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Subject: RPM vs Ball Moment of Inertia- Bowlers Rotation Study

Date: 10/22/15

Place: International Training & Research Center

Present: Danny Speranza

Purpose:

Determine if bowlers generate different rotation when they use balls with different moment of inertias (MOI).

Summary:

Bowlers do rotate balls differently based on the moment of inertia of the ball. They get more rotation on low MOI balls and less rotation on high MOI balls. The rate of change follows the rotational energy equations very closely:

$$(½*I*w^2)_{ball1} = (½*I*w^2)_{ball2}$$

Data:

Bowlers were videotaped using the high-speed camera to measure their RPM rate with different moment of inertia balls. We have a specification on radius of gyration. The formula for RG is:

$$RG^2 = I/w$$

with: I=moment of inertia
w= weight

This allowed USBC to set one value for all weight balls. But, the same RG value will have totally different moments of inertia if the ball weight is changed, according to the chart below:

Weight (lbs.)	RG min (inches)	Min moment of inertia (lbs.*in^2)	RG max (inches)	Max moment of inertia (lbs.*in^2)
16	2.46	97	2.8	125
15	2.46	91	2.8	118
14	2.46	85	2.8	110
13	2.46	79	2.8	102

Moment of inertia, by definition, is resistance to rotating motion. Therefore, it makes sense that bowlers might rotate balls differently based on the moment of inertia of the ball.

Bowlers were asked to throw their normal balls. The moment of inertia was measured about their positive axis point (their rotation point) using the RG swing. The bowlers threw 10-12 shots with each ball and the rotation rate was measured at the release point (at foul line), along with the axis rotation angle. Both of these properties involve rotating the ball and could be affected by the moment of inertia of the ball.

Below are the bowlers' results:

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Bowler	Wt (#)	RG about PAP	Moment of Inertia about PAP	Measured RPM	Axis Rotation Angle	RPM delta	calc RPM delta	Calc RPM	Delta Axis angle
1	**13.9**	**2.532**	**89.2**	**337**	**51.5**			**337**	
1	14.1	2.593	94.5	321	48.2			327	
1	13.9	2.714	102.0	312	48.5	-25	-22	315	-3.0
2	**14.8**	**2.503**	**93.0**	**298**	**68.6**			**298**	
2	14.9	2.629	103.3	285	69.3	-13	-15	283	0.7
3	**14.2**	**2.57**	**93.5**	**248**	**61.9**			**248**	
3	15.0	2.548	97.3	239	59.2	-9	-5	243	-2.7
4	**15.1**	**2.513**	**95.1**	**219**	**68.5**			**219**	
4	15.1	2.719	111.5	211	74.2	-8	-17	202	5.7
5	**14.9**	**2.53**	**95.4**	**216**	**56.5**			**216**	
5	14.9	2.695	108.2	202	55.7	-14	-13	203	-0.8
6	**15.8**	**2.536**	**101.5**	**316**	**64.8**			**316**	
6	15.9	2.685	114.6	289	63.8	-27	-19	297	-1.0
7	**14.0**	**2.545**	**90.7**	**189**	**79.5**			**189**	
7	13.7	2.733	102.3	186	76.0	-2	-11	178	-3.5
8	**14.7**	**2.518**	**93.1**	**446**	**63.3**			**446**	
8	15.0	2.696	109.1	381	52.1	-65	-34	412	-11.2
9	**14.9**	**2.53**	**95.4**	**246**	**60.5**			**246**	
9	14.9	2.695	108.2	239	60.4	-7	-15	231	-0.2
10	**15.0**	**2.538**	**96.9**	**234**	**70.5**			**234**	
10	15.1	2.719	111.6	225	75.6	-9	-16	218	5.1
11	**14.8**	**2.503**	**93.0**	**302**	**65.2**			**302**	
11	14.9	2.629	103.3	292	65.2	-10	-15	287	0.1
12	**14.8**	**2.513**	**93.7**	**411**	**67.0**			**411**	
12	15.0	2.567	99.1	410	67.3	-1	-11	400	0.3
13	**14.9**	**2.532**	**95.7**	**405**	**54.6**			**405**	
13	15.0	2.621	103.3	396	52.9	-8	-15	389	-1.7
14	**15.0**	**2.554**	**97.5**	**319**	**74.2**			**319**	
14	14.8	2.631	102.2	315	74.7	-5	-7	312	0.5
Average	**14.8**	**2.6**	**99.7**	**292.7**	**63.8**	**-14.5**	**-15.4**	**292.5**	**-0.8**

Calculated results assume the RPM results for the **low** moment of inertia ball for each bowler are starting values (**start by using bold #'s)**. Then, calculate the RPM for high moment of inertia ball using the rotational energy equation.

The RPM delta is the measured difference in the RPM rate when comparing the low and high moment of inertia balls. The Calc. RPM delta is the theoretical RPM difference between the two balls.

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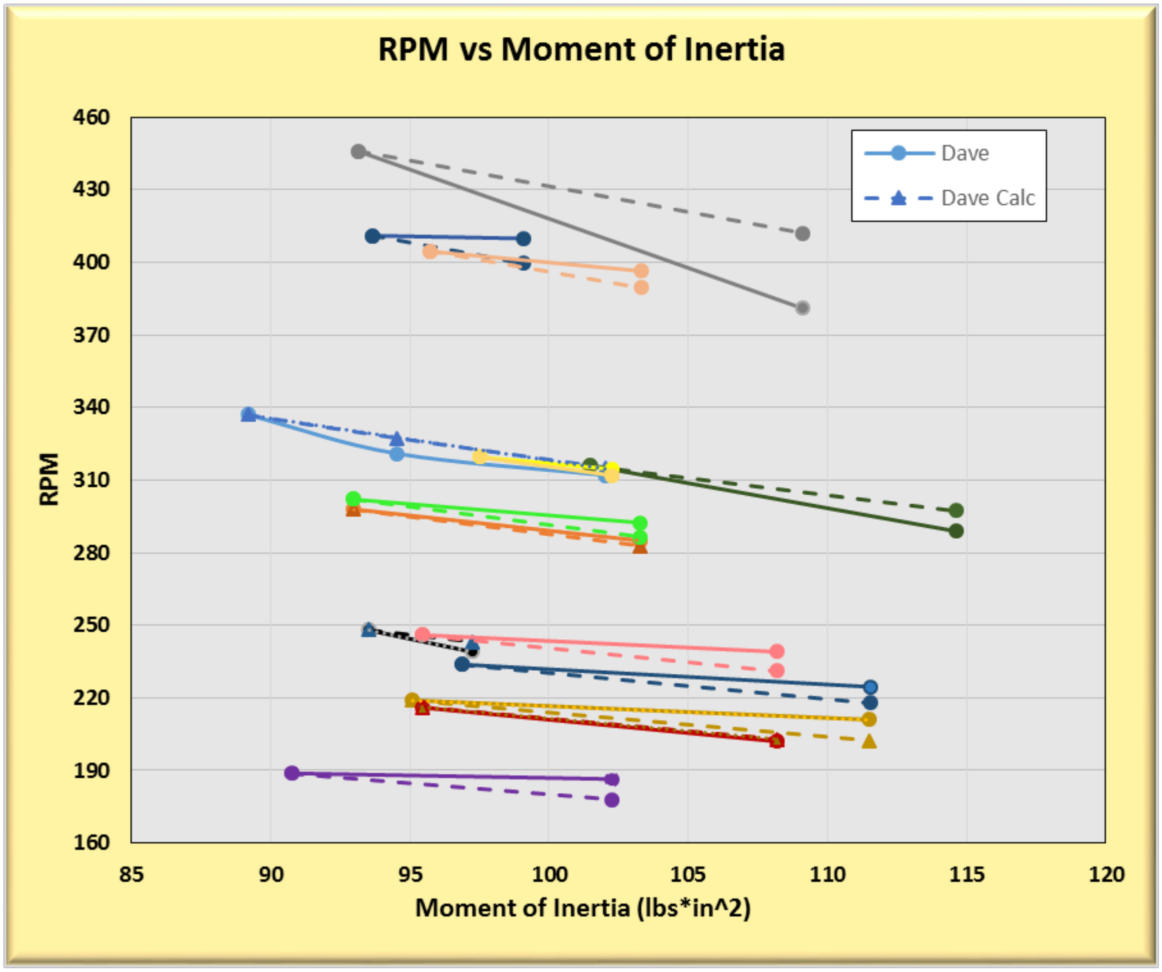
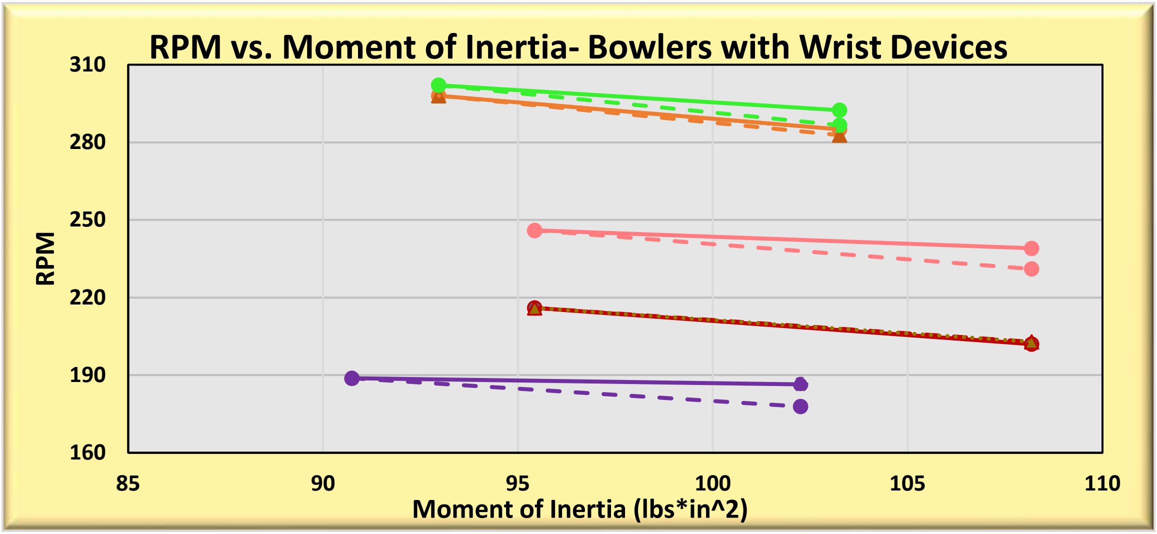
Below is a chart for Rotation rate vs. Moment of Inertia for each bowler with their two balls:



The rotation rate for all bowlers decreased as their ball moment of inertia increased. Some bowlers had a greater change in their RPM rate as their ball MOI was changed. Only one bowler had the same RPM rate with his low and high MOI balls, but his MOI difference for the two balls was very small.

The solid line in the above chart is the measured RPM results with their high and low moment of inertia ball. The dotted line is a calculation assuming the same rotational energy for both balls. For the most part, the experimental results follow the calculated results.

Three bowlers in the test wore wrist devices (see below).



Two bowlers bowled, both, with and without a wrist device. Their RPM differences for the low and high moment of inertia balls were about the same with and without a wrist device. The wrist device did give one bowler more RPM with all his balls, but the RPM difference when they changed from a low to a high moment of inertia ball was the same. There is a good possibility that the wrist device locks their wrist into a stronger position than normal (holds wrist straight and not allowed to bend backwards) to create more RPMs but did not alter the affect from the ball dynamics.

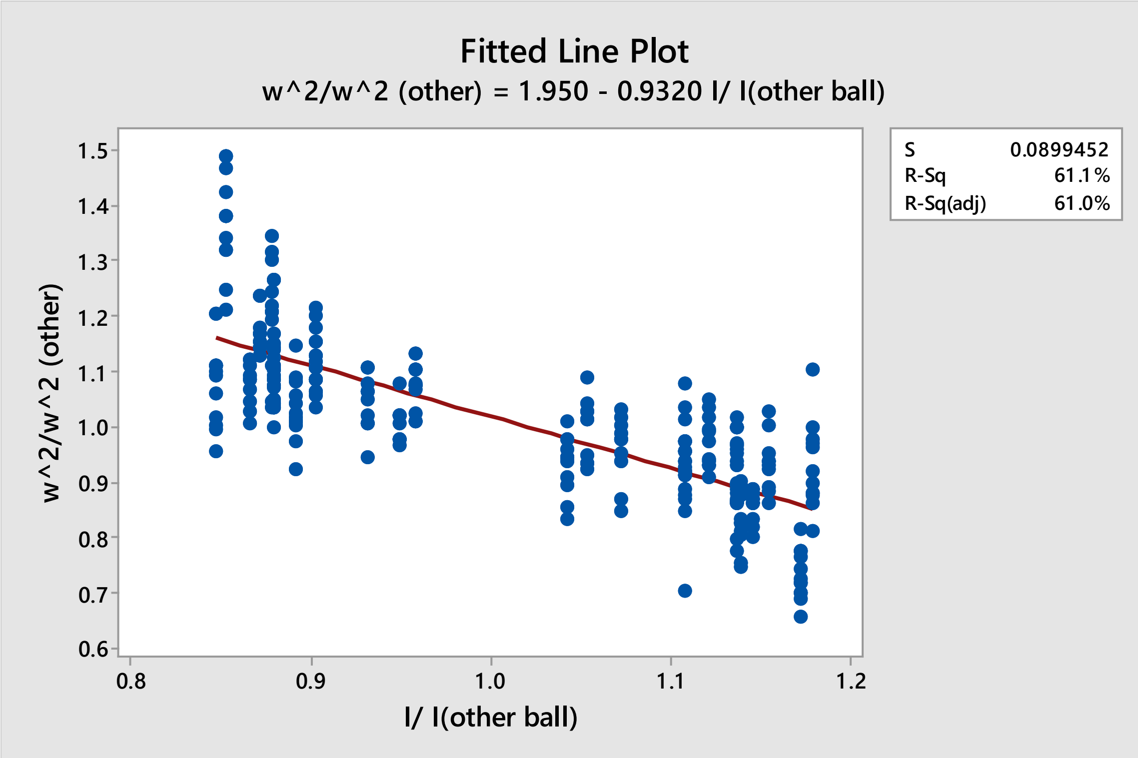
Below are the overall averages:

Ball	Ave MOI	Ave RPM	Calc. 15# RG value
Ave. Low MOI	94.3	297	2.51
Ave. High MOI	105.7	**282**	2.65
	Difference	15.3	
Calc. RPM for high MOI ball with same rotational energy as low MOI Ball		**281**	

For the 14 bowlers in the study, they averaged 15.3 RPM more when they threw their low moment of inertia ball compared to their high moment of inertia ball. If all the balls were 15 pounds, it would be the equivalent of throwing a 2.51 RG ball with 297 RPM and a 2.65 RG ball with 282 RPM. If we use our conservation on angular moment equation and assume the low RG results are accurate, then it predicts 281 RPM for the high RG ball (vs. 282 RPM measured). So, the measured and calculated results match well.

Ratio of RPM difference to MOI difference= For every 1 lbm-in^2 increase in the MOI, the RPM decreases 1.35 RPM.

Below is a fitted line plot generated by Minitab of the same data using the variable of I_{ball1}/I_{ball2} for the x-axis and the variable of $(w^2)_{ball1} = (w^2)_{ball2}$ for the y-axis. These values are a rearrangement of the rotational energy equation.



The R-Sq (adj.) value of 61.0% does not show great correlation.

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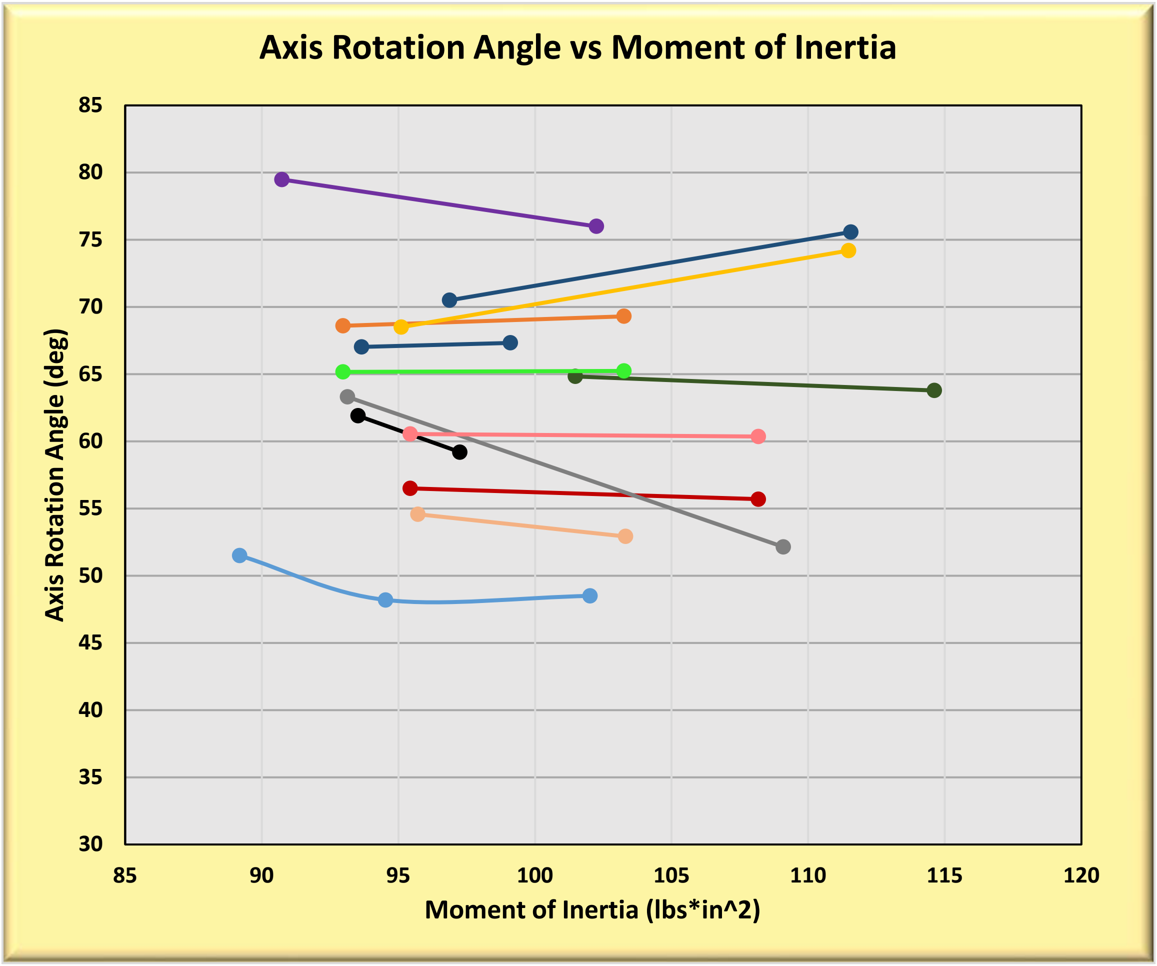
Below is a summary by bowlers of their ball rotation including the predicted results using both the fitted line plot (regression) equation and the rotational energy equation. The predicted results for both are very similar.

Bowler	RPM ave	I1/I2	regression equation for w^2/w^2 (other)	RPM (other) calc using regression equat.	RPM (other) using rotational energy
Bowler #1	285	1.108	0.918	285	283
Bowler #1	298	0.903	1.108	300	300
Bowler #2	337	0.873	1.137	333	334
Bowler #2	312	1.146	0.882	316	315
Bowler #3	239	1.043	0.978	245	243
Bowler #3	248	0.959	1.056	246	244
Bowler #4	219	0.848	1.159	227	229
Bowler #4	211	1.179	0.851	202	202
Bowler #5	216	0.880	1.130	215	215
Bowler #5	202	1.137	0.890	204	203
Bowler #6	316	0.878	1.131	307	308
Bowler #6	289	1.139	0.889	298	296
Bowler #7	189	0.892	1.119	197	197
Bowler #7	186	1.121	0.905	180	179
Bowler #8	446	0.892	1.119	403	403
Bowler #8	381	1.121	0.905	424	421
Bowler #9- wrist	246	0.880	1.130	254	255
Bowler #9- wrist	239	1.137	0.890	232	231
Bowler #10	234	0.866	1.143	241	242
Bowler #10	225	1.155	0.874	219	218
Bowler #11- wrist	292	1.108	0.918	289	287
Bowler #11- wrist	302	0.903	1.108	307	307
Bowler #12	411	0.949	1.065	423	400
Bowler #12	410	1.053	0.968	404	421
Bowler #13	405	0.932	1.081	412	391
Bowler #13	396	1.073	0.950	395	410

Below is a chart of the axis rotation angle vs the moment of inertia of the ball for each bowler:



The chart colors match the same bowler in the “RPM vs Moment of Inertia” chart on page 4.

The ball moment of inertia did not chance the axis rotation angle consistently. Overall, it lowered the axis rotation angle by 0.9 degrees when the high MOI ball was thrown, but one bowler had an 11-degree difference (gray line in chart above), which accounted for most of the difference. Therefore, for future testing with E.A.R.L., we will not adjust the axis rotation angle depending on the moment of inertia of the ball.

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Below is additional RPM vs ball moment of inertia results after testing all Junior Team USA bowlers. The results show the same trends as before with high moment of inertia balls having less RPM compared to same bowler throwing a lower moment of inertia ball. The dotted line is, again, the calculated RPM rate.