ENGINEERING REPORT

Subject: Balance Hole vs. 3 oz. Static Weight in All Directions

Date: 2/2/18

Place: International Training & Research Center

Present: Dan Speranza ball tester

Purpose:

Build an adjustable ball that can be used to change the static weights within the proposed 3 oz. +/- side weight, 3 oz. top/bottom weight and 3 oz. finger/thumb weight and test vs. a ball with a 1-1/4" diameter balance hole.

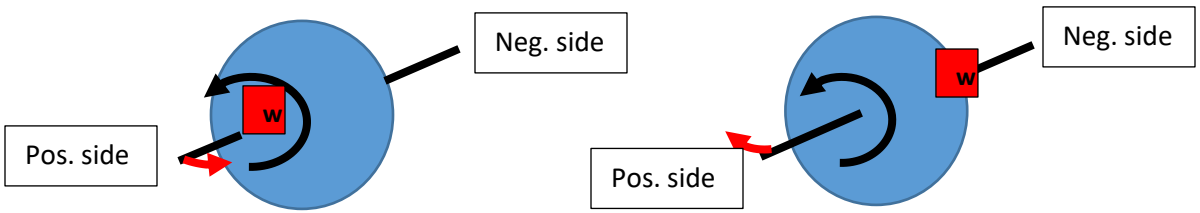
Summary:

The goal is to build a ball that can be adjusted to determine if a large balance hole increases the ball reaction more than changing the static weight limits to 3 oz. in all directions.

Initial results show that ball with a large balance hole which is designed to increase flare will hook more than a ball with an increase in static weights hooked.

Discussion:

A new ball specification that would eliminate all balance holes in a ball but allow static weight to increase to 3 oz. in any direction has been proposed and needs further investigation. Static weight along the spin axis affects the precession rate of a rotating ball. This rotational force changes how quickly the axis point rotates around the ball. Adding weight along the positive axis side (red box in picture on left) make the spinning ball want to rotate backwards (red arrow in left picture) adding to the hook potential. Weight along the negative axis (red box in picture on right) makes the ball want to rotate forward (red arrow on right) which reduces the potential hook.

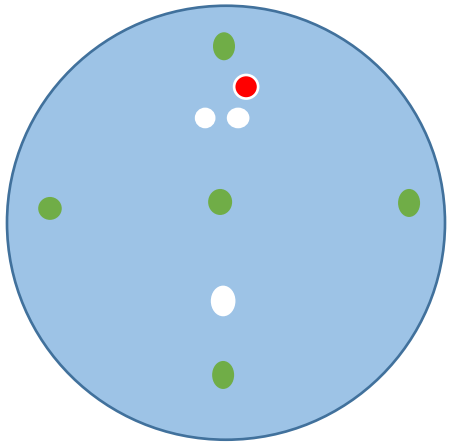


We need to measure how this force affects a rotating bowling ball with up to 3 oz. of imbalance measured in three directions.

Test# 1

A test ball was built using commercial available, adjustable finger inserts with different interchangeable slugs to adjust the static weights. The ball was drilled with a 5” pin (red location in picture below) to PAP for our ball tester. Six interchangeable inserts were installed in the ball (green locations in picture below):

- At center of grip (to add top weight)
- 6-3/4” to the right from center of grip (to add side weight)
- 6-3/4” to the left from center of grip (to add negative side weight)
- 6-3/4” from pin below center of grip past the thumb hole (to add thumb weight)
- 6-3/4” from center of grip above the finger holes (to add finger weight)
- Opposite center of grip (to add bottom weight)



The ball had a 5” pin to PAP drilling. This was to try to get the ball to flare very little, so the static weight would not move relative to the PAP during the entire ball path.

Inserts were made to add 3 oz. of static weight in any direction. This required a 31/32” diameter steel rod x 1” long at ¼” from the bottom of the insert with ball plug on top and below the steel. Other inserts were built using just ball plug material to replace the original ball material that was removed from drilling the holes.

Below are the ball properties used during the test:

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Description	Top wt.	Side wt.	Finger wt.	Thumb wt.	RG	Diff RG
Before drilling	5				2.470	.053
Drilled and added 3.85 oz. slug in grip center	5				2.470	.069
Drilled and added 0.9 oz. slug in grip center	1.875				2.475	.052
3 oz. top/ side/ thumb	3	3		3	2.518	.051
3 oz. top/ side/ finger	3	3	3		2.517	.052
3 oz. top/ neg. side/ finger	3	-3	3		2.517	.052
3 oz. bottom/neg side/ thumb	-3	-3		3	2.518	.050
3 oz. bottom/side/ thumb	-3	3		3	2.518	.051
3 oz. bottom/side/ finger	-3	3	3		2.458	.052
3 oz. bottom/neg. side/ finger	-3	-3	3		2.458	.052
Minimum static weights	0	0	0			

A ball with 3 oz. positive side, 3 oz. thumb weight and 3 oz. top weight was measured on a bowling ball scale and determined to have 5-1/8 oz. of imbalance at the point in the middle of these three locations. Mathematically, a ball with 3 oz. of imbalance at three locations will have a maximum imbalance of:

$$\sqrt{(3^2 + 3^2 + 3^2)} = \sqrt{27} = 5.19 \text{ oz.}$$

The existing static weight spec (3 oz. top, 1 oz. side and 1 oz. finger/thumb) allows a maximum imbalance of:

$$\sqrt{(3^2 + 1^2 + 1^2)} = \sqrt{11} = 3.32 \text{ oz.}$$

The ball tester threw the ball on a flat 35-foot oil pattern which hooked a lot. He bowled until he had 5 or 6 good shots with each ball. The results are from Specto. Below is the lane graph of the average ball path for each static weight combination.

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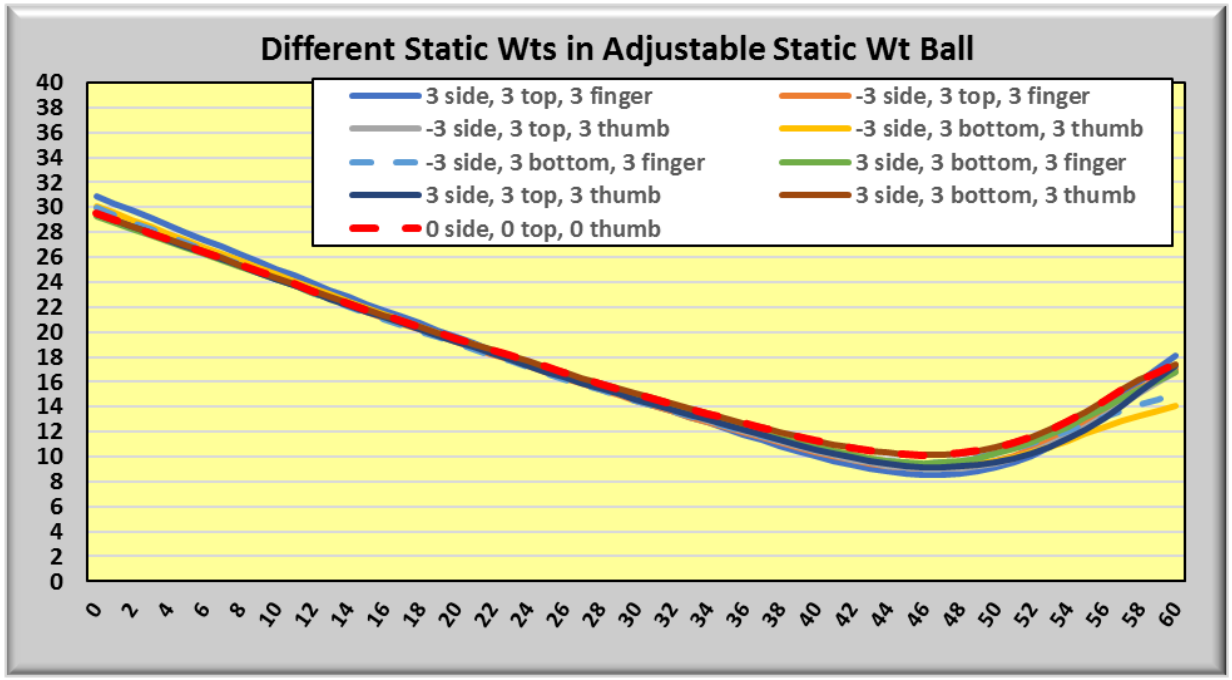
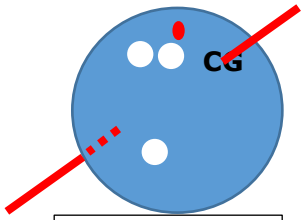


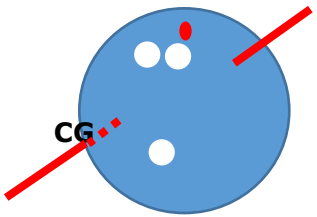
The red dotted line is the 0, 0, 0 oz. static weight ball (base line drilling). This will be used as a reference line in all attached charts to follow in this report.

By allowing 3-ounce in any direction for static weights, the tester was able to change the balls final position by four boards (from 14.1 to 18.1).

The most hooking ball had 3 oz. positive side, 3 oz. finger, and 3 oz. top. The least hooking ball had 3 oz. negative side, 3 thumb, and 3 bottom – these are opposite locations along axis line running through most hooking Cg location.

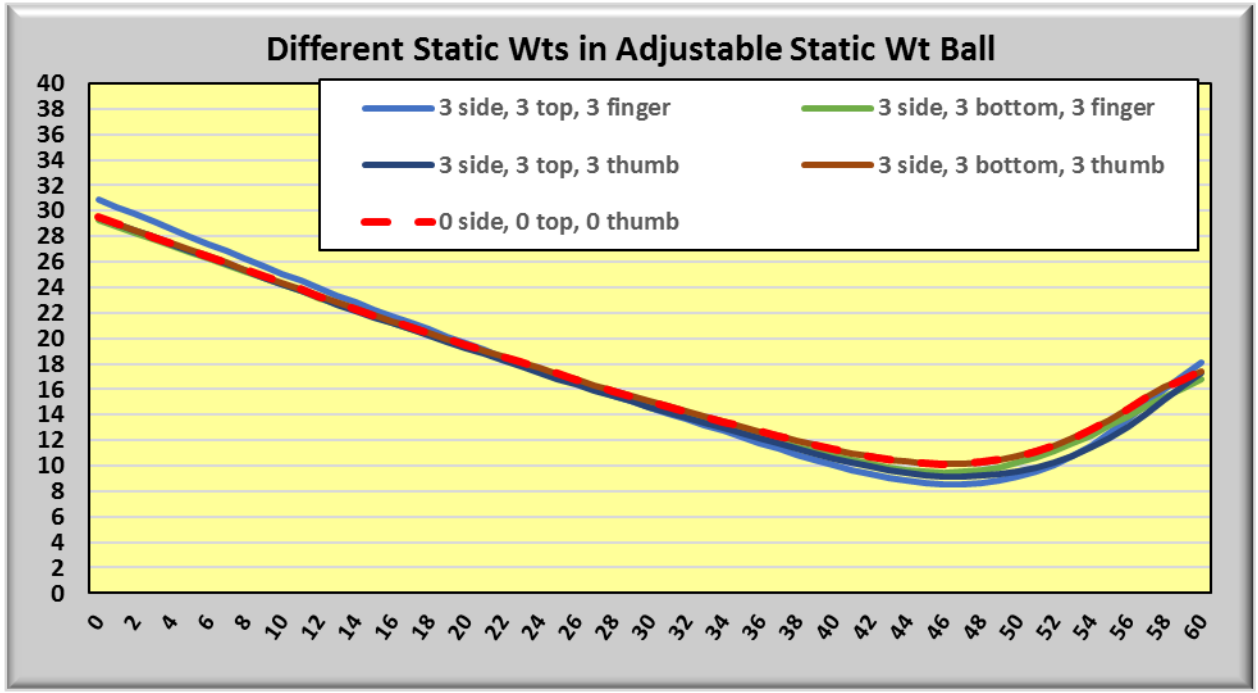


Most hooking



Least hooking- Cg on bottom side (opposite grip)

Below are all the +3 side wt. combinations:



All ball paths are similar. Below is the data that goes with each average ball path. The 3 oz. side, top and finger hooked the most:

- Hooked approximately 0.7 boards more than the 0-static weight ball
- Entry angle was almost 2 degrees more than the 0-static weight ball
- Went longer with more backend

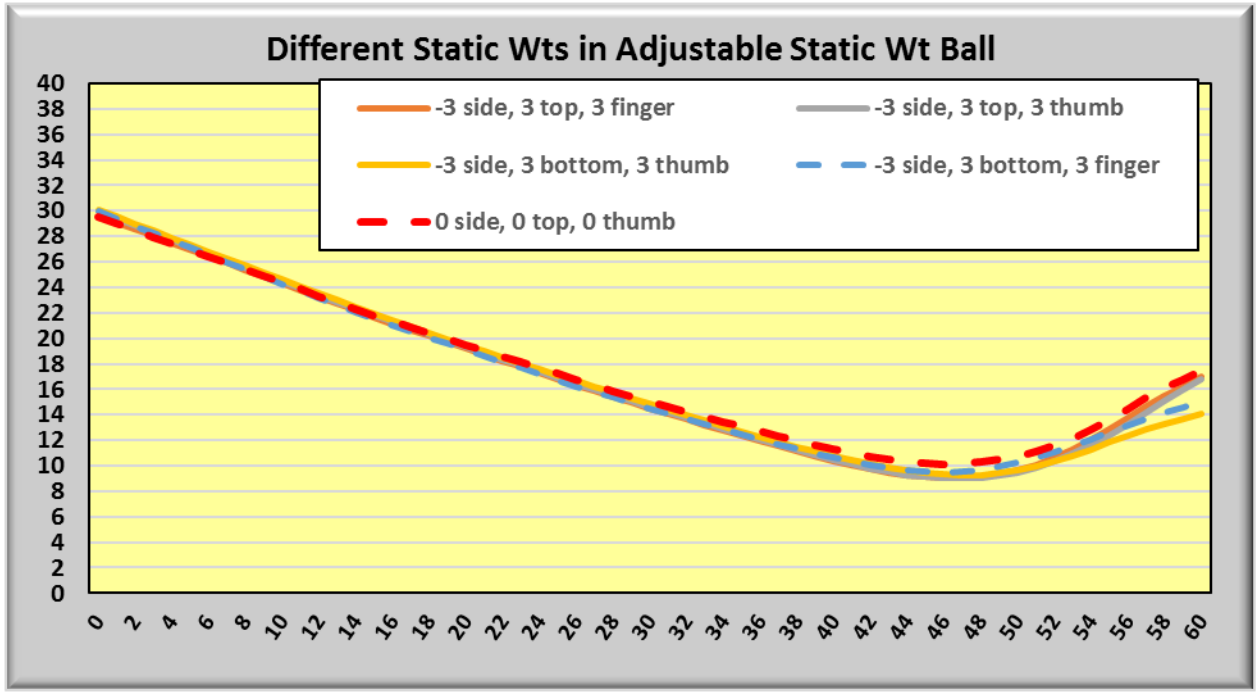
Data	3 side, 3 top, 3 finger	3 side, 3 bottom, 3 finger	3 side, 3 top, 3 thumb	3 side, 3 bottom, 3 thumb	0 side, 0 top, 0 thumb	Average
Positions 60	**18.08**	16.82	17.29	17.40	17.40	**16.66**
Launch Angle	-2.97	-2.58	-2.68	-2.62	-2.62	**-2.74**
Angle (53-57')	5.27	3.75	4.21	4.04	4.04	**3.90**
Entry Angle	**5.60**	3.65	**5.50**	3.69	3.69	**3.90**

total angle	**8.57**	6.23	**8.18**	6.31	6.31	**6.63**
4th phase of motion	no	yes	no	yes	yes	
Backup Angle (57-60')		0.11		0.36	0.36	
Positive Angle Change (57-60')	0.33		**1.29**			

The 3 oz. side, top and thumb ball had the greatest angle change in the last 7 feet of the lane (changing **1.29** degrees). This ball went longer down the lane before hooking later and sharper resulting in not hooking back as far.

Interesting that the 0-static weight ball has a 4th phase of motion (meaning it backed up in the last 7 feet having more entry angle between 53-57 feet then the final entry angle) as indicated in the above change with a "yes" in the 4th phase of motion row. This might be an issue with how Specto calculates the ball path. It uses a polynomial calculation and might be giving a false angle result when a ball stops hooking. But we can say that based on these results, a 0-static weight ball is acceptable today and therefore this amount of backup angle is accepted in today's game. Further testing will be conducted using BOLTS to measure the angle change and see if this is a Specto issue or correct result.

Below are all the -3 side wt. combinations:



The -3 oz. side weight combinations all hooked less boards than the 0-static weight ball or less. Two hooked much less:

- 3 oz. negative side, bottom and thumb hooked 3.3 boards less and 1.6 degree less entry angle
- 3 oz. negative side, bottom, and finger hooked 2.3 boards less and 1.27 degrees less entry angle

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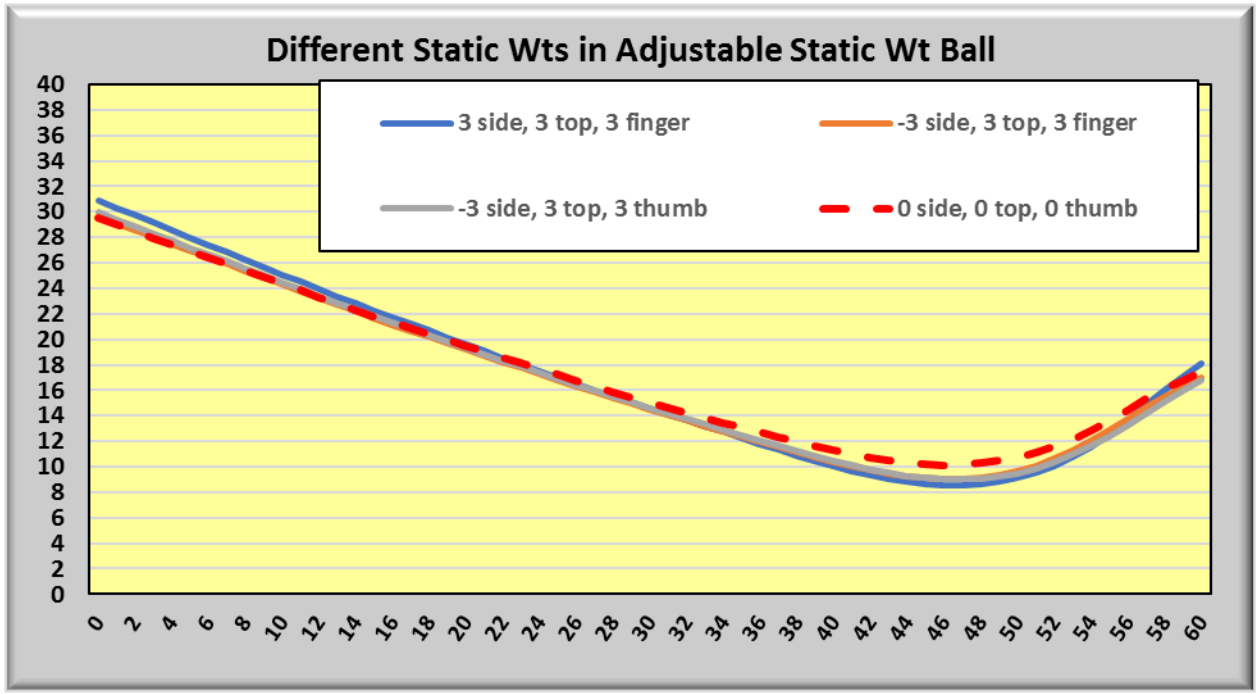
Data	-3 side, 3 top, 3 finger	-3 side, 3 top, 3 thumb	-3 side, 3 bottom, 3 thumb	-3 side, 3 bottom, 3 finger	0 side, 0 top, 0 thumb	Average
Positions 60	16.99	16.78	14.10	15.10	17.40	**16.66**
Launch Angle	-2.70	-2.79	-2.79	-2.88	-2.62	**-2.74**
Angle (53-57')	4.25	4.15	2.66	2.69	4.04	**3.90**
Entry Angle	**3.98**	**4.46**	2.09	2.42	3.69	**3.90**
Total angle	**6.68**	**7.25**	4.88	5.30	6.31	**6.63**
4th phase of motion	yes	no	yes	yes	yes	
Backup Angle (57-60')	0.27		**0.57**	0.27	0.36	
Positive Angle Change (57-60')		0.31				

The 3 oz. negative side, bottom and thumb had the most backup angle (**0.57** degrees) but only .2 degree less than the 0-static weight ball.

Below are all the 3 oz. top wt. combinations:

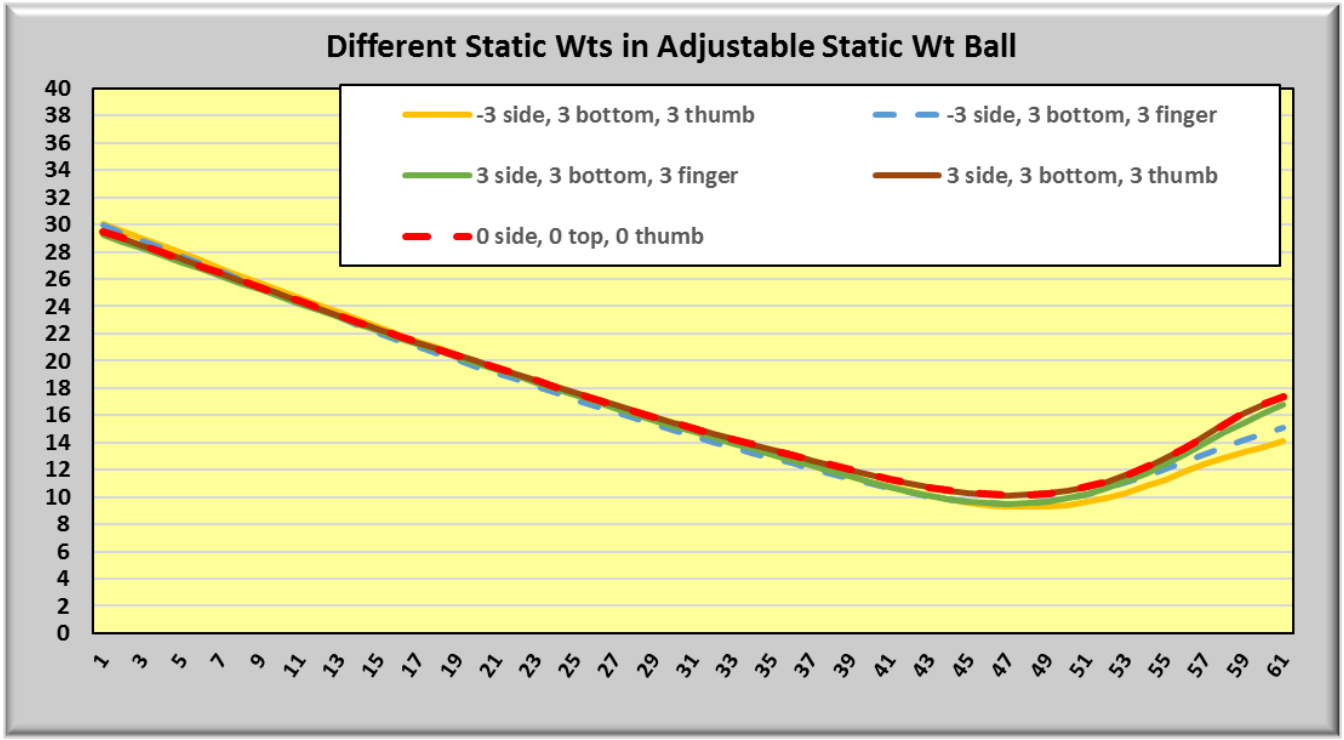


All the 3 oz. top weight combinations hooked within +/- 0.7 boards of the 0-static weight ball. All had more entry angle with the 3 oz., top, side and finger ball having almost 2-degrees more entry angle. We probably should compare these balls to a ball with 3 oz. top, 1 oz. side and 1 oz. of finger/thumb (all legal with today's 3,1,1 oz. static weight specs).

Data	3 side, 3 top, 3 finger	-3 side, 3 top, 3 finger	-3 side, 3 top, 3 thumb	3 side, 3 top, 3 thumb	0 side, 0 top, 0 thumb	Average
Positions 60	**18.08**	16.99	16.78	17.29	17.40	**16.66**
Launch Angle	-2.97	-2.70	-2.79	-2.68	-2.62	**-2.74**
Angle (53-57')	5.27	4.25	4.15	4.21	4.04	**3.90**
Entry Angle	**5.60**	**3.98**	**4.46**	**5.50**	3.69	**3.90**
Total angle	**8.57**	**6.68**	**7.25**	**8.18**	6.31	**6.63**
4th phase of motion	no	yes	no	no	yes	

Backup Angle (57-60')		0.27			0.36	
Positive Angle Change (57-60')	0.33		0.31	1.29		

Below are all the 3 oz. bottom wt. combinations:



All combinations with 3 oz. of bottom weight hook the same or less than the 0-static weight and had the same or less entry angle.

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Data	-3 side, 3 bottom, 3 thumb	-3 side, 3 bottom, 3 finger	3 side, 3 bottom, 3 finger	3 side, 3 bottom, 3 thumb	0 side, 0 top, 0 thumb	Average
Positions 60	14.10	15.10	16.82	17.40	17.40	**16.66**
Launch Angle	-2.79	-2.88	-2.58	-2.62	-2.62	**-2.74**
Angle (53-57')	2.66	2.69	3.75	4.04	4.04	**3.90**
Entry Angle	2.09	2.42	3.65	3.69	3.69	**3.90**
Total angle	4.88	5.30	6.23	6.31	6.31	**6.63**
4th phase of motion	yes	yes	yes	yes	yes	
Backup Angle (57-60')	0.57	0.27	0.11	0.36	0.36	
Positive Angle Change (57-60')						

All balls had a small amount of backup angle but similar to the 0 oz. static weight ball.

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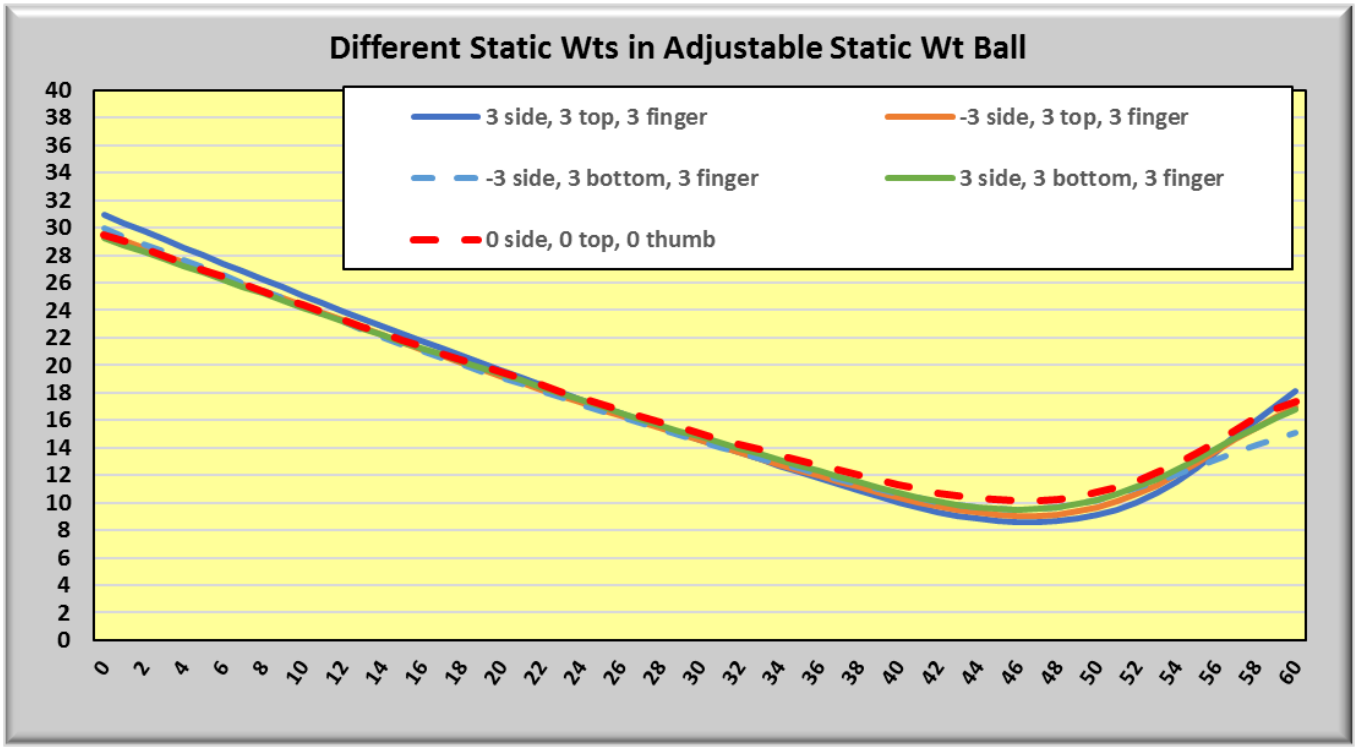
All 3 oz. finger wt. combinations:



One finger weight ball hooked more than the 0-static weight ball and 3 hooked less. Some had more entry angle than the 0-static weight ball and some had less. Finger weight does not have any consistent trend.

Data	3 side, 3 top, 3 finger	-3 side, 3 top, 3 finger	-3 side, 3 bottom, 3 finger	3 side, 3 bottom, 3 finger	0 side, 0 top, 0 thumb	Average
Positions 60	**18.08**	16.99	15.10	16.82	17.40	**16.66**
Launch Angle	-2.97	-2.70	-2.88	-2.58	-2.62	**-2.74**
Angle (53-57')	5.27	4.25	2.69	3.75	4.04	**3.90**
Entry Angle	**5.60**	**3.98**	2.42	3.65	3.69	**3.90**

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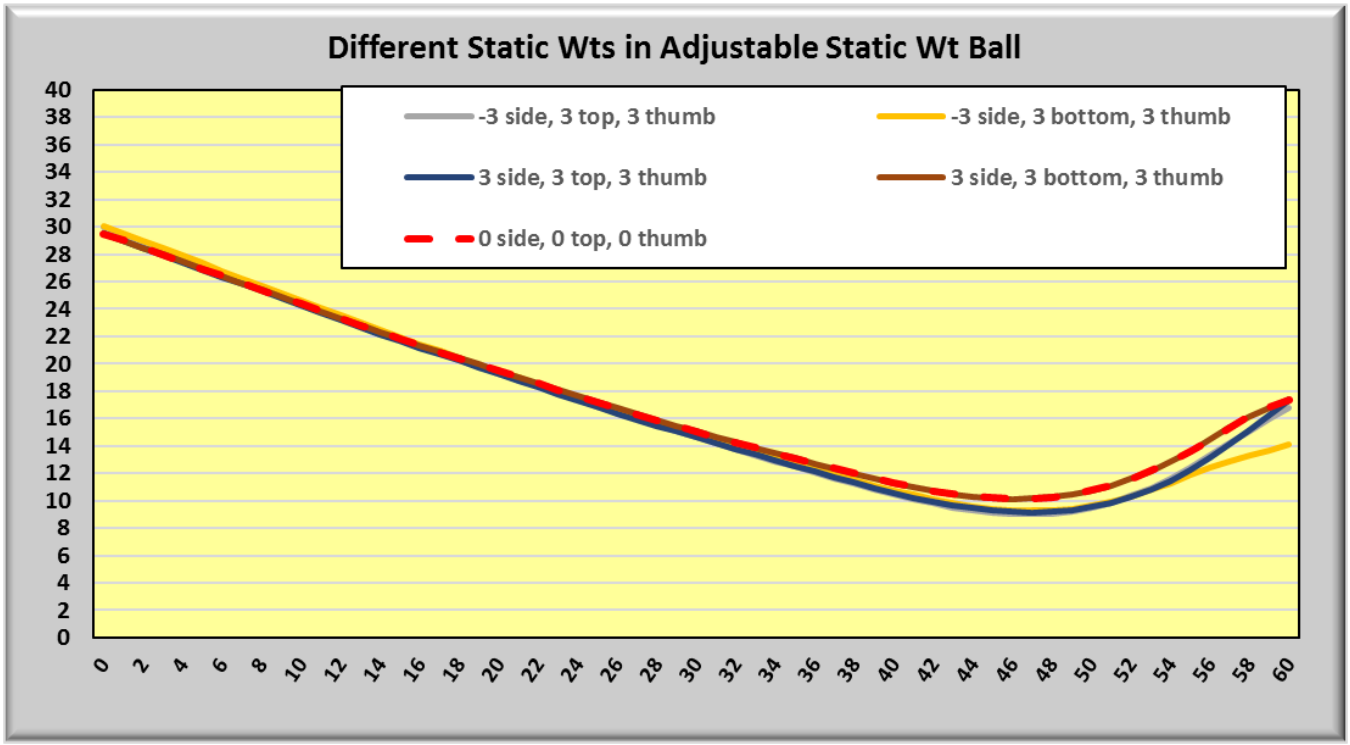
Total angle	8.57	6.68	5.30	6.23	6.31	6.63
4th phase of motion	no	yes	yes	yes	yes	
Backup Angle (57-60')		0.27	0.27	0.11	0.36	
Positive Angle Change (57-60')	0.33					

All 3 oz. thumb wt. combinations:



All the thumb weight balls hooked the same or less than the 0-static weight ball. Some had more entry angle, and some had less.

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Data	-3 side, 3 top, 3 thumb	-3 side, 3 bottom, 3 thumb	3 side, 3 top, 3 thumb	3 side, 3 bottom, 3 thumb	0 side, 0 top, 0 thumb	Average
Positions 60	16.78	14.10	17.29	17.40	17.40	**16.66**
Launch Angle	-2.79	-2.79	-2.68	-2.62	-2.62	**-2.74**
Angle (53-57')	4.15	2.66	4.21	4.04	4.04	**3.90**
Entry Angle	**4.46**	2.09	**5.50**	3.69	3.69	**3.90**
Total angle	**7.25**	4.88	**8.18**	6.31	6.31	**6.63**
4th phase of motion	no	yes	no	yes	yes	
Backup Angle (57-60')		0.57		0.36	0.36	
Positive Angle Change (57-60')	0.31		1.29			

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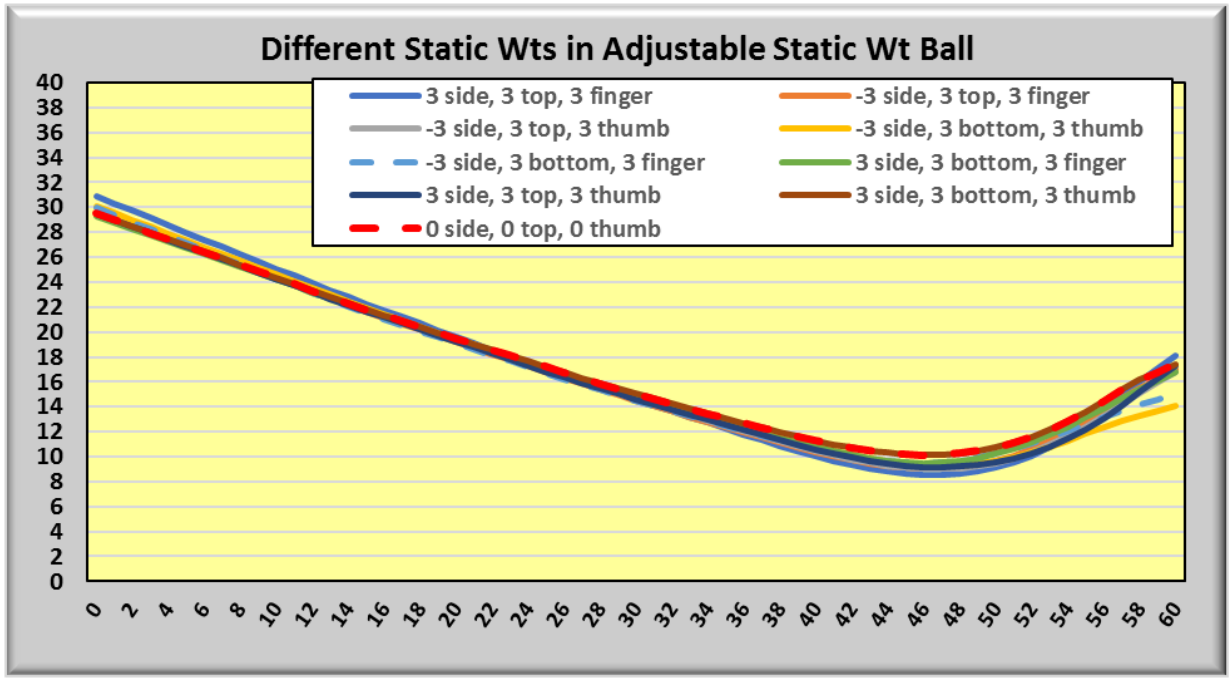
All Static weight combinations:



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Data	3 side, 3 top, 3 finger	-3 side, 3 top, 3 finger	-3 side, 3 top, 3 thumb	-3 side, 3 bottom, 3 thumb	-3 side, 3 bottom, 3 finger	3 side, 3 bottom, 3 finger	3 side, 3 top, 3 thumb	3 side, 3 bottom, 3 thumb	0 side, 0 top, 0 thumb	Avg
COF (0-40)	0.016	0.019	0.023	0.028	0.025	0.021	0.024	0.019	0.021	**0.022**
COF (40-44)	0.039	0.133	0.122	0.131	0.133	0.134	0.118	0.122	0.137	**0.119**
COF (44-48)	0.070	0.181	0.174	0.182	0.168	0.194	0.173	0.180	0.186	**0.168**
Positions 60	**18.08**	16.99	16.78	14.10	15.10	16.82	17.29	17.40	17.40	**16.66**
Launch Angle	-2.97	-2.70	-2.79	-2.79	-2.88	-2.58	-2.68	-2.62	-2.62	**-2.74**
Angle (53-57')	5.27	4.25	4.15	2.66	2.69	3.75	4.21	4.04	4.04	**3.90**
Entry Angle	**5.60**	**3.98**	**4.46**	2.09	2.42	3.65	**5.50**	3.69	3.69	**3.90**
Total angle	**8.57**	**6.68**	**7.25**	4.88	5.30	6.23	**8.18**	6.31	6.31	**6.63**
4th phase of motion	no	yes	no	yes	yes	yes	no	yes	yes	
Backup Angle (57-60') vs (53-57')		0.27		0.57	0.27	0.11		0.36	0.36	
Positive Angle Change (57-60')	0.33		0.31				1.29			

Summary of 3 oz. static weight combinations compared to 0-static weight ball:

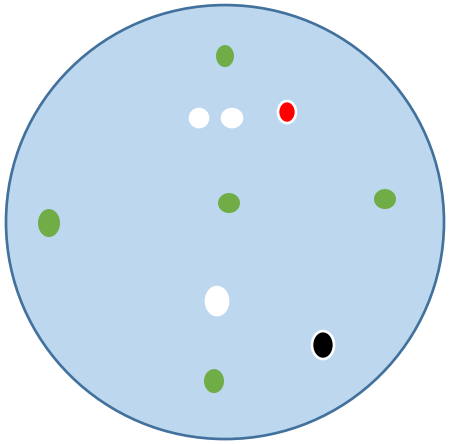
- Only one ball hooked more (3 oz. positive side, top and finger hooked .7 boards more)
- 4 balls had more entry angle
  - 3 oz. positive side, top and finger- 5.6 deg. (most)
  - 3 oz. positive side, top and thumb- 5.5 deg. (2nd most)
  - 3 oz. negative side, top and thumb- 4.5 deg. (3rd most)
  - 3 oz. negative side, top and finger- 3.98 deg. (4th)
  - Balls with more entry angle are a combination of different static weight excluding bottom weight (i.e. all had 3 oz. top weight)
  - For all these balls to have more entry angle but hook less overall, they must travel further down the lane before hooking which can be seen in the ball paths

Test #2 - 3 oz. static weight in any direction vs. added flare from weight hole

The second part of this test was to determine which hooked more:

- 3 oz. static weight in any direction
- Large balance located to increase differential RG

A 2nd ball was drilled to investigate the difference in the ball path with a balance hole vs. opening the static weight to 3 oz. in all directions. The ball was drilled like the first ball with the six adjustable static weight switch grip finger sleeves except the pin was located 3-3/8" from the PAP (leverage drilling) to maximize the track flare. Also, a 1-1/4" balance hole X 2-1/2" deep was added at 5-1/2" from the pin. An adjustable thumb insert sleeve was installed in the balance hole (black hole below) so that the ball could be tested with the balance hole or add a regular thumb slug to simulate no balance hole.



The ball used had .055 RG Differential and the following properties:

Properties	Top wt.	Side wt.	Finger wt.	Thumb wt.	RG	Diff RG
3 oz. top/ side/ finger	3	3	3		2.539	.051
3 oz. top/ side/ finger with regular slug in the balance hole	3	3	3		2.544	.051
3 oz. top/ side/ finger with balance hole	3	3	3		2.539	.063

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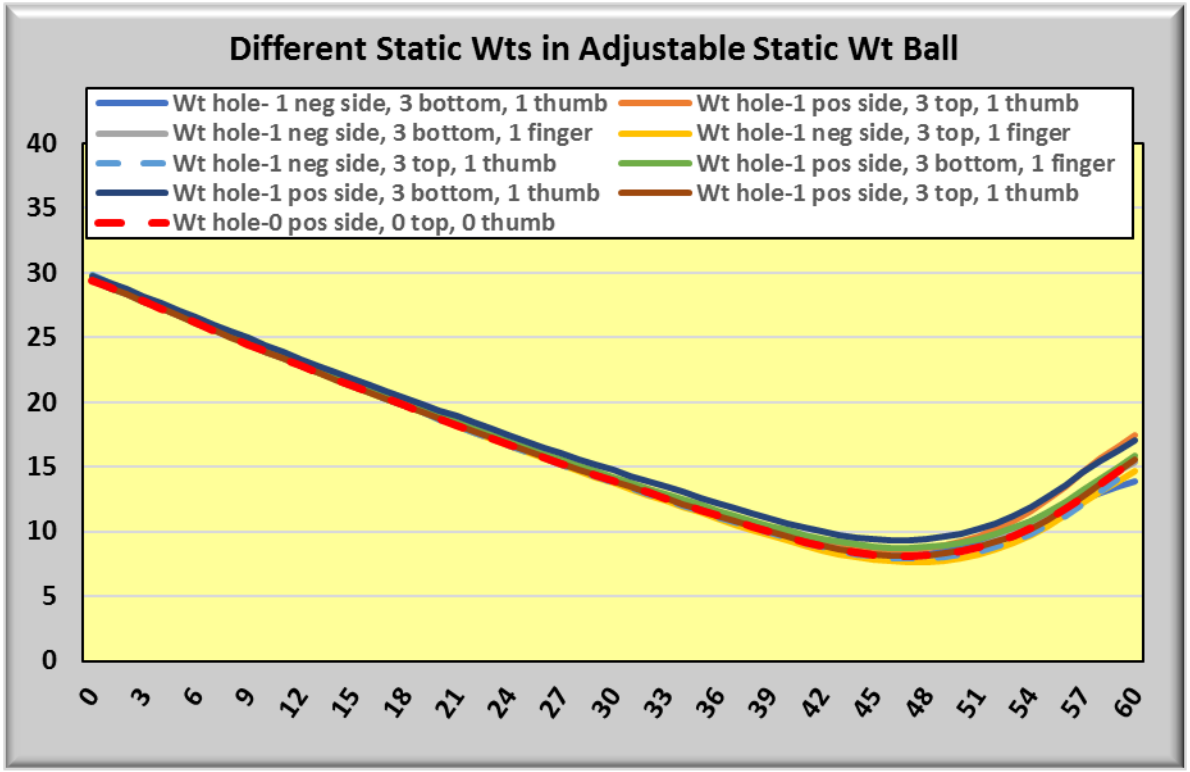
Using the thumb slug in the balance hole to replace the ball material removed from drilling returned the ball to the same diff RG (.051) and changed the Rg slightly (.005). Adding the balance hole, increased the diff RG by .012 (.051 vs .063).

For the first test, the ball was throw with the weight holes and various combinations of legal static weights (3 oz. top, 1 oz. side and 1 oz. finger/thumb). We wanted to determine what the range of ball paths were possible with adding a balance hole and changing static weights. These are all legal combinations with the current specifications. Each ball was thrown until 5 good shots were recorded to determine an average ball path.



The red dotted line is the 0-static weight ball. Below is the summary data for all balls. A quick look at the ball paths (chart above) and they appear similar except for the ball with a weight hole and -1 oz. side weight, 3 bottom and 1 thumb which hooked the least. Below we isolate this ball vs the 0-static weight ball and this ball just stops hooking on the backend.

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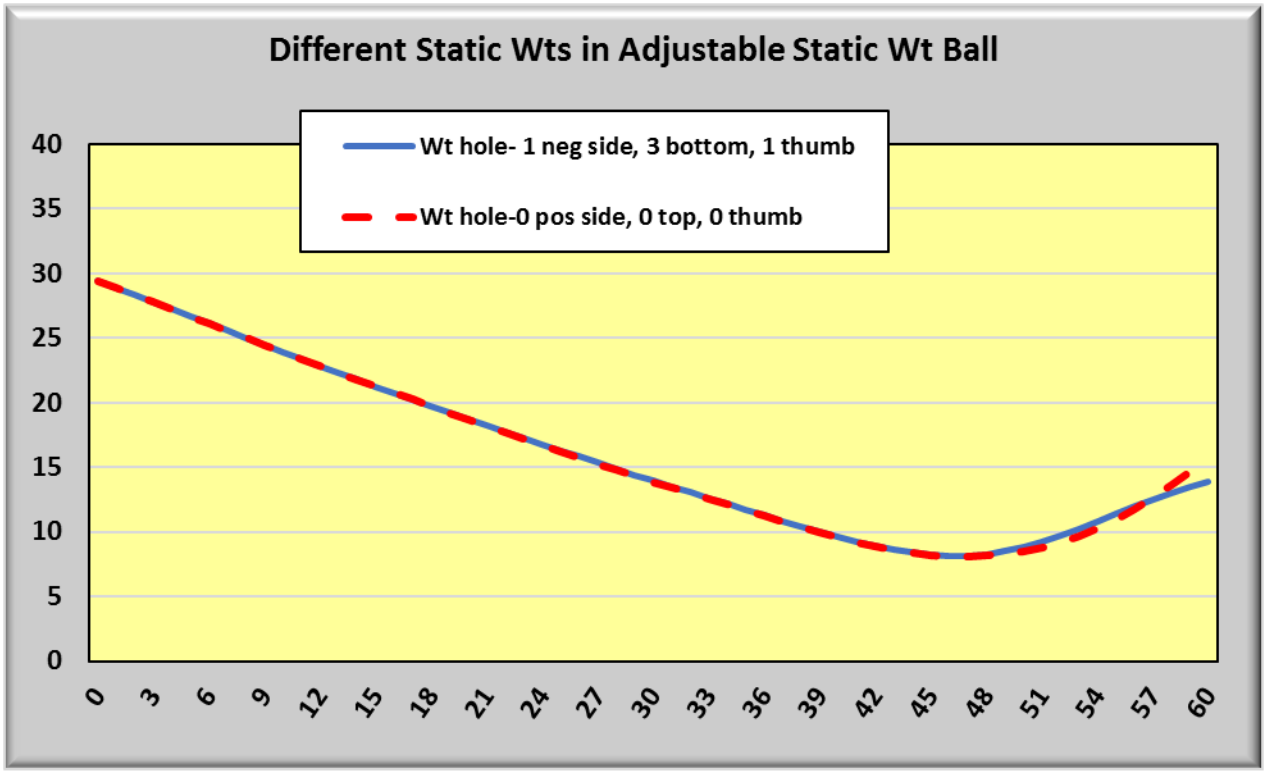

Below are the test results:

Data	Wt. hole-1 neg side, 3 bottom, 1 thumb	Wt. hole-1 pos. side, 3 top, 1 finger	Wt. hole-1 neg side, 3 bottom, 1 finger	Wt. hole-1 neg side, 3 top, 1 finger	Wt. hole-1 neg side, 3 top, 1 thumb	Wt. hole-1 pos. side, 3 bottom, 1 finger	Wt. hole-1 pos. side, 3 bottom, 1 thumb	Wt. hole-1 pos. side, 3 top, 1 thumb	Wt. hole-0 pos. side, 0 top, 0 thumb	AVG
COF (0-40)	0.018	0.021	0.019	0.019	0.021	0.025	0.020	0.016	0.021	**0.020**
COF (40-44)	0.040	0.113	0.136	0.127	0.119	0.122	0.114	0.121	0.128	**0.113**
COF (44-48)	0.074	0.164	0.195	0.178	0.171	0.181	0.160	0.163	0.179	**0.163**

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Speeds 0	15.83	15.85	**16.35**	**16.19**	**16.22**	**16.34**	**16.24**	16.11	**16.26**	**16.16**
Positions 60	13.92	**17.47**	15.39	14.71	15.11	**15.81**	**17.02**	15.61	15.61	**15.63**
Launch Angle	-2.80	-2.81	-2.81	-2.86	-2.93	-2.85	-2.73	-2.80	-2.80	**-2.82**
Angle (53-57')	2.91	4.73	4.05	3.98	3.68	3.69	4.29	3.84	3.84	**3.89**
Entry Angle	2.37	**5.02**	4.01	4.25	**5.02**	4.59	4.40	4.97	4.97	**4.40**
Total angle	5.17	**7.83**	6.82	7.11	**7.95**	7.44	7.13	7.77	7.77	**7.22**
4th phase of motion	yes	no	yes	no	no	no	no	no	no	
Backup Angle (57-60') vs (53-57')	0.548		0.042							
Positive Angle Change (57-60')		0.285		0.276	1.345	0.900	0.103	1.135	1.135	

Summary of results for a ball with a large balance hole within current static weights:

- Total range of hook was 3.6 boards of hook (13.9 to 17.5 boards)
- Total range of entry angle was 2.6 degrees (2.4 to 5.0 degrees)
- Two balls (one very minor) backed up (4th phase of motion) in the last 7 feet of lane
- Most balls (7 out of 9) had a positive change in their entry angle (angle still increasing) in the last 7 feet of lane including the 0-static weight ball

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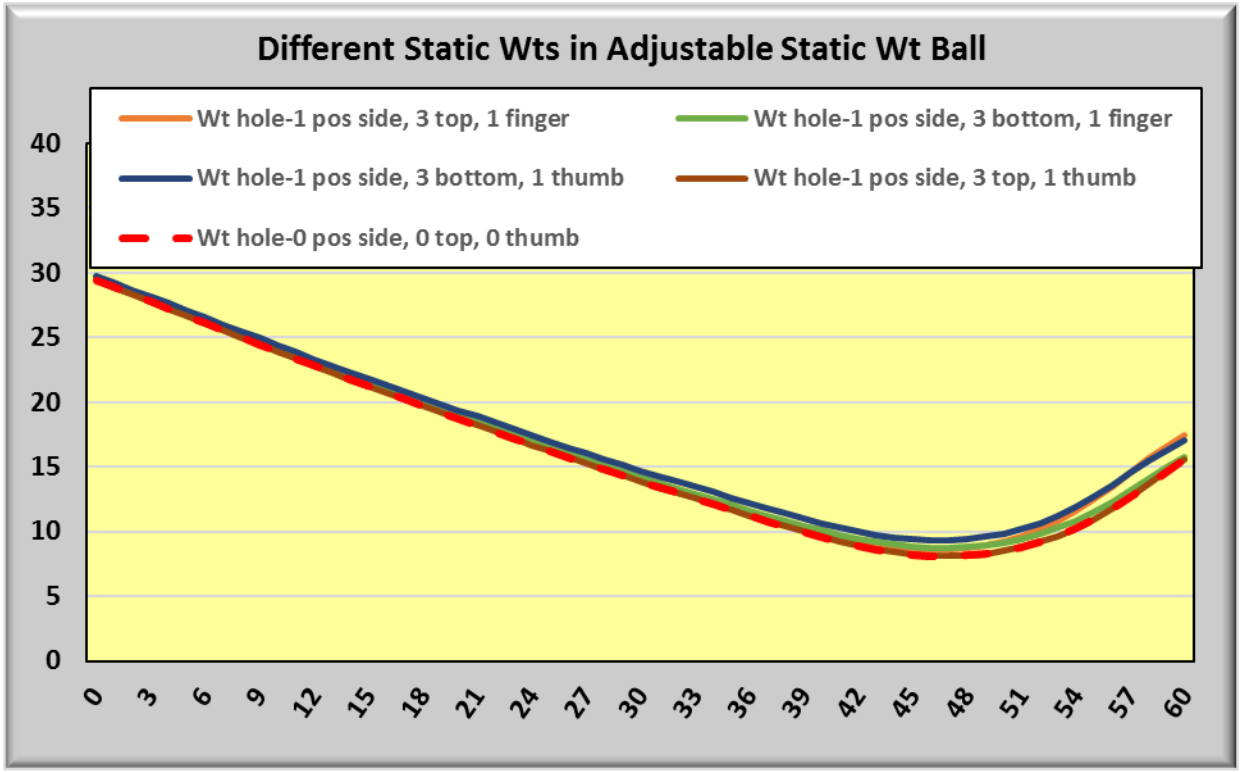
The following balls hooked the same or more than the 0-static weight ball.



ENGINEERING REPORT

Data	Wt hole-1 pos side, 3 top, 1 finger	Wt hole-1 pos side, 3 bottom, 1 finger	Wt hole-1 pos side, 3 bottom, 1 thumb	Wt hole-1 pos side, 3 top, 1 thumb	Wt hole-0 pos side, 0 top, 0 thumb	Average
COF(0-40)	0.021	0.025	0.020	0.016	0.021	**0.020**
COF(40-44)	0.113	0.122	0.114	0.121	0.128	**0.113**
COF(44-48)	0.164	0.181	0.160	0.163	0.179	**0.163**
Speeds 0	15.846	**16.342**	**16.244**	16.113	**16.264**	**16.155**
Positions 60	**17.473**	**15.811**	**17.017**	15.607	15.607	**15.628**
LaunchAngle	-2.807	-2.854	-2.734	-2.796	-2.796	**-2.820**
Angle(53-57')	4.735	3.686	4.294	3.836	3.836	**3.889**
EntryAngle	**5.020**	4.587	4.397	4.971	4.971	**4.399**
Total angle	**7.827**	7.440	7.131	7.767	7.767	**7.220**
4th phase of motion	no	no	no	no	no	
Backup Angle (57-60') vs (53-57')						
Positive Angle Change (57-60')	0.285	0.900	0.103	1.135	1.135	

Most hooking balls with balance hole and legal static weight combinations:

- Wt. hole-1 pos. side, 3 top, 1 finger – 17.5 board
- Wt. hole-1 pos. side, 3 bottom, 1 thumb- 17.0 board

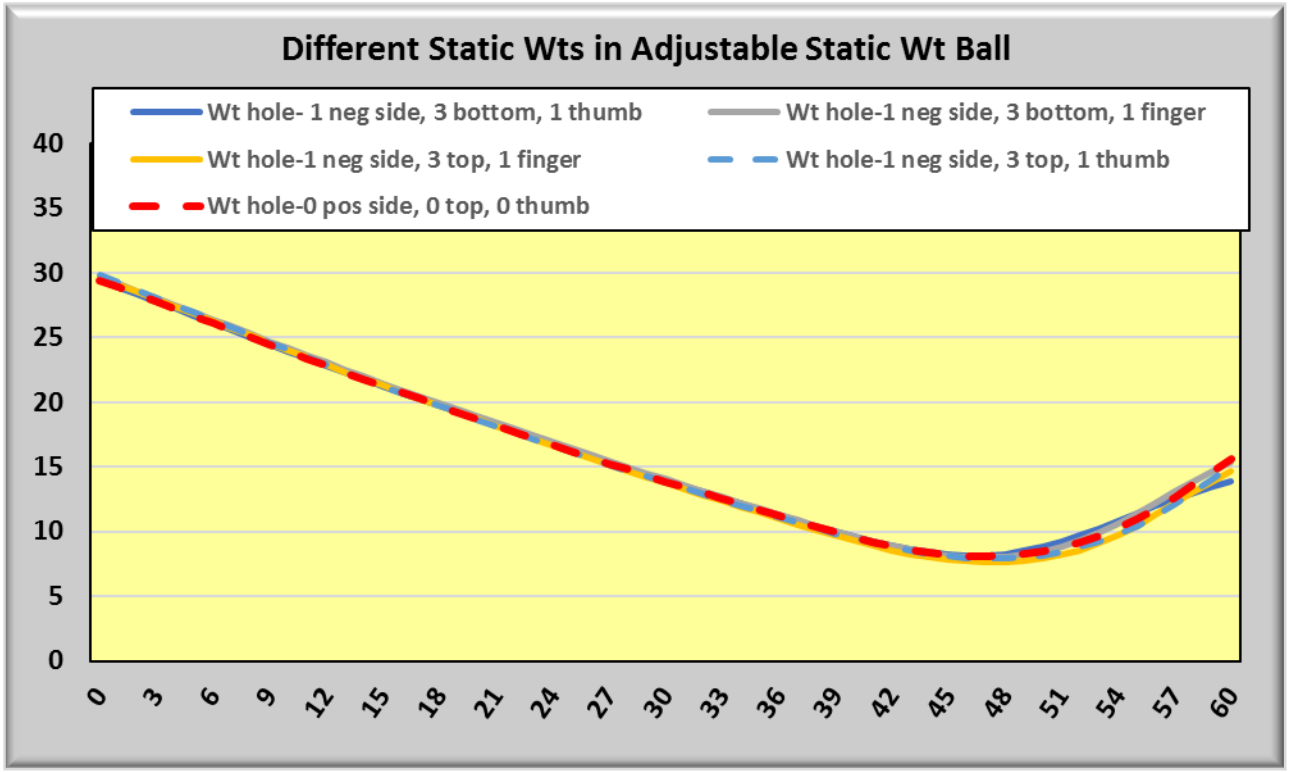
No ball that hooked more than the 0-static weight ball backed up in the last 7 feet of lane as noted with a "no" in the 4th phase of motion row.

The same two balls had more entry angle than the 0-static weight ball:

- Wt. hole-1 pos. side, 3 top, 1 finger – 0.9 degrees more
- Wt. hole-1 pos. side, 3 bottom, 1 thumb- 0.4 degrees more

ENGINEERING REPORT

The following balls hooked less than the 0-static weight balls:



ENGINEERING REPORT

Data	Wt. hole-1 neg side, 3 bottom, 1 thumb	Wt. hole-1 neg side, 3 bottom, 1 finger	Wt. hole-1 neg side, 3 top, 1 finger	Wt. hole-1 neg side, 3 top, 1 thumb	Wt. hole-0 pos side, 0 top, 0 thumb	Average
COF (0-40)	0.018	0.019	0.019	0.021	0.021	**0.020**
COF (40-44)	0.040	0.136	0.127	0.119	0.128	**0.113**
COF (44-48)	0.074	0.195	0.178	0.171	0.179	**0.163**
Speeds 0	15.83	**16.35**	**16.19**	**16.22**	**16.26**	**16.16**
Positions 60	13.92	15.39	14.71	15.11	15.61	**15.63**
Launch Angle	-2.80	-2.81	-2.86	-2.93	-2.80	**-2.82**
Angle (53-57')	2.91	4.05	3.98	3.68	3.84	**3.89**
Entry Angle	2.37	4.01	4.25	**5.02**	4.97	**4.40**
Total angle	5.17	6.82	7.11	**7.95**	7.77	**7.22**
4th phase of motion	yes	yes	no	no	no	
Backup Angle (57-60') vs (53-57')	0.548	0.042				
Positive Angle Change (57-60')			0.276	1.345	1.135	

The least hooking ball was:

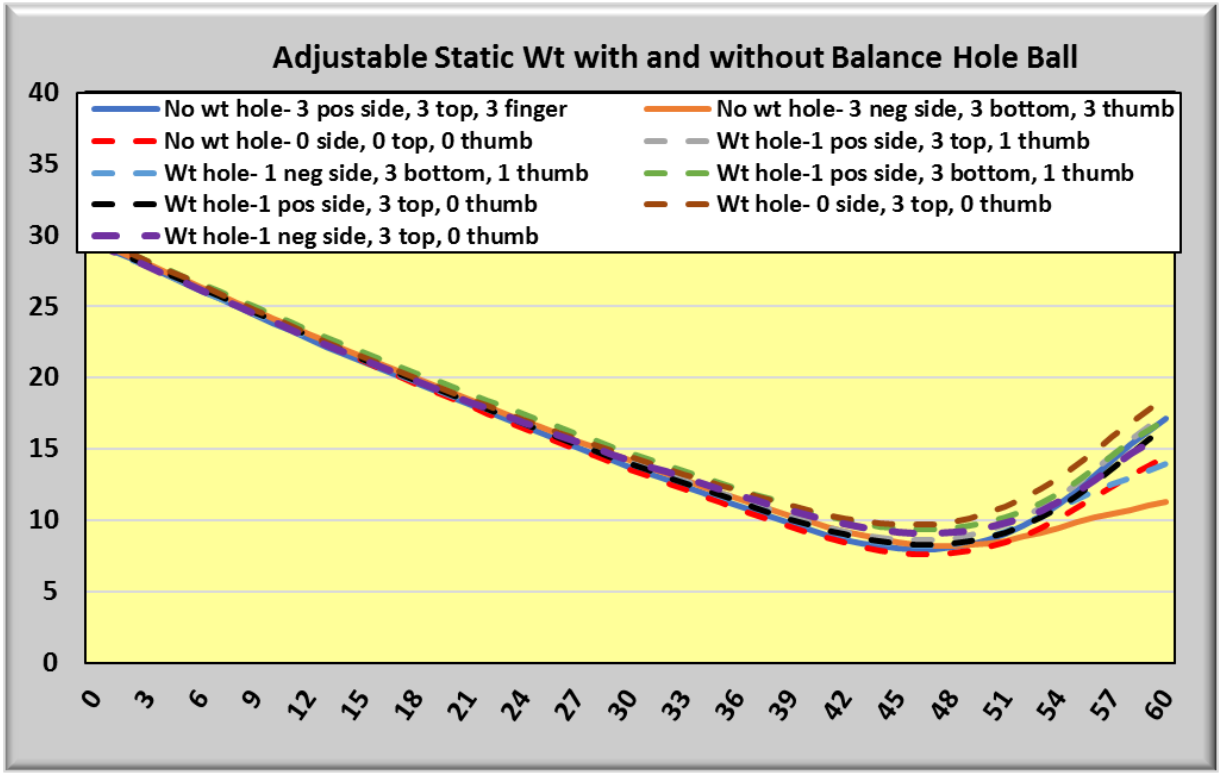
- Wt. hole- 1 neg side, 3 bottom, 1 thumb- 13.9 boards or 1.7 boards less than the 0 static weight ball

This same ball backed up .55 degrees in the last 7 feet of lane. This resulted in a 2.9-degree entry angle vs. 3.8- degree for the 0-static weight ball (0.9 degrees less). Again, this is a legal drilling with today's specifications and resulted in the back-up motion. (We still have to determine if this is a Specto calculation issues or if the ball really backs up).

Comparing balance hole to 3 oz. of static weight in any direction

A proposal was made to eliminate the balance in all balls which will reduce the flare potential of ball, while increasing the allowable static weights to 3 oz. in any direction. Therefore, we tested both of these ideas with our adjustable ball to determine how they affect the ball path. Again, the ball was drilled with leverage weight and built with adjustable static weights for 3 oz. in any direction.

Below are the results:



Once again, the red dotted line is the no weight hole with 0-static weight, baseline ball.

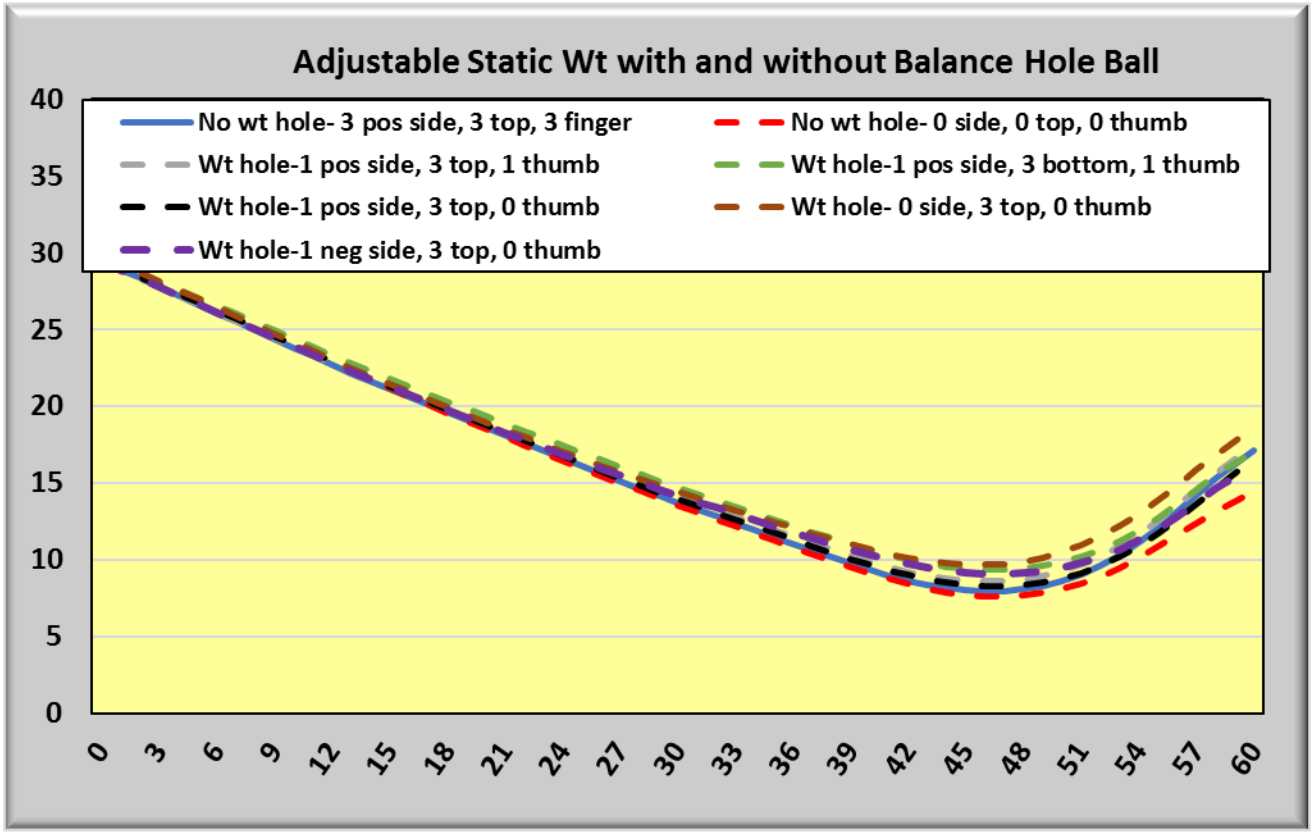
ENGINEERING REPORT

Data	No wt. hole- 3 pos. side, 3 top, 3 finger	No wt. hole- 3 neg side, 3 bottom, 3 thumb	No wt. hole- 0 side, 0 top, 0 thumb	Wt. hole- 1 pos. side, 3 top, 1 thumb	Wt. hole- 1 neg side, 3 bottom, 1 thumb	Wt. hole-1 pos. side, 3 bottom, 1 thumb	Wt. hole- 1 pos. side, 3 top, 0 thumb	Wt. hole- 0 side, 3 top, 0 thumb	Wt. hole- 1 neg side, 3 top, 0 thumb
COF (0-40)	0.023	0.024	0.021	0.021	0.018	0.020	0.023	0.023	0.022
COF (40-44)	0.039	0.130	0.126	0.113	0.140	0.114	0.131	0.128	0.112
COF (44-48)	0.069	0.179	0.178	0.164	0.184	0.160	0.180	0.174	0.153
Speeds 0	16.30	16.15	16.17	15.85	15.83	16.24	16.05	16.28	15.94
Positions 60	**17.08**	11.31	14.47	**17.47**	13.92	**17.02**	**16.50**	**18.62**	16.11
Launch Angle	-2.87	-2.76	-2.90	-2.81	-2.80	-2.73	-2.78	-2.89	-2.82
Angle (53-57')	5.01	1.70	3.72	4.73	2.91	4.29	4.37	4.67	3.89
Entry Angle	**5.17**	1.38	3.58	**5.02**	2.37	**4.40**	**5.08**	**4.75**	4.28
Total angle	**8.04**	4.15	6.48	**7.83**	5.17	**7.13**	**7.87**	**7.64**	7.10
4th phase of motion	no	yes	yes	no	yes	no	no	no	no
Backup Angle)		0.32	0.14		0.55				
Positive Angle Change	0.16			0.28		0.10	0.72	0.080	0.388

Results summary:

- Range for boards of hook
  - For balls with weight hole and legal static weights- 13.9 to 18.6 boards (4.7 boards)
  - For balls with no weight hole and 3 oz. max in any direction- 11.3 to 17.1 (6.2 boards)
- Range is larger but on the less hooking end (not more hook)
  - Most hooking ball was the ball that met current specs with weight hole and 0 side, 3 top, 0 thumb
- Range for entry angle
  - For balls with weight hole and legal static weights- 2.9 to 4.7 (1.8 degree range)
  - For balls with no weight hole and 3 oz. max in any direction- 1.7 to 5 (3.3 degree range)
  - Ball with most angle had no weight hole and 3 positive side, 3 top, 3 finger which had 5.2 degree entry angle
- 2nd place ball was ball with weight hole and 1 positive side, 3 top, 1 thumb with 5.1 degree entry angle

Balls that hooked more than ball with no weight hole and 0-static weight:



Most hooking balls were a combination of two balls with balance holes and legal static weights along with a ball without balance hole and 3 oz. static weights in the positive/ top/ finger static weight combination.

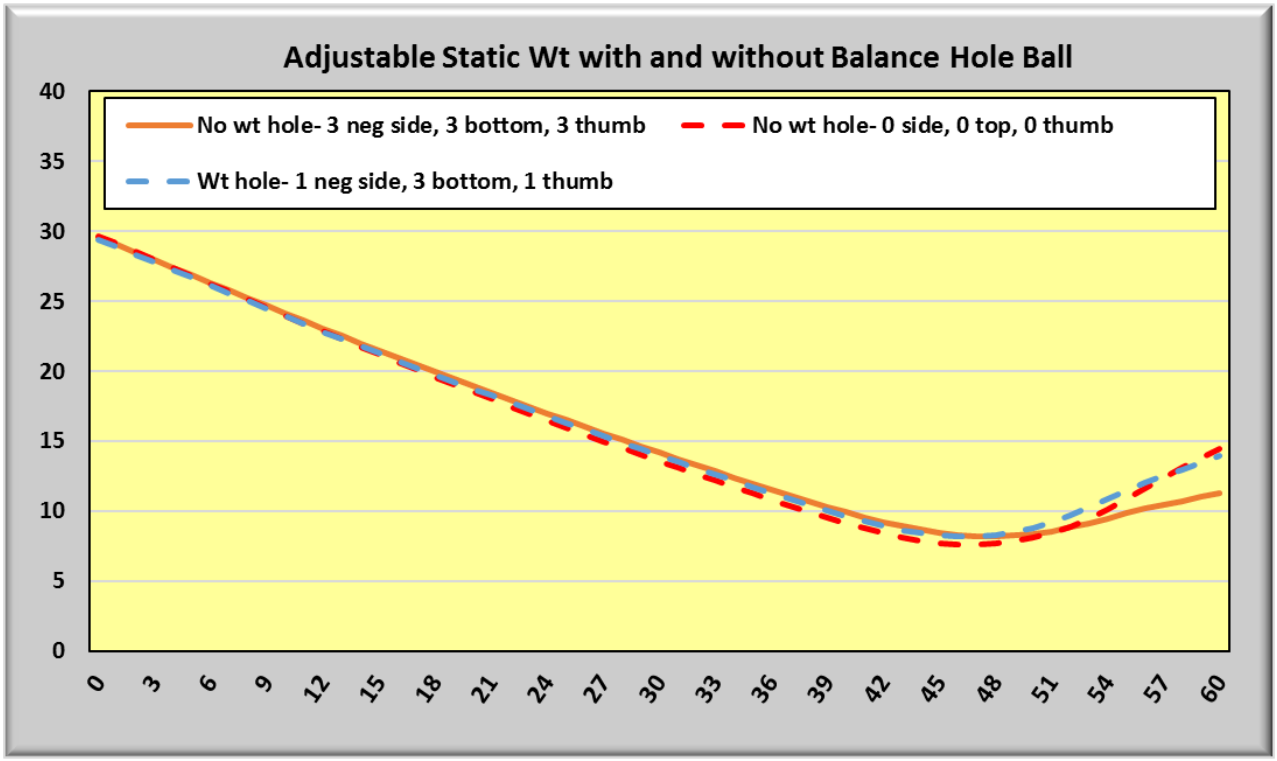
ENGINEERING REPORT

Data	No wt. hole-3 pos. side, 3 top, 3 finger	No wt. hole-0 side, 0 top, 0 thumb	Wt. hole-1 pos. side, 3 top, 1 thumb	Wt. hole-1 pos. side, 3 bottom, 1 thumb	Wt. hole-1 pos. side, 3 top, 0 thumb	Wt. hole-0 side, 3 top, 0 thumb	Wt. hole-1 neg side, 3 top, 0 thumb
COF (0-40)	0.023	0.021	0.021	0.020	0.023	0.023	0.022
COF (40-44)	0.039	0.126	0.113	0.114	0.131	0.128	0.112
COF (44-48)	0.069	0.178	0.164	0.160	0.180	0.174	0.153
Speeds 0	16.30	16.17	15.85	16.24	16.05	16.28	15.94
Positions 60	**17.08**	14.47	**17.47**	**17.02**	**16.50**	**18.62**	16.11
Launch Angle	-2.87	-2.90	-2.81	-2.73	-2.78	-2.89	-2.82
Angle (53-57')	5.01	3.72	4.73	4.29	4.37	4.67	3.89
Entry Angle	**5.17**	3.58	**5.02**	**4.40**	**5.08**	**4.75**	4.28
Total angle	**8.04**	6.48	**7.83**	**7.13**	**7.87**	**7.64**	7.10
4th phase of motion	no	yes	no	no	no	no	no
Backup Angle		0.14					
Positive Angle Change	0.16		0.28	0.10	0.72	0.080	0.388

The 6 balls that hooked more than the 0-static weight ball:

- Hooked from 17.0 to 18.6 boards vs 14.5 for the 0 static weight ball with no weight hole
- Had entry angles between 4.3 and 5.0 degrees vs 3.7 for the 0-static weight ball with no wt. hole
- 5 balls met current specs and 1 had no weight hole with 3 oz. positive side, top and finger weights

The two balls that hooked less than the ball with no weight hole and 0-static weight:



The two balls that hooked less than the 0-static weight ball, both had negative, bottom, and thumb with one having a weight hole with legal static weight and one having no weight hole with 3 oz. of imbalance in all directions.

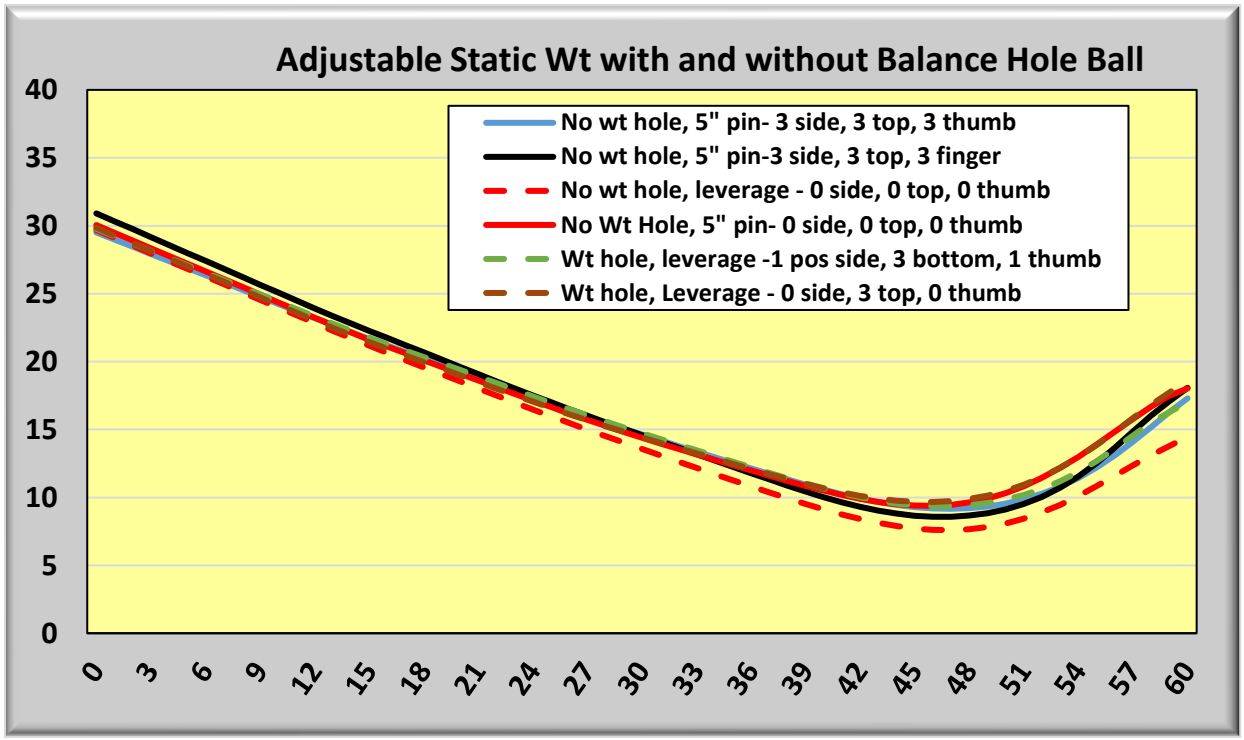
Data	No wt. hole- 3 neg side, 3 bottom, 3 thumb	No wt. hole- 0 side, 0 top, 0 thumb	Wt. hole- 1 neg side, 3 bottom, 1 thumb
COF (0-40)	0.024	0.021	0.018
COF (40-44)	0.130	0.126	0.140
COF (44-48)	0.179	0.178	0.184
Speeds 0	16.15	16.17	15.83
Positions 60	**11.31**	14.47	**13.92**
Launch Angle	-2.76	-2.90	-2.80
Angle (53-57')	1.70	3.72	2.91
Entry Angle	**1.38**	3.58	**2.37**
Total angle	4.15	6.48	5.17
4th phase of motion	yes	yes	yes
Backup Angle	0.32	0.14	0.55

Most hooking balls from all Tests with Adjustable Static weight ball

Two adjustable weight balls were built:

- 5” pin, no weight hole and adjust static weights up to 3 oz. in all directions
- 3-3/8” pin, can add weight hole or not add weight hole with 3 oz. static weight in all directions

ENGINEERING REPORT



Data	No wt. hole, 5" pin- 3 side, 3 top, 3 thumb	No wt. hole, 5" pin-3 side, 3 top, 3 finger	No wt. hole, leverage - 0 side, 0 top, 0 thumb	No Wt. Hole, 5" pin- 0 side, 0 top, 0 thumb	Wt. hole, leverage -1 pos. side, 3 bottom, 1 thumb	Wt. hole, Leverage - 0 side, 3 top, 0 thumb
COF (0-40)	0.024	0.016	0.021	0.021	0.020	0.023
COF (40-44)	0.041	0.133	0.126	0.137	0.114	0.128
COF (44-48)	0.066	0.181	0.178	0.186	0.160	0.174
Speeds 0	16.28	16.01	16.17	15.95	16.24	16.28
Positions 60	17.29	18.08	14.47	18.03	17.02	**18.62**
Launch Angle	-2.68	-2.97	-2.90	-2.89	-2.73	-2.89
Angle (53-57')	4.21	5.27	3.72	4.61	4.29	4.67

Entry Angle	5.50	**5.60**	3.58	4.29	4.40	4.75
Total angle	8.18	8.57	6.48	7.19	7.13	7.64
4th phase of motion	no	no	yes	yes	no	no
Backup Angle			0.14	0.31		
Positive Angle Change (57-60')	1.29	0.33			0.10	0.080

Summary:

Most hook/ most entry angle balls:

Drilling	Static wt.	Boards of hook	Entry angle
Leverage w/ wt. hole	0 side, 3 top, 0 thumb	**18.6**	4.8
5" pin no wt. hole	0 side, 0 top, 0 thumb	**18.0**	4.6
5" pin no wt. hole	3 side, 3 top, 3 finger	18.1	**5.6**
5" pin no wt. hole	3 side, 3 top, 3 thumb	17.3	**5.5**

- Most hook came from ball drilled leverage with weight hole and legal static weights
- Most entry angle came from 5" pin with 3 oz. static weights