling angle, the second number represents the pin-to-PAP distance, and the third number represents the VAL angle; we will use this standard format for the remainder of the paper).

To start, we must first virtually drill the ball using Blueprint. After all of the required input data is supplied, this is accomplished with the click of a button. The result of the drilling operation is shown in figure 3. In this image, the thick yellow line/cylinder represents the location of the pin (nominally, the undrilled low RG axis) and the thick red line/cylinder represents the location of the mass bias marker (nominally, the undrilled high RG axis). Also shown are a thinner yellow line/cylinder and a thinner red line/cylinder. These represent the locations

of the as-drilled low and high RG axes, respectively. For this drilling, it can be seen that the low RG axis has shifted a large amount from its nominal location, as indicated by the separation of the two yellow cylinders.

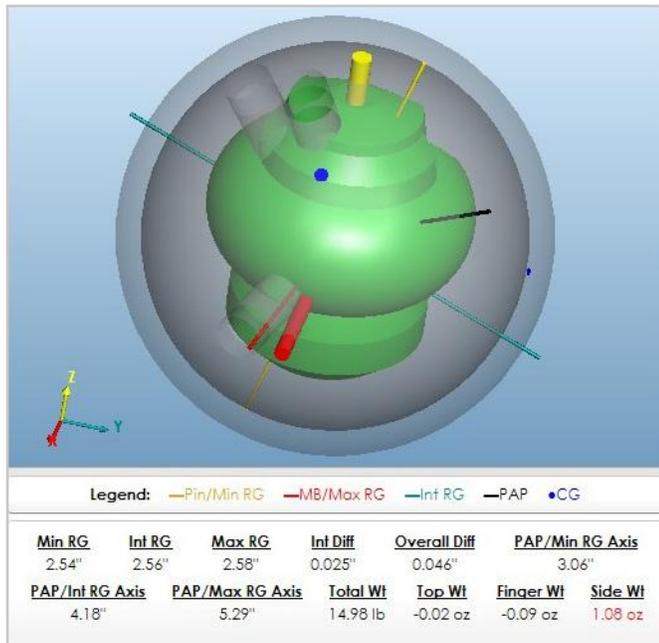


Figure 3. Example of a drilled bowling ball in Blueprint.

With the ball drilled, we now simulate its motion in Blueprint so that we can examine its track flare. Again, after all inputs have been supplied, this is accomplished with one click. A resulting flare plot is shown in figure 4. Note here that the solid blue line is the ball track in the oiled portion of the lane, the dotted blue line is the ball track in the non-oiled backend portion of the lane, and the solid black line is a trace of the ball's axis of rotation.

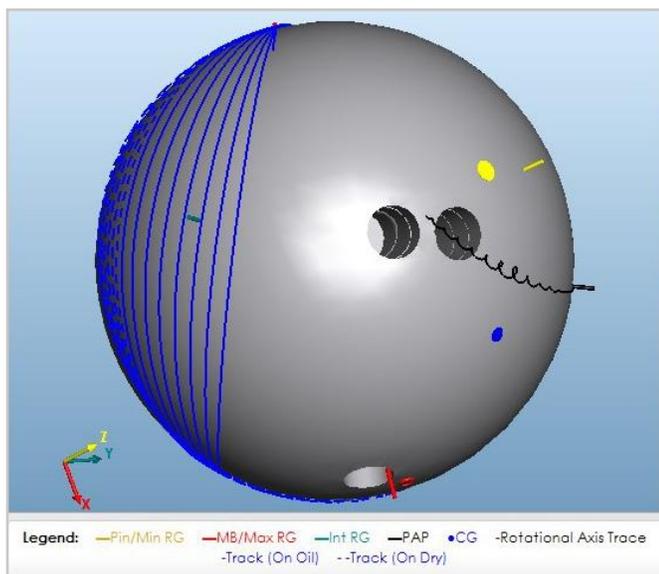


Figure 4. Example of predicted track flare in Blueprint.

The ball's track flare distance can then be determined by measuring the distance along the ball surface that the axis of rotation has migrated. This is functionally equivalent to measuring flare ring separation, but is slightly more accurate (this method is only really feasible in a virtual simulated environment like Blueprint). For each drilling in this study, track flare in the oil and track flare in the dry are both measured, with the total flare being the sum of the two. In this example, the ball flared 3.3 inches in the oiled portion of the lane and 2.5 inches in the dry backend portion of the lane, for a total track flare distance of 5.8 inches.

## II. STUDY #1: THE IMPACT OF PIN-TO-PAP DISTANCE ON TRACK FLARE

Here, we will drill all three balls with five different pin-to-PAP distances while holding the other two drilling parameters (VAL angle and drilling angle) constant. We will repeat this for two different drilling angles. This results in a total of six "mini-studies", each one containing flare results for five different pin-to-PAP distances. One such mini-study's results are shown below in figure 5. This plot is for the Columbia 300 Omen drilled with a 30 degree VAL angle and a 50 degree drilling angle:

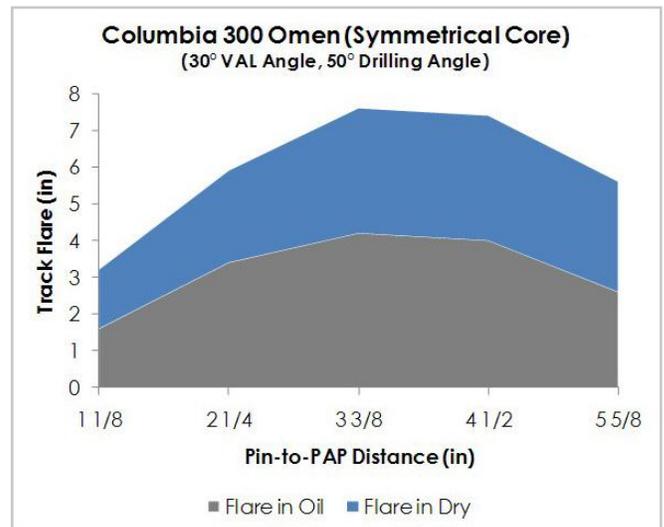


Figure 5. Columbia 300 Omen - track flare vs. pin distance (50 x pin-to-PAP distance x 30).

Not surprisingly, the graph reveals that flare is at its maximum at pin distances of around 3 to 4 inches, with reduced flare for distances both smaller and larger. This is behavior that is traditionally expected by today's bowlers and ball drillers for symmetrical bowling balls and is generally consistent with the long-held belief that flare is maximized by using "leverage" drillings with pin-to-PAP distances of 3 3/8 inches. Repeating the above process five additional times (two different drilling angles for each of the three balls) results in the graphic shown in figure 6.

## The Effect of Pin-to-PAP Distance on Track Flare

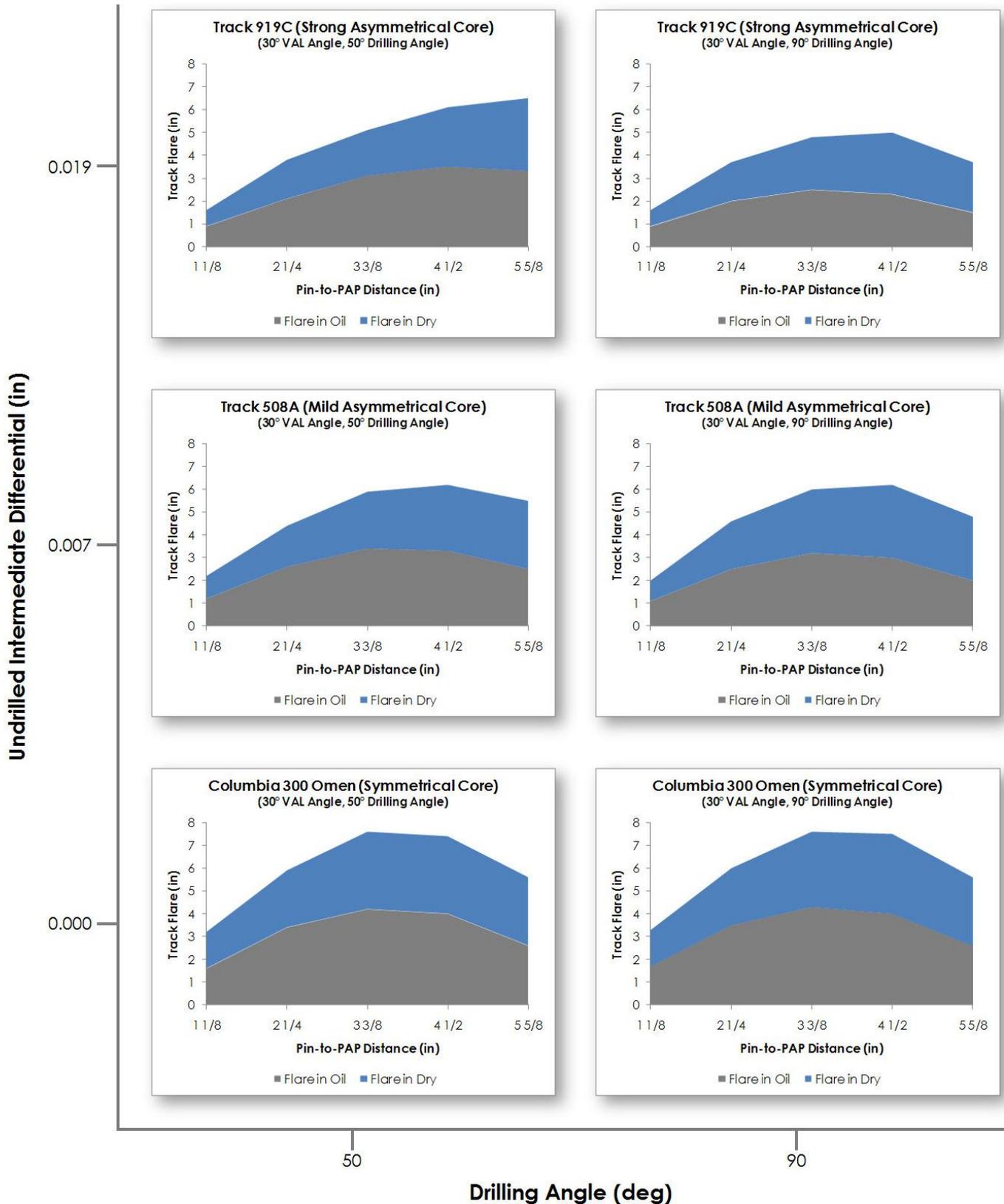


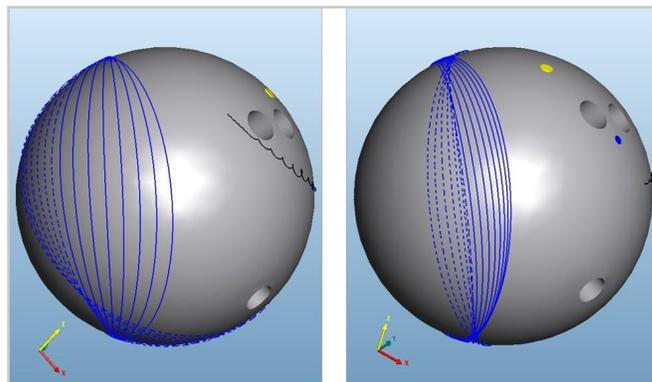
Figure 6. Plot showing effect of pin-to-PAP distance for three different bowling balls, using two different drilling angles.

Upon detailed inspection of figure 6, it can be seen that there are a number of really interesting things revealed, including the following:

- Let's start with the left-most column. These drillings utilized a strong mass bias position (drilling angle) of 50 degrees. Working from bottom to top (which is in order of increasing undrilled asymmetry), we can see a definite shift in the general shape of each graph's curve. Starting at the bottom, the symmetrical ball has a drop in total track flare for longer pin-to-PAP distances. Working up the left column, we see the same behavior with the mild asymmetrical ball, but to a much lesser extent. Finally, the strong asymmetrical actually has the most flare with the longest pin-to-PAP distance of 5 5/8 inches. This shows that **asymmetrical balls can exhibit large amounts of track flare even with long pin-to-PAP distances. This is a critical difference between symmetrical balls and asymmetrical balls.**
- Now, let's examine the right-most column. Here, the three balls are drilled using the same pin distances and VAL angle, but with a much weaker drilling angle of 90 degrees. What we see here is that all three balls essentially behave the same as the symmetrical ball from above. The reason for this is that **the large 90 degree drilling angle places the high RG axis in such a weak position for the longer pin-to-PAP drillings that its impact is significantly minimized, making all three graphs look just like the symmetrical from the left column.**
- Looking at the plots from left-to-right in pairs, we can see how the drilling angle impacts the track flare for each ball. Not surprisingly, drilling angle has the strongest impact on the Track 919C, the ball with the strongest mass bias of the three. This leads to another interesting conclusion: **Asymmetrical balls can, in general, provide a ball driller with more reaction options than symmetrical balls. Symmetrical balls have only two ball motion "tuning parameters": pin-to-PAP distance and VAL angle. Asymmetrical balls add a third in the drilling angle (which essentially has no impact in symmetricals).**

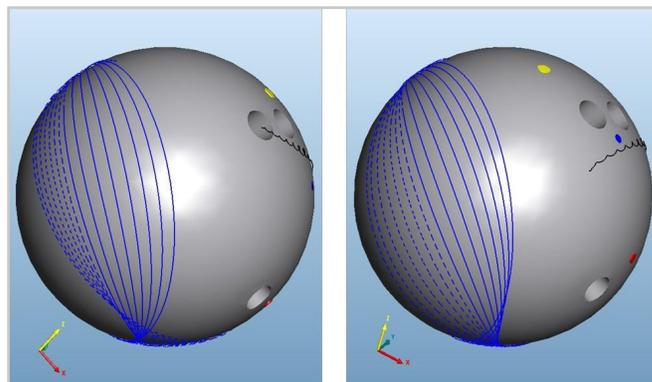
While the above observations provide numerous useful insights, we will now elaborate on one specific example that clearly and graphically illustrates one way in which asymmetrical balls differ from symmetrical balls.

Consider the situation of comparing two otherwise identical layouts with different pin-to-PAP distances in both an asymmetrical ball (in this case, the Track 919C) and a symmetrical ball (the Columbia 300 Omen). We will start with the symmetrical ball. Figure 7 shows an image of this ball drilled with two layouts that differ only with respect to pin-to-PAP distance. The two pin distances used are 4 inches and 6 1/4 inches, with a drilling angle of 50 degrees and a VAL angle of 30 degrees for both cases.



**Figure 7. Columbia 300 Omen (symmetrical) with a 50 x 4 x 30 layout (left) and a 50 x 6 1/4 x 30 layout (right).**

Note that for this ball, the longer pin-to-PAP distance layout (on the right above) results in significantly less flare than the shorter pin-to-PAP distance drilling. Now, we'll repeat the same two layouts with the strongly-asymmetrical Track 919C, as shown in figure 8.



**Figure 8. Track 919C (strong asymmetrical) with a 50 x 4 x 30 layout (left) and 50 x 6 1/4 x 30 layout (right).**

Here, we see the opposite result: the ball actually flares more with the longer 6 1/4 inches pin-to-PAP distance layout than it does with the shorter 4 inches pin-to-PAP distance layout! This illustrates a very important difference between symmetrical and asymmetrical balls that becomes extremely important when using long pin-to-PAP distance layouts.

### III. STUDY #2: THE IMPACT OF VAL ANGLE ON TRACK FLARE

We will next explore the VAL angle's impact on track flare using an approach similar to that which was used above. This time, each mini-study will simulate the on-lane track flare of five different VAL angle layouts while holding the other two drilling parameters constant. We will repeat this for all three balls for two different pin-to-PAP distances, again resulting in a total of six mini-studies plotted on a two-dimensional grid. The results are shown in figure 9.

## The Effect of VAL Angle on Track Flare

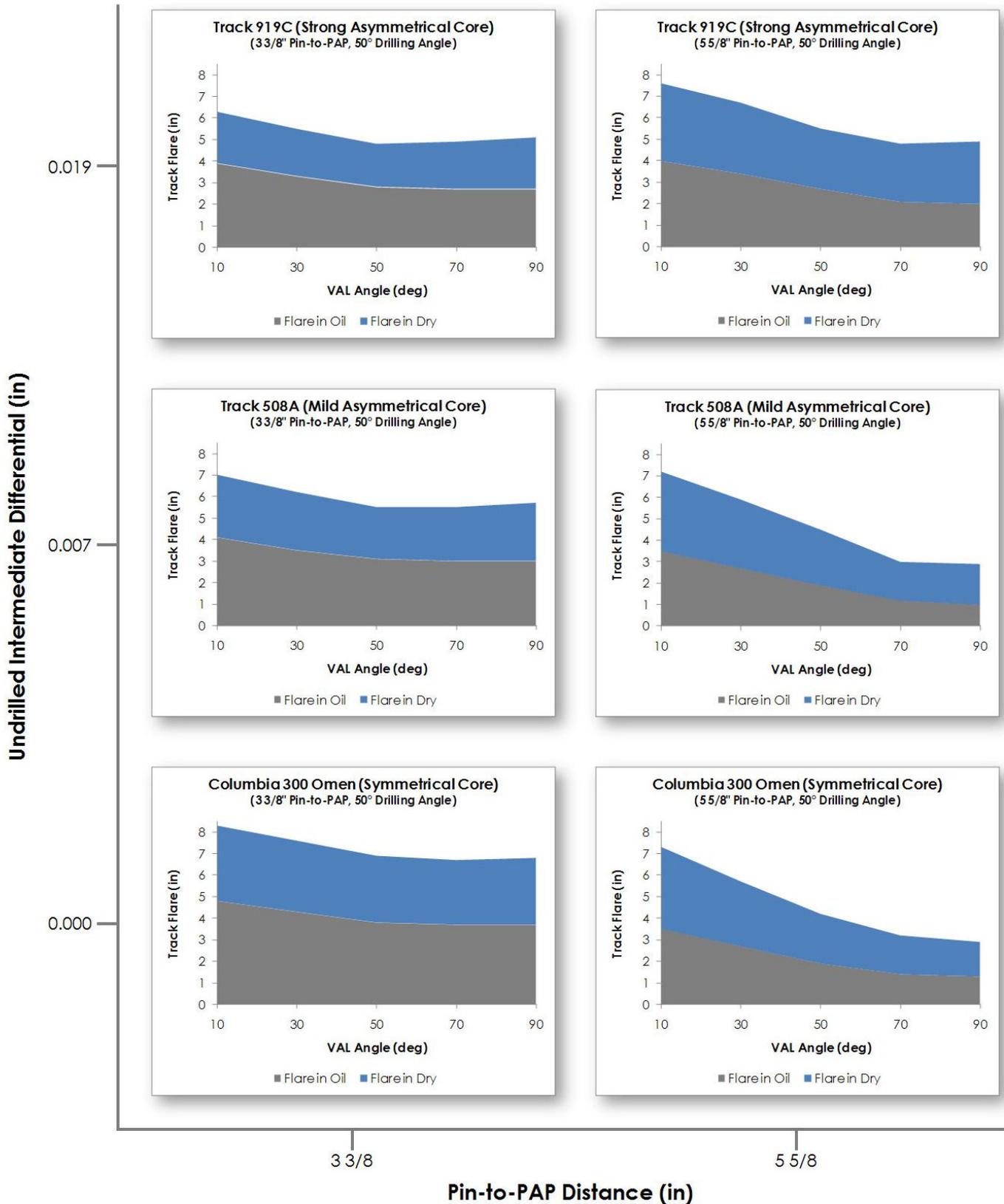
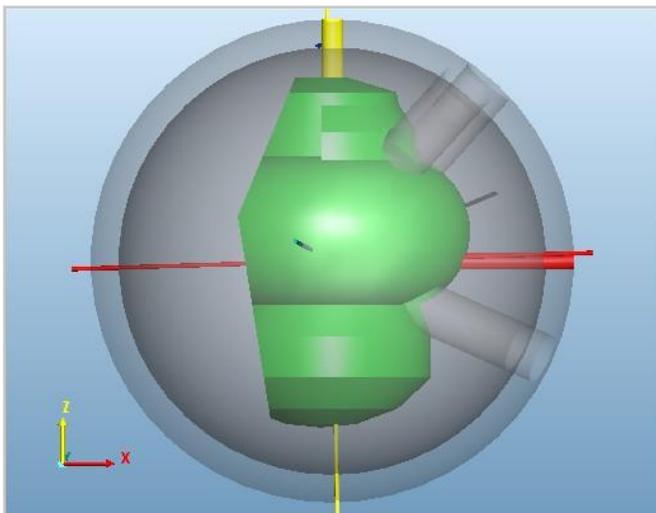


Figure 9. Plot showing effect of VAL angle for three different bowling balls, using two different drilling angles.

Once again, there are many interesting things revealed by the results of this study:

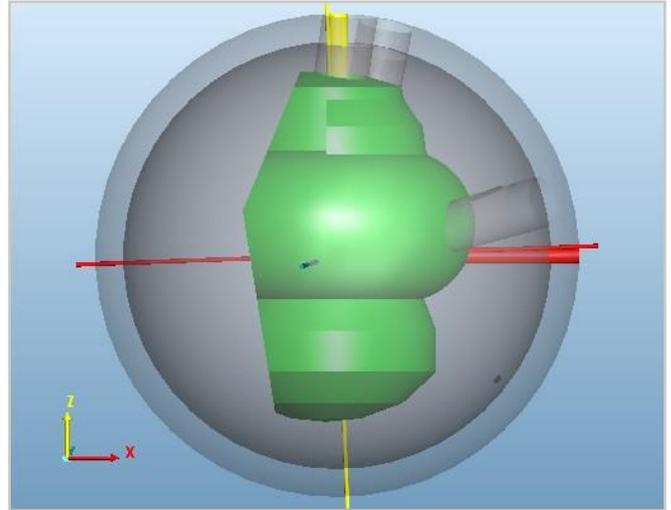
- Let's start by taking a look at any of the six mini-studies and examining what happens, in general, when VAL angle changes. As each plot clearly shows, **the greatest amount of track flare is achieved with low VAL angles, with lesser amounts of track flare for medium and high VAL angles.**
- Next, we'll compare the left column (with the 3 5/8 inches pin distance) to the right column (with the 5 5/8 inches pin distance) to better understand how the pin-to-PAP distance impacts the influence of VAL angle. **VAL angle has a larger impact on flare for the layouts using the longer pin distance of 5 5/8 inches.** The main reason for this is that this longer pin distance places the core in such a position that the gripping holes "reshape" the core and lower its differentials to a greater extent than the layouts using the shorter pin distance.
- Looking at the plots from top to bottom, we see that all three of the balls respond similarly to changes in VAL angle. That is, **the general impact of VAL angle is the same regardless of the ball's undrilled intermediate differential.**
- **The impact of VAL angle on track flare is highly non-linear.** In each of the six mini-studies, the greatest flare reduction occurs when increasing the VAL angle from 10 degrees to about 50 to 60 degrees and then the flare reduction essentially goes to zero when VAL angle is increased further.

Why do large VAL angles reduce flare and small VAL angles increase flare? The answer, which was hinted at above, is that different VAL angles cause the core to be reshaped in different ways. We'll demonstrate with a simple example. First consider the ball below, which is a Track 919C drilled using a 50 x 5 5/8 x 10 layout.



**Figure 10. Track 919C with 50 x 5 5/8 x 10 layout. Note that all three gripping holes remove material from the side of the core, causing the differential to increase.**

With this drilling, we see that all three of the gripping holes remove material from the "side" of the core. The effect of this is that the overall shape of the core is altered so that it is less spherical (taller relative to its width and height). This reshaping causes an increase in total differential. Now, we will examine a pin-down layout with drilling parameters of 50 x 5 5/8 x 50:



**Figure 11. Track 919C with 50 x 5 5/8 x 50 layout. Note that the finger holes remove material from the top of the core, causing the differential to decrease.**

In this case, the finger holes hit the core directly on top (through the pin, in fact). This, in effect, causes the overall shape of the core to be altered such that it is more spherical (not as tall relative to its width and height), which causes the total differential to drop.

These two examples can also help us understand why the flare reduction of increasing the VAL angle is non-linear. For this particular bowler (with his PAP and spans), additional increases in VAL angle beyond 50 degrees moves the finger holes off the top of the ball while moving the thumb closer to the top. These changes in finger and thumb position essentially cancel each other out, causing the as-drilled total differential to be relatively constant for VAL angles from 50 to 90 degrees.

#### **IV. STUDY #3: THE IMPACT OF DRILLING ANGLE ON TRACK FLARE**

Finally, we will now examine the impact of drilling angle on track flare. Again, following the same general format that was used above in Studies #1 and #2, we will simulate track flare of five different drilling angles while holding the other two drilling parameters constant. We will repeat this for all three balls for two different VAL angles, again resulting in a total of six mini-studies plotted on a two-dimensional grid. The results of this are shown in figure 12.

## The Effect of Drilling Angle on Track Flare

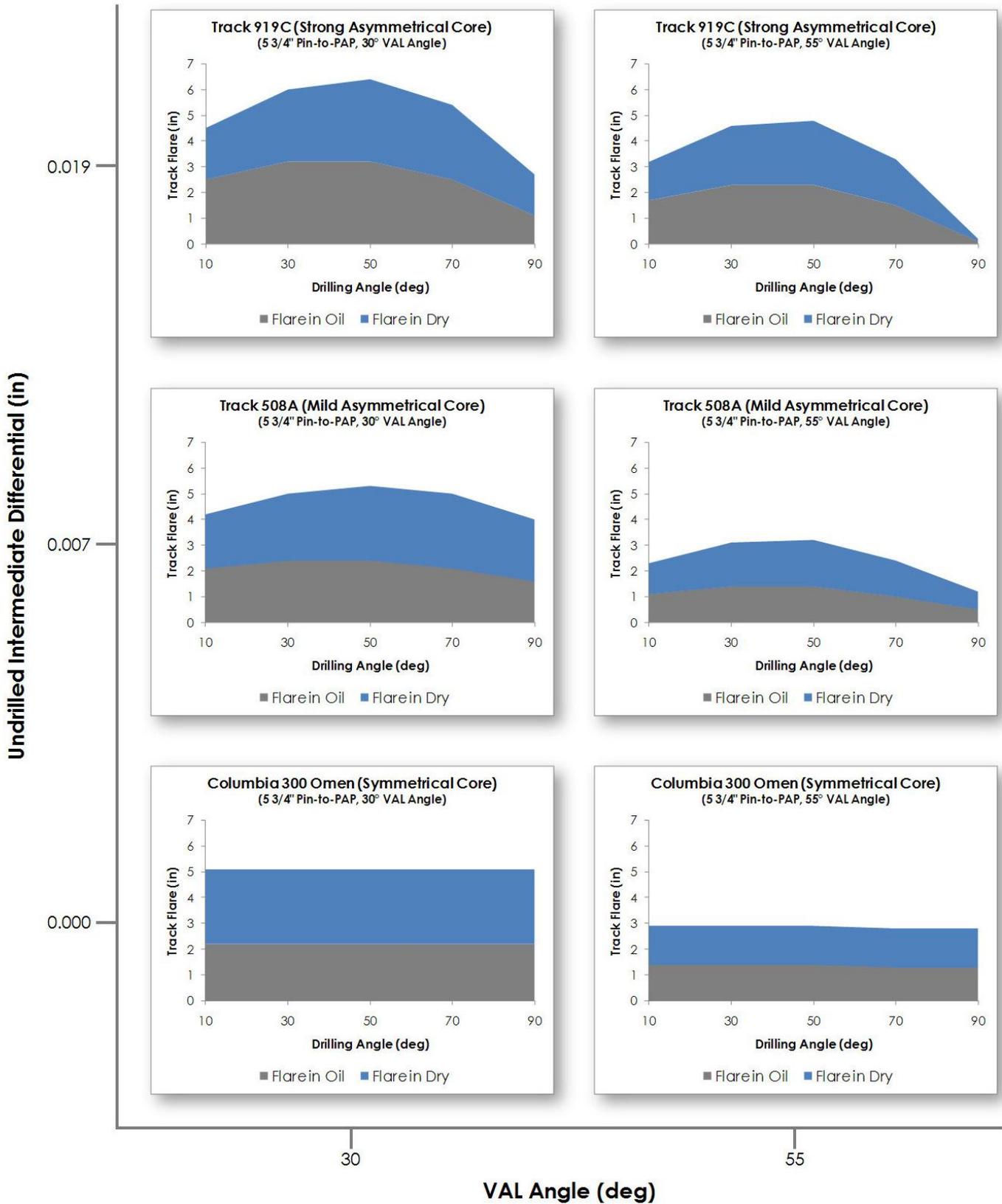
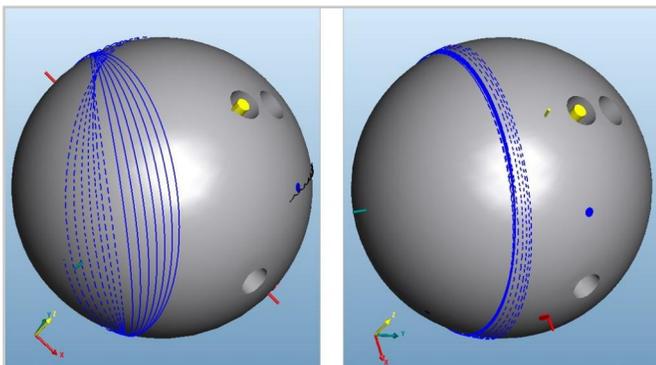


Figure 12. Plot showing effect of drilling angle for three different bowling balls, using two different VAL angles.

Once again, several interesting things are revealed by the study's results:

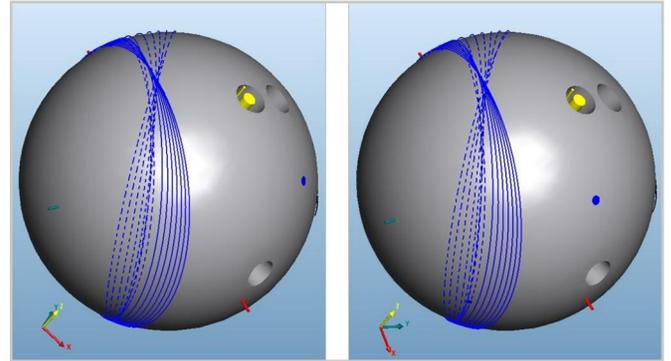
- We will first examine the shape of each of the six mini-studies. As undrilled intermediate differential increases, so does the height of the peak in the flare plot at around 50 degrees of drilling angle. This indicates that **drilling angle has the greatest impact on high intermediate differential balls. For symmetrical balls, in fact, drilling angle has no impact whatsoever on the flare of the ball**, as shown by the two plots for the Columbia 300 Omen.
- Referring back to Study #1, recall that it was shown that **an asymmetrical ball can flare large amounts with long pin-to-PAP distances**. Looking at the two mini-studies for the Track 919C above, we can see that **the opposite can also be true and the ball can sometimes flare very little**. The actual amount of flare seen in asymmetrical balls when using large pin-to-PAP distances is heavily dependent on both the drilling angle and the VAL angle.
- Comparing the left column of plots to the right column, we see that, in every single instance, **the low VAL drilling on the left plot out-flares the corresponding high VAL drilling on the right plot**. This, of course, shouldn't be particularly surprising, given the results of Study #2 above.
- While this isn't shown directly by figure 12 above, it bears mentioning that **the impact of drilling angle on track flare is much less for drillings with shorter pin-to-PAP distances**. For example, if the drillings in the plot used a pin-to-PAP distance of 3 3/4 inches instead of 5 3/4 inches, the shape of each of the plots would be much flatter.

We will now graphically compare a few key drillings to further illustrate the difference between asymmetrical and symmetrical balls. Figure 13 below shows two drillings for the asymmetrical Track 919C. The drillings have the same pin-to-PAP distance of 5 3/4 inches and the same VAL angle of 55 degrees, but with two different drilling angles (50 degrees for the ball on the left and 90 degrees for the ball on the right).



**Figure 13: Track 919C (asymmetrical) with a 50 x 5 3/4 x 55 layout (left) and a 90 x 5 3/4 x 55 layout (right).**

Here, we see that the 50 degree drilling angle drilling on the left flares significantly, while the 90 degree drilling angle layout essentially doesn't flare at all. The reason for this result is that the 90 degree drilling angle layout results in both the min RG axis and the max RG axis being approximately 6 3/4 inches from the PAP. This places the core in a position that is not conducive to flare. We'll now repeat the above two drillings in the symmetrical Columbia 300 Omen, as shown in figure 14.



**Figure 14. Columbia 300 Omen (symmetrical) with a 50 x 5 3/4 x 55 layout (left) and a 90 x 5 3/4 x 55 layout (right).**

In this case, we see that the change in drilling angle has no impact on the flare of the bowling ball. The primary reason for this is that, since symmetrical balls do not have a strong undrilled intermediate differential, the location of the as-drilled high RG axis is not impacted by the drilling angle. As the image shows, the high RG axis in both cases ended up just below the thumb hole, which is typical for symmetrical balls that do not have balance holes.

## V. CLOSING REMARKS

To summarize some of the important results and takeaways presented above, we will now take a step back and make some general comments in closing.

### A. SO, WHAT AFFECTS THE BALL'S TRACK FLARE?

There are several ways of answering this important question. On one level, we could say that pretty much everything can significantly affect a bowling ball's track flare. This paper explored four parameters: undrilled intermediate differential, drilling angle, pin-to-PAP distance, and VAL angle. The results presented above make it very clear that, in the general sense, track flare is affected by all four of these parameters.

But, track flare is also affected by many other factors, including such things as hole depths and diameters, spans, pitches, balance hole parameters (location, depth, diameter, and pitches), core size, shape, and density, and undrilled total differential (although none of these factors were specifically addressed here).

On a different level, however, there is a much simpler answer to the question. Quite simply, track flare is affected by the as-drilled mass properties of the bowling ball. Primarily, the critical mass properties are the total differential, the intermediate differential, and the locations of the low RG and high RG axes (relative to the PAP) of the drilled bowling ball. For those readers who wish to explore the the topic of mass properties in more detail, tables are included in the Appendix showing the as-drilled mass properties of all 90 drillings used to construct figures 6, 9, and 12 above. For those that are content to take our word for it, the following general statements can be made about mass properties and their influence on track flare:

- All other things equal, an increase in total differential will generally result in an increase in track flare. The exception to this is when the low RG axis is near 0 or 6 ¾ inches from the PAP. In these cases, the value of the total differential is largely insignificant with respect to track flare magnitude.
- All other things equal, an increase in intermediate differential will generally result in an increase in track flare, assuming the high RG axis is not near 0 or 6 ¾ inches from the PAP.
- Placing the low RG axis near the PAP will result in a ball that flares very little. This is true regardless of the total differential, intermediate differential, or position of the high RG axis.
- The importance of the location of the high RG axis depends on both the strength of the intermediate differential and the location of the low RG axis. As the low RG axis approaches 6 ¾ inches from the PAP, the high RG axis' location becomes more important, but only if the ball has sufficient intermediate differential. For example, in a ball with 0.002 inches of as-drilled intermediate differential, it does not much matter where the high RG axis ends up; on the other hand, if a ball has 0.035 inches of intermediate differential, the location of the high RG axis can be extremely important.

## B. FINAL CAUTIONS

As we hope we have clearly demonstrated, properly laying out and drilling modern bowling balls for a specific on-lane behavior can be an incredibly difficult undertaking. With so much variation in things like bowling ball mass properties, core geometries, bowler grip sizes, and PAPs, what is true for ball #1 is not always necessarily true for ball #2 (and similarly, what is true for bowler #1 is not always true for bowler #2). This is simply the reality of today's sport. A small difference in core shape or a small change in PAP from one bowler to the next can drastically change both the location and the amount of mass removed from the ball's core, resulting in significant differences in the as-drilled mass properties (and resulting on-lane performance), even if identical layout parameters are used.

For this reason, many of the results presented here should not be considered all-encompassing truths. Instead, the results shown are simply those that hold true for the bowling balls and bowler used in the study. Therefore, try to pay attention to the high-level trends that the results presented expose (and that have been specifically mentioned in the text) without getting too caught up in the details. Certain details could very likely be ball-specific or bowler-specific and, therefore, would not consistently be true in the general sense.

Finally, it should be noted that nothing in this paper should be considered as a ball drilling recommendation. There are several important reasons for making this disclaimer. First, a large number of the drilled balls shown in this paper do not satisfy the static weight limits of the USBC. Also, **many of the drillings shown are not flare-safe for all bowlers, meaning that the ball may flare over one or more gripping holes when thrown.** Those familiar with the Dual Angle Layout Technique will likely notice that some of the drillings in Study #2 (namely, the 10 degree and 90 degree VAL angle layouts) are not within the recommended guidelines of the system. Since these recommended guidelines are set primarily to ensure flare-safeness for all bowlers, extreme caution should be used when going beyond the recommendations of the system. It is primarily for these reasons that we do not recommend the layouts shown in this paper be blindly used in the real-world. Instead, we recommend that bowlers work with their pro shop operators in determining the proper layouts for their games. A knowledgeable pro shop operator is the best source for input to make sure that the layouts selected will both be statically legal and flare-safe for a particular bowler's style.

## C. FUTURE OPPORTUNITIES

While this paper hopefully answered some questions and cleared up some confusion on the topic of track flare and its effects, it certainly does not provide all the answers. Our scope was limited to the exploration of how core orientation and undrilled intermediate differential affect track flare. We have not yet addressed things like balance hole parameters, undrilled total differential, finger hole sizes and depths, and delivery-specific parameters like PAP and rev rate. These topics will be saved for future studies.

## D. ACKNOWLEDGEMENTS

The authors wish to thank Ebonite International for its support of Powerhouse Blueprint. Thank you as well to the members of BowlingChat.net, as their questions and curiosity inspired many of the topics covered by this paper. Special thanks to Mo Pinel for providing the original idea for this study and for reviewing and providing insightful feedback on several early drafts.

## VI. APPENDIX: MASS PROPERTIES TABLES

<b>Study #1: Analysis of Pin-to-PAP Distances with 30 deg. VAL Angle</b>									
<b>Columbia 300 Omen (Undrilled: Low RG = 2.474, Int. Diff. = 0.000, Total Diff. = 0.054)</b>									
<b>Pin-to-PAP Distance (in)</b>	<b>Drill Angle (deg)</b>	<b>Int. Diff. (in)</b>	<b>Total Diff. (in)</b>	<b>Low RG (in)</b>	<b>Low RG Axis to PAP (in)</b>	<b>High RG Axis to PAP (in)</b>	<b>Flare in the Oil (in)</b>	<b>Flare in the Dry (in)</b>	<b>Total Flare (in)</b>
1 1/8	50	0.005	0.062	2.471	0.74	6.54	1.6	1.6	3.2
2 1/4	50	0.005	0.057	2.474	1.77	6.47	3.4	2.5	5.9
3 3/8	50	0.007	0.053	2.478	2.94	6.58	4.2	3.4	7.6
4 1/2	50	0.010	0.051	2.480	4.32	6.00	4.0	3.4	7.4
5 5/8	50	0.011	0.051	2.480	5.80	5.40	2.6	3.0	5.6
1 1/8	90	0.005	0.061	2.471	0.75	6.52	1.7	1.6	3.3
2 1/4	90	0.005	0.057	2.475	1.77	6.48	3.5	2.5	6.0
3 3/8	90	0.007	0.053	2.478	2.96	6.49	4.3	3.3	7.6
4 1/2	90	0.009	0.050	2.480	4.34	5.89	4.0	3.5	7.5
5 5/8	90	0.011	0.051	2.480	5.82	5.28	2.6	3.0	5.6

<b>Track 508A (Undrilled: Low RG = 2.519, Int. Diff. = 0.007, Total Diff. = 0.049)</b>									
<b>Pin-to-PAP Distance (in)</b>	<b>Drill Angle (deg)</b>	<b>Int. Diff. (in)</b>	<b>Total Diff. (in)</b>	<b>Low RG (in)</b>	<b>Low RG Axis to PAP (in)</b>	<b>High RG Axis to PAP (in)</b>	<b>Flare in the Oil (in)</b>	<b>Flare in the Dry (in)</b>	<b>Total Flare (in)</b>
1 1/8	50	0.003	0.052	2.516	0.66	6.21	1.2	1.0	2.2
2 1/4	50	0.007	0.049	2.519	1.60	5.88	2.6	1.8	4.4
3 3/8	50	0.011	0.046	2.523	2.73	5.55	3.4	2.5	5.9
4 1/2	50	0.015	0.044	2.526	4.15	5.16	3.3	2.9	6.2
5 5/8	50	0.018	0.045	2.526	5.83	4.74	2.5	3.0	5.5
1 1/8	90	0.010	0.056	2.516	0.65	6.59	1.1	0.9	2.0
2 1/4	90	0.012	0.052	2.520	1.58	6.61	2.5	2.1	4.6
3 3/8	90	0.015	0.048	2.523	2.75	6.44	3.2	2.8	6.0
4 1/2	90	0.018	0.045	2.526	4.30	6.12	3.0	3.2	6.2
5 5/8	90	0.018	0.046	2.526	6.04	5.76	2.0	2.8	4.8

<b>Track 919C (Undrilled: Low RG = 2.530, Int. Diff. = 0.019, Total Diff. = 0.050)</b>									
<b>Pin-to-PAP Distance (in)</b>	<b>Drill Angle (deg)</b>	<b>Int. Diff. (in)</b>	<b>Total Diff. (in)</b>	<b>Low RG (in)</b>	<b>Low RG Axis to PAP (in)</b>	<b>High RG Axis to PAP (in)</b>	<b>Flare in the Oil (in)</b>	<b>Flare in the Dry (in)</b>	<b>Total Flare (in)</b>
1 1/8	50	0.014	0.055	2.527	0.49	6.26	0.9	0.7	1.6
2 1/4	50	0.016	0.051	2.530	1.33	5.67	2.1	1.7	3.8
3 3/8	50	0.020	0.047	2.534	2.38	5.15	3.1	2.0	5.1
4 1/2	50	0.025	0.045	2.537	3.72	4.72	3.5	2.6	6.1
5 5/8	50	0.028	0.046	2.538	5.52	4.36	3.3	3.2	6.5
1 1/8	90	0.020	0.057	2.528	0.43	6.65	0.9	0.7	1.6
2 1/4	90	0.023	0.053	2.531	1.35	6.62	2.0	1.7	3.7
3 3/8	90	0.026	0.049	2.535	2.50	6.52	2.5	2.3	4.8
4 1/2	90	0.029	0.046	2.538	4.12	6.37	2.3	2.7	5.0
5 5/8	90	0.029	0.046	2.538	6.13	6.20	1.5	2.2	3.7

**Study #2: Analysis of VAL Angles with 50 deg. Drilling Angle**

**Columbia 300 Omen (Undrilled: Low RG = 2.474, Int. Diff. = 0.000, Total Diff. = 0.054)**

VAL Angle (deg)	Pin-to-PAP Distance (in)	Int. Diff. (in)	Total Diff. (in)	Low RG (in)	Low RG Axis to PAP (in)	High RG Axis to PAP (in)	Flare in the Oil (in)	Flare in the Dry (in)	Total Flare (in)
10	3 3/8	0.010	0.059	2.475	3.09	6.15	4.8	3.5	8.3
30	3 3/8	0.007	0.053	2.478	2.94	6.58	4.3	3.3	7.6
50	3 3/8	0.005	0.048	2.480	2.79	6.67	3.8	3.1	6.9
70	3 3/8	0.004	0.047	2.481	2.75	6.74	3.7	3.0	6.7
90	3 3/8	0.006	0.050	2.480	2.81	6.59	3.7	3.1	6.8
10	5 5/8	0.014	0.059	2.477	5.68	5.26	3.5	3.8	7.3
30	5 5/8	0.011	0.051	2.480	5.80	5.40	2.7	3.0	5.7
50	5 5/8	0.008	0.045	2.483	5.90	5.81	1.9	2.3	4.2
70	5 5/8	0.007	0.044	2.484	5.92	6.71	1.4	1.8	3.2
90	5 5/8	0.009	0.048	2.483	5.88	5.90	1.3	1.6	2.9

**Track 508A (Undrilled: Low RG = 2.519, Int. Diff. = 0.007, Total Diff. = 0.049)**

VAL Angle (deg)	Pin-to-PAP Distance (in)	Int. Diff. (in)	Total Diff. (in)	Low RG (in)	Low RG Axis to PAP (in)	High RG Axis to PAP (in)	Flare in the Oil (in)	Flare in the Dry (in)	Total Flare (in)
10	3 3/8	0.015	0.053	2.520	2.97	5.42	4.1	2.9	7.0
30	3 3/8	0.011	0.046	2.523	2.73	5.55	3.5	2.7	6.2
50	3 3/8	0.008	0.041	2.525	2.50	5.46	3.1	2.4	5.5
70	3 3/8	0.010	0.041	2.526	2.62	5.61	3.0	2.5	5.5
90	3 3/8	0.010	0.044	2.524	2.75	5.86	3.0	2.7	5.7
10	5 5/8	0.020	0.053	2.521	5.66	4.74	3.5	3.7	7.2
30	5 5/8	0.018	0.045	2.526	5.83	4.74	2.7	3.2	5.9
50	5 5/8	0.014	0.038	2.529	6.06	4.75	1.9	2.6	4.5
70	5 5/8	0.010	0.036	2.530	6.18	5.29	1.2	1.8	3.0
90	5 5/8	0.010	0.040	2.527	6.07	6.07	1.0	1.9	2.9

**Track 919C (Undrilled: Low RG = 2.530, Int. Diff. = 0.019, Total Diff. = 0.050)**

VAL Angle (deg)	Pin-to-PAP Distance (in)	Int. Diff. (in)	Total Diff. (in)	Low RG (in)	Low RG Axis to PAP (in)	High RG Axis to PAP (in)	Flare in the Oil (in)	Flare in the Dry (in)	Total Flare (in)
10	3 3/8	0.024	0.053	2.531	2.67	5.11	3.9	2.4	6.3
30	3 3/8	0.020	0.047	2.534	2.38	5.15	3.3	2.2	5.5
50	3 3/8	0.019	0.043	2.537	2.10	5.27	2.8	2.0	4.8
70	3 3/8	0.021	0.044	2.536	2.28	5.41	2.7	2.2	4.9
90	3 3/8	0.022	0.046	2.535	2.51	5.58	2.7	2.4	5.1
10	5 5/8	0.030	0.053	2.532	5.42	4.40	4.0	3.6	7.6
30	5 5/8	0.028	0.046	2.538	5.52	4.36	3.4	3.3	6.7
50	5 5/8	0.025	0.038	2.542	5.86	4.38	2.7	2.8	5.5
70	5 5/8	0.021	0.037	2.541	6.17	4.62	2.1	2.7	4.8
90	5 5/8	0.020	0.041	2.538	6.00	4.90	2.0	2.9	4.9

**Study #3: Analysis of Drilling Angles with 5 3/4 Pin-to-PAP Distance**

**Columbia 300 Omen (Undrilled: Low RG = 2.474, Int. Diff. = 0.000, Total Diff. = 0.054)**

Drill Angle (deg)	VAL Angle (deg)	Int. Diff. (in)	Total Diff. (in)	Low RG (in)	Low RG Axis to PAP (in)	High RG Axis to PAP (in)	Flare in the Oil (in)	Flare in the Dry (in)	Total Flare (in)
10	30	0.011	0.052	2.480	5.95	5.37	2.2	2.9	5.1
30	30	0.011	0.052	2.480	5.96	5.35	2.2	2.9	5.1
50	30	0.011	0.052	2.480	5.96	5.34	2.2	2.9	5.1
70	30	0.011	0.051	2.480	5.97	5.28	2.2	2.9	5.1
90	30	0.011	0.052	2.480	5.98	5.21	2.2	2.9	5.1
10	55	0.007	0.044	2.484	6.08	5.95	1.4	1.5	2.9
30	55	0.007	0.044	2.484	6.08	5.98	1.4	1.5	2.9
50	55	0.007	0.044	2.484	6.09	5.96	1.4	1.5	2.9
70	55	0.007	0.044	2.484	6.10	5.89	1.3	1.5	2.8
90	55	0.007	0.045	2.483	6.11	5.80	1.3	1.5	2.8

**Track 508A (Undrilled: Low RG = 2.519, Int. Diff. = 0.007, Total Diff. = 0.049)**

Drill Angle (deg)	VAL Angle (deg)	Int. Diff. (in)	Total Diff. (in)	Low RG (in)	Low RG Axis to PAP (in)	High RG Axis to PAP (in)	Flare in the Oil (in)	Flare in the Dry (in)	Total Flare (in)
10	30	0.010	0.042	2.526	5.95	3.93	2.1	2.1	4.2
30	30	0.015	0.044	2.526	5.95	4.22	2.4	2.6	5.0
50	30	0.018	0.046	2.526	6.01	4.69	2.4	2.9	5.3
70	30	0.019	0.047	2.526	6.11	5.21	2.1	2.9	5.0
90	30	0.018	0.046	2.526	6.22	5.71	1.6	2.4	4.0
10	55	0.005	0.033	2.529	6.16	3.14	1.1	1.2	2.3
30	55	0.010	0.036	2.529	6.22	3.98	1.4	1.7	3.1
50	55	0.012	0.037	2.529	6.31	4.75	1.4	1.8	3.2
70	55	0.014	0.038	2.529	6.40	5.52	1.0	1.4	2.4
90	55	0.014	0.038	2.529	6.47	6.28	0.5	0.7	1.2

**Track 919C (Undrilled: Low RG = 2.530, Int. Diff. = 0.019, Total Diff. = 0.050)**

Drill Angle (deg)	VAL Angle (deg)	Int. Diff. (in)	Total Diff. (in)	Low RG (in)	Low RG Axis to PAP (in)	High RG Axis to PAP (in)	Flare in the Oil (in)	Flare in the Dry (in)	Total Flare (in)
10	30	0.015	0.040	2.537	5.63	2.23	2.5	2.0	4.5
30	30	0.023	0.044	2.537	5.59	3.36	3.2	2.8	6.0
50	30	0.028	0.046	2.537	5.72	4.33	3.2	3.2	6.4
70	30	0.030	0.047	2.537	6.01	5.26	2.5	2.9	5.4
90	30	0.028	0.046	2.537	6.33	6.19	1.1	1.6	2.7
10	55	0.014	0.033	2.542	5.82	1.74	1.7	1.5	3.2
30	55	0.020	0.036	2.542	5.92	3.18	2.3	2.3	4.6
50	55	0.024	0.038	2.542	6.23	4.37	2.3	2.5	4.8
70	55	0.026	0.039	2.542	6.63	5.47	1.5	1.8	3.3
90	55	0.025	0.039	2.542	6.56	6.55	0.1	0.1	0.2