# Marketing vs. Physics

## The truth about axis migration and core dynamics

*By Nick Siefers, USBC research engineer*

Many theories about why and how a bowling ball rolls down a lane have been discussion topics within the bowling industry in recent years, including at the United States Bowling Congress, where a ball motion study is a major research focus.

With key trends appearing in the data, the significant factors that affect bowling ball motion are becoming scientifically apparent. A separate study relating to how and why the ball rolls the way it does has been conducted. In the following discussion, an attempt will be made to explain the physics that govern bowling ball motion relating to core dynamics.

Of the many theories available to explain the motion of a bowling ball, different companies take a wide variety of stances on this subject. Several beliefs include the following:

1) Core dominates cover
2) Cover dominates core
3) Core and cover have a delicate balance with each other
4) Mass bias strength governs axis migration
5) Asymmetrical vs. symmetrical cores determine bowling ball motion
6) RG, differential and cover stock work together to affect the roll
7) Other(s)

To the average bowler, these different theories provided by the industry can be confusing. Which one is correct? Is more than one theory useful in determining why a ball rolls as it does? At the USBC, we set out to discover the truth regarding these theories, as they relate to core dynamics and the roll of the ball.

Before describing the testing parameters, it is important to understand the facts and certain physics principles used in this research. First, the radius of gyration (RG) is defined as the square root of the moment of inertia divided by the mass of the object. Therefore, the radius of gyration is the distance that, if the entire mass of the object were together at only that specific radius, would yield the same moment of inertia. The moment of inertia for an object is the ratio of applied torque and the resultant angular acceleration of the object. Translating the physics definition, the moment of inertia measures how easy an object will rotate when a force is applied. Thus, in simple terms, the radius of gyration determines how easy it is for the bowling ball of particular weight to rotate about a given axis and is a measurement of where the weight is located inside the ball, relative to the center. Second, Sir Isaac Newton's laws of motion state that energy is neither created nor destroyed, but rather conserved and all matter in the universe had a natural tendency to go from an unstable state to a stable state in which forces are balanced. This is called equilibrium. To reverse the process and move from a stable state to an unstable state whereas forces are not balanced, work or energy must be added to the system.

With these concepts in mind, when a bowler releases a ball during delivery, the ball will first begin rotating about what is called his or her positive axis point (PAP). Simply defined, the positive axis point serves as the initial point of rotation. Then, due to the influence of ball properties, bowler attributes, lane conditions and the laws of physics (unstable to stable), new axis of rotation will exist as the ball travels down the lane. This change from the initial point of rotation to each subsequent point of rotation is called "Axis Migration." The migration of axis points can be determined and traced for a bowler by using an armadillo® to locate the axis of rotation for each flare ring as the ball rolls down the lane. Each flare ring will have an individual axis that the ball has rotated about to create that particular flare ring. The armadillo® is able to measure and find the rotation axis. Thus, for each flare ring, there is an axis point. The migration of axis points can be plotted on the ball and, depending upon certain characteristics, will yield different shapes (curved vs. straight line) due to the drilling pattern used. The plots will be at different distances away from the pin of the bowling ball.

It is at this point, the many theories come into play. In regards to performance, does having a straight line axis migration path differ than having a curved path? Does an axis migration path closer to the pin affect the roll different than a path further away from the pin? Does the ball's path migrate toward the high RG or Mass Bias spot? Does the ball's path migrate toward the low RG or pin? Is the axis migration path dependant upon the core's orientation inside the ball? Is the path due to RG differences or similarities? Is the migration path a combination of any of these theories or does the path not depend on any of these theories? What does the axis migration path have to do with ball performance at all? These are some of the questions that have been asked and now for the first time answers are being found.

In order to dig into these questions, five major types of tests were completed. Several types of bowling balls, drillings, and bowlers in the USBC Equipment Specifications and Certification department were selected for measuring axis migration and the results were used to determine the trends in axis migration. The chart below lists all of the balls that were tested:

# Axis Migration Testing: Ball Static Sheet

| | Ball | Asymmetrical or Symmetrical (Prior to Drilling) | Low Rg (After Drilling) | High RG (After Drilling) | Total Diff. (After Drilling) | Intermediate Diff. (After Drilling) | Drilling (PIN x High Rg Spin Spot) |
|---|---|---|---|---|---|---|---|
| 1 | Ricochet Rebound | Symmetrical | 2.523 | 2.567 | 0.044 | 0.012 | 4 ¾ x 5 3/4 |
| 2 | Track Machine | Asymmetrical | 2.518 | 2.570 | 0.052 | 0.009 | 4 ½ x 5 1/2 |
| 3 | Awesome Finish (KW) | Asymmetrical | 2.479 | 2.530 | 0.051 | 0.031 | 3 x 4 1/2 |
| 4 | Awesome Finish (PR) | Asymmetrical | 2.486 | 2.537 | 0.051 | 0.037 | 4 x 5 |
| 5 | Rampage | Symmetrical | 2.548 | 2.583 | 0.035 | 0.006 | 4 x 6 |
| 6 | Special Agent 007 | Symmetrical | 2.506 | 2.558 | 0.052 | 0.010 | 4 x 5 |
| 7 | Action Force | Symmetrical | 2.465 | 2.520 | 0.055 | 0.005 | 2 ¾ x 6 |
| 8 | Awesome Finish (NS) | Asymmetrical | 2.474 | 2.529 | 0.055 | 0.024 | 3 x 5 1/2 |
| 9 | Triumph Tour Sanded | Symmetrical | 2.495 | 2.545 | 0.050 | 0.004 | PIN on PAP |
| 10 | Beetle Cross Core Test Ball | Asymmetrical | 2.465 | 2.525 | 0.060 | 0.038 | 4 ¾ x 6 |
| 11 | Revolution | Symmetrical | 2.509 | 2.547 | 0.038 | 0.011 | 3 x 5 1/2 |
| 12 | Strike Machine | Asymmetrical | 2.505 | 2.558 | 0.053 | 0.016 | 3 ½ x 6 |
| 13 | Sahara | Asymmetrical | 2.544 | 2.598 | 0.054 | 0.023 | 3 ¼ x 6 1/2 |
| 14 | Black MoRich Test Ball | Asymmetrical | 2.512 | 2.565 | 0.053 | 0.043 | 3 ¼ x 6 1/2 |
| 15 | Storm Shift | Asymmetrical | 2.536 | 2.583 | 0.047 | 0.028 | MB on PAP |
| 16 | RotoGrip Odyssey | Asymmetrical | 2.487 | 2.543 | 0.056 | 0.026 | PIN on PAP |
| 17 | REV AGL Danger | Symmetrical | 2.467 | 2.524 | 0.057 | 0.010 | PIN in Center of Grip |
| 18 | RotoGrip Destiny | Asymmetrical | 2.497 | 2.551 | 0.054 | 0.026 | MB on PAP |
| 19 | Awesome Finish #4 | Asymmetrical | 2.470 | 2.518 | 0.048 | 0.019 | PAP on Line from MB to Pin |
| 20 | Columbia "10" | Asymmetrical | 2.455 | 2.510 | 0.055 | 0.026 | MB on “normal” migration path |
| 21 | Ebonite NVS #1 (No Balance hole) | Asymmetrical | 2.503 | 2.561 | 0.058 | 0.031 | 5 ¼ x 5 |
| 22 | Ebonite NVS #1 (Balance Hole) | Asymmetrical | 2.519 | 2.580 | 0.061 | 0.036 | 5 ¼ x 5 |
| 23 | Large Differential Test Ball | Symmetrical | 2.439 | 2.629 | 0.190 | 0.005 | 3 ½ x 5 1/2 |

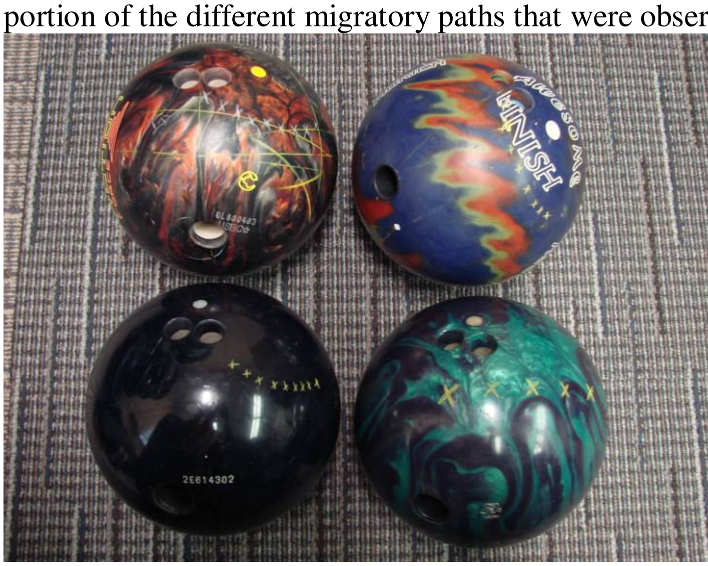
**Figure 1: Static Measurements of All Balls Tested**

## ***TEST I – Standard and Unconventional Drillings***

Test I used both normal/standard and unconventional drillings. The balls used for this test were all approved for USBC competition prior to drilling (balls nos. 1-19). This first set of test balls were subject to one of four designed oil patterns ranging from a 38-foot house pattern to a 44-foot PBA pattern. For each ball tested, the bowler threw enough shots to accurately portray all possible flare rings in both the oil and dry part of the lane on the surface of the ball. Each flare ring was then traced with a grease pencil and the armadillo® was used to locate the axis of rotation. An example of this process is shown below in Picture 1.

Picture 1: Marking the PAP

Depending on the bowler’s rev rate and actual flare of the ball, different numbers of rings were traced for each ball. Once the axis migration points were plotted, the path was seen to be either straight or curved. At this point, the distance of each migration point from the pin was also recorded. This distance describes the core’s orientation (standing up or laying down) as the ball traveled down lane. Finally, the RG value about each axis migration point was measured to investigate the motion of the bowling ball. The RG was recorded to the third decimal but rounded to the second decimal point, due to the accuracy of the RG device and process used to measure. The following pictures show a portion of the different migratory paths that were observed.



Picture 2: Different migratory paths (conventional layouts)

Picture 3: Pin or MB on PAP (unconventional layouts)

The figures below show a graphical representation of each axis point on all balls in all tests as it relates to distance away from the pin. The next figure shows the RG value for each axis point.

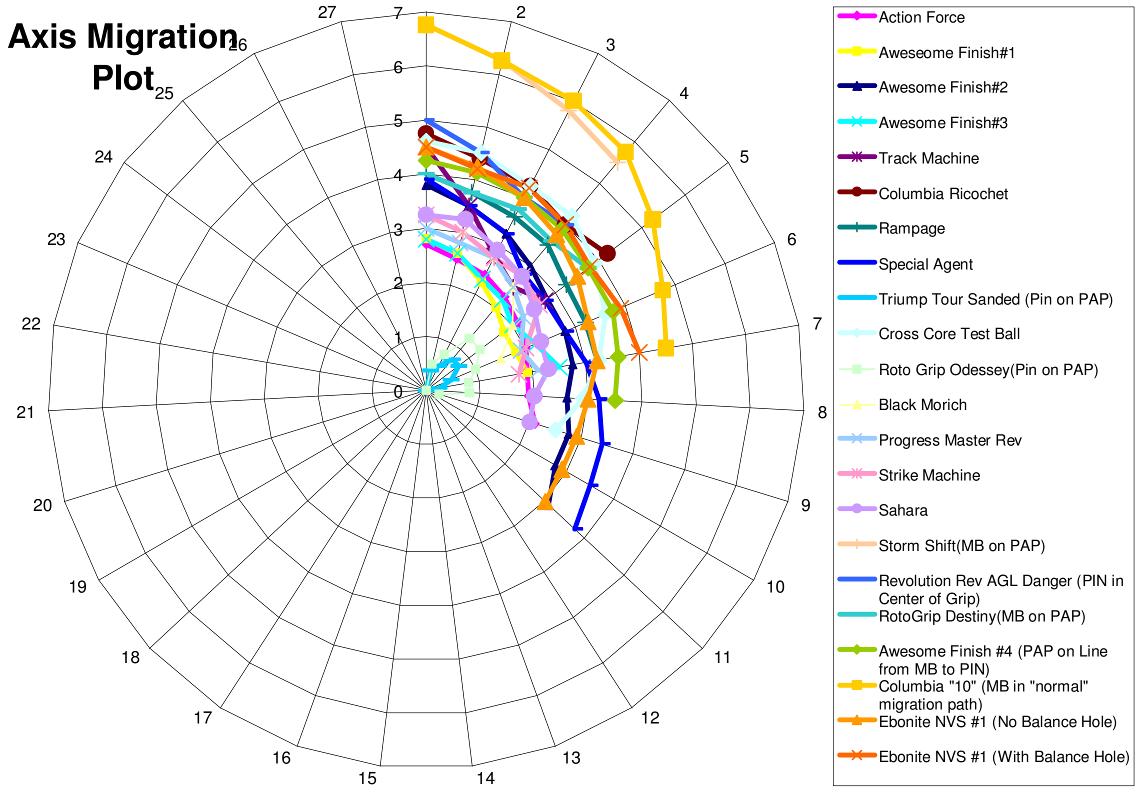



Figure 2: Axis migration point distance from pin

Figure 2 shows the axis migration as it occurred on the surface of each bowling ball. The center of the “spider web” graph is labeled 0. Imagine this as being the location of the pin on the bowling ball. As you move upward the numbers range from 0 to 7 and represent the distance, in inches, away from the pin. The numbers on the outside portion of the graph that move in a circular notation represent an individual axis point as the flared down the lane. Thus, the overall plot is a function of the distance each axis point in the migratory path is away from the pin.

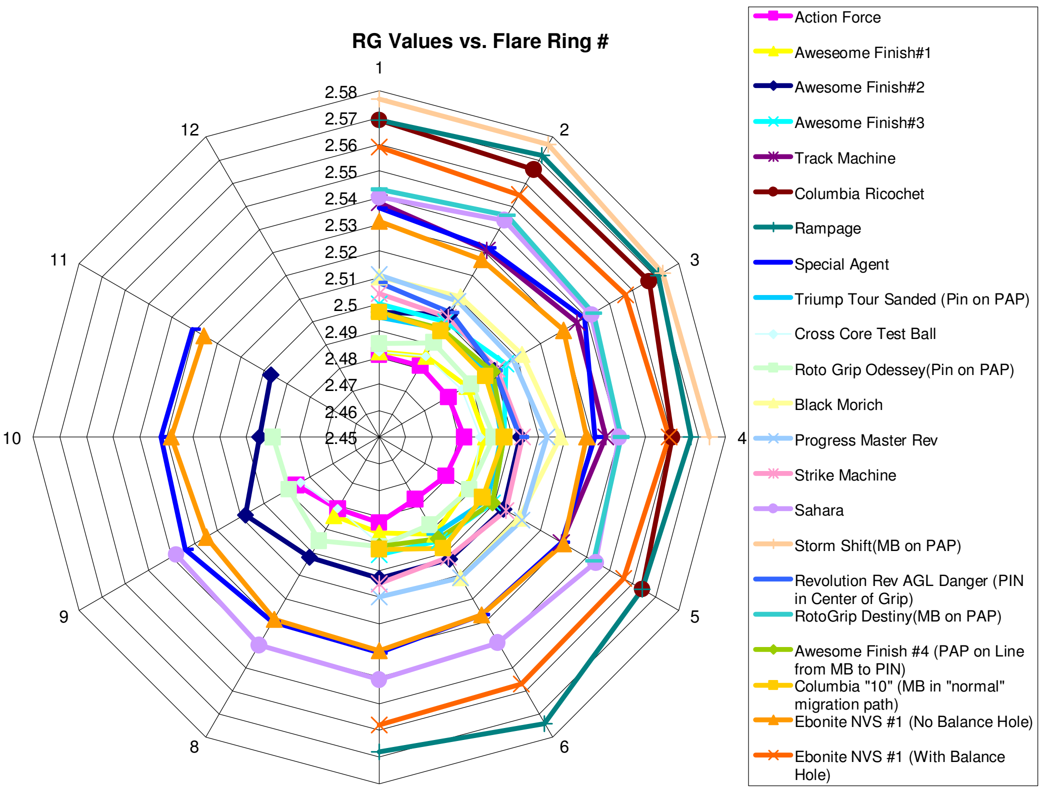


Figure 3: RG values vs. axis point

Figure 3 is the same type of "spider web" graph as previously noted. However, the center of this graph represents a low RG value of 2.45''. Moving upward on the chart, the RG values range from 2.45'' to 2.58''. The numbers going around the outside of the graph are again, just as in Figure 2, representing each axis point in the migratory path as the ball flares down lane. This figure graphically shows the RG value at each axis point in the path.

The graphs for Test I show that despite having different distances or migratory paths, a trend is noticed. The most important overall factor that was consistent through out this test was noticed:

> "**While on the lane, RG values of the migratory path remained approximately constant at each migratory axis point for all core geometries and drillings."**

Based on the variety of ball tested, an accurate analysis concluded that the axis migration path was INDEPENDENT (not dependant) of the following:

1) Core shape
2) Core angle/orientation
3) Cover stock
4) Asymmetry
5) Symmetry
6) Mass bias strength/intermediate differential

7) Spin time
8) Oil Pattern
9) Mass Distribution of the Core
10) Ratio of the Intermediate to Total Differential

Regardless of the above factors, the same trend in axis migration occurred. While the approved ball is on the lane, the bowling ball flared and created an axis migration to yield approximately the same RG value that the ball was initially rotating on from the bowlers PAP.

## ***<u>TEST II – Large Differential Test Ball</u>***

Next, in Test II a particular case study was conducted. In this case study, a ball was made outside the limits of the total differential specification set forth by the USBC (ball no. 23). The maximum allowable limit on differential is currently .060''. Differential directly relates to the flare potential of the ball. The test ball was designed to have three times the legal limit of total differential. The drilling used was 3 3/8'' (pin to pap) x 4'' (pap to cg). After drilling, the low radius of gyration was 2.43'' and the total differential was .190''. This ball also had an intermediate differential of .005''. Subject to multiple lane conditions, this test ball flare around the entire ball. Because of the large amount of flare, a greater axis migration plot was obtained.

In this particular case, as shown in Figure 4 below, the ball initially started rolling around the bowler's PAP (green circle). As flaring occurred, the axis of rotation transgressed through the red circle, then the yellow circle and finally the white circle. Since this ball was able to flare a great deal more than a standard USBC approved ball, a greater detailed picture of axis migration was found. As in Test I, the RG values were obtained for each of the colored axis points. Picture 4 below shows the actual ball and colored axis migration points.

# Test II

| Test Ball | |
|---|---|
| XRg: | 2.439" |
| Yrg: | 2.629" |
| ZRg: | 2.624" |
| Total Diff: | .190" |
| Int. Diff: | .005" |
| | |
| Green Axis Rg: | 2.546" |
| Red Axis Rg: | 2.554" |
| Yellow Axis Rg: | 2.526" |
| White Axis Rg: | 2.520" |

Figure 4: Large differential test ball core properties

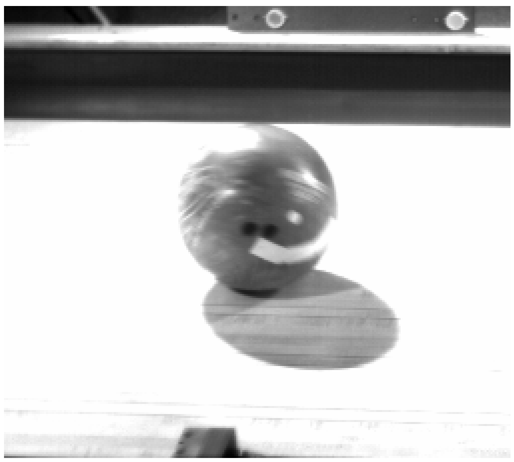
Picture 4: Large differential test ball

The interesting trend in this test actually coincides with the results of Test I. If this test ball flared within USBC specifications, the path would start on the green axis point and end up down lane approximately on the red axis point. After looking at the data, the green axis and the red axis point exhibit the virtually same RG value, which directly matches the trend results of Test I. However, since the ball flares more and no energy is added to the ball as it travels down lane, an important trend it noticed in the subsequent RG axis points. The RG value at the yellow and white axis points actually decrease compared to the first two rotation axis. As in Test I, with energy being lost as the ball rolls down the lane, the migration is controlled by physics and the conservation of energy. The test ball **loses energy** and **migrates toward a lower energy and lower RG values.** Also as in Test I, the on lane migration **does not seek a higher RG state or the mass bias spot (the highest RG of the ball).**

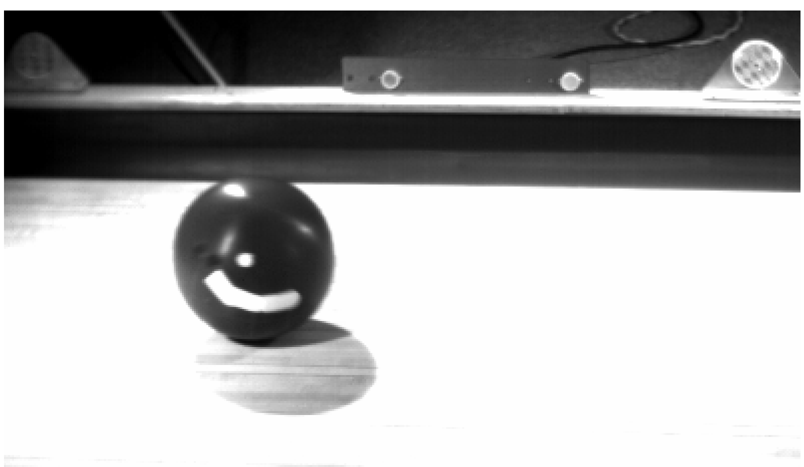
## ***TEST III – High Speed Camera***

Test III was conducted on a dry/stripped lane with no oil applied. A high speed camera was set up at approximately 53 feet down lane to capture the axis migration after the ball stopped hooking. It is important to understand that friction causes the ball to stop hooking but axis migration is a function of RPM and total differential RG of the ball. Thus, the axis of rotation will continue to migrate after the ball has reached its final directional rolling phase.

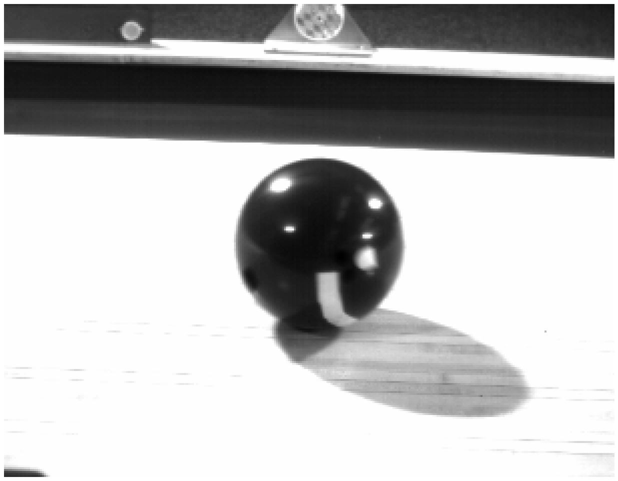
Several of the balls in Test I were subject to Test III - high speed camera testing. A few freeze frame examples are shown below in Pictures 4, 5 and 6. In each of these video segments, it is certain that the axis of rotation is not the high RG axis of the ball (regardless of strength of intermediate differential). However, in each video segment, it can be seen that the axis of rotation is in a region near the low Rg axis of the ball. The low RG axis is located near the pin, which can be seen in the pictures below. It is the round/circular dot near the center of the ball in the pictures. This trend, would again, show the same result as both Test I and II.



Picture 4: Sahara axis of rotation at 53 feet on dry lane



Picture 5: Black MoRich test ball axis of rotation at 53 feet on dry lane



Picture 6: Beetle core test ball axis of rotation at 53 feet on dry lane

## *TEST IV – Standard Drilling without/with Balance Hole*

An Ebonite NVS was used for Test IV. The ball was drilled in a 4 ½'' x 4'' (pin X Mass Bias) with no balance hole and the axis migration was traced. Again, just as the previous tests, the migration path was shaped in way that each axis point had an approximate equal RG value. The axis points were plotted in the above charts (Figures 2 and 3) as well. Next an inch and a quarter weight hole was placed 4 inches deep on the bowler's PAP.

Due to the removal of core weight, the RG value about the same PAP was increased. This step was done to determine and verify what the effect on migration would be. Would it follow the original path before the weight hole or would the path be generated in the same since as all other testing and therefore create a second migratory path of same RG values? The ball was tested and sure enough a second path was created that followed the same trend in RG values. The PAP (with weight hole) had a higher RG, and a new path that had the same higher RG as the PAP was traced. The picture below illustrates this test.


Picture 7: Ebonite NVS – No balance hole/balance hole on PAP

## ***TEST V – Mass Bias Marking on Traditional Migratory Path***

Lastly, in Test 5, a Columbia Ten was drilled in an unconventional manner with the Mass Bias marking beneath the ring finger and approximately 2-1/2 inches towards the PAP. The picture below shows the layout. The thought behind this test was to place the mass bias spot in a location along a normal migratory path that was traced in several previous test balls.

While on the lane, if the ball wanted to show an axis of migration path toward the highest RG, this drilling layout would present prime opportunity to do so. However, as in all previous testing, the migration points plotted a path with the same trend. The ball created a migratory path such that each axis rotation point was equal to the initial RG value of the PAP.

Picture 8: Columbia 10 – Mass bias in "normal" migration path

## ***Testing Results***

What does all of this mean in the practical world of bowling? For starters, many marketing tactics have been employed by companies to explain how and why a bowling ball rolls down the lane. The research presented here shows USBC testing results, which may differ from others in the industry. It is important to remember that the research was conducted in a non-bias and neutral atmosphere. This test was not comparing cover stock strengths, but concentrated on core dynamics and how the core behaves in motion on the lane. All testing shows the same trends and indicates that on-lane Axis migration is **DEPENDENT** upon the following two things:

1) **Physics**
   a. While on the lane, the bowling ball did not migrate to an axis that had a higher RG value (ball did not end up rotating about the mass bias spot or high RG axis).
   b. Newton's Law of Energy Conservation and Work still applied.
2) **Radius of Gyration**
   a. While on the lane, the USBC approved ball always flared and migrated toward an axis of rotation that was approximately equal in the RG value of the starting PAP (measured and rounded to the second decimal point).
   b. RG is measured for the entire bowling ball as a "system" and not on the core alone.

The laws of physics stay intact and have not been broken. Physics terms such as Radius of Gyration, Moment of Inertia, Conservation of Energy, Work and Equilibrium have proven to be applied in the motion of a bowling ball. Certain terms and ideas that are not found in physics books and principles show little affect on true core dynamics.

In short, an asymmetrical core ball drilled with the same layout as a symmetric ball merely has a different initial RG value on a bowlers PAP (of same low RG and Diff.

RG). Thus, in proving that all asymmetrical or symmetrical cores have the same RG progression as the ball rolls down the lane, testing now in progress will attempt to answer another highly debated question:

**<u>"Assuming the same coverstock, Differential RG, and the same starting RG value on the bowlers PAP with the same flare potential, will an asymmetrical core exhibit the same on-lane core dynamics and ball motion as a symmetrical core?"</u>**

Hopefully, this in depth analysis on bowling ball motion and core dynamics help sort through the marketing campaigns and distinguish the "real" factors that influence how and why a ball rolls as it does. Remember, though, changes in cover stock technology are separate and will influence ball motion separately. Integrating the concepts of cover stock options with the balls radius of gyration and total differential should help a bowler become more successful in choosing an arsenal. USBC would like to thank MoRich Bowling Company for supplying some of the test balls used in this investigation.

If there are any questions regarding any of the above information presented, please send an e-mail to Nick.Siefers@bowl.com.