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A Comparative Study of the Spin Rates of Golf Balls

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Abstract

My research is an in-depth look at the trajectories of high-performance golf balls. These balls come from three of the top ball manufactures in the world: Titleist, Callaway and Bridgestone. We chose the low-spin ball from each company, and hit each 20-30 times using a 7- iron. We recorded the trajectory predictions using a range simulator called a FlightScope, which a ided b he U i e i f L chb g G lf g am. The purpose of this experiment was to create a computer model that compares the distance, time of flight and vertical descent of a golf ball that was predicted by the model and the simulator.

INTRODUCTION

This study will look at the comparative trajectories between a flight simulator and a computer model of three high-performance golf balls. Information about these balls is ap- pealing because many people play golf and use these expensive golf balls, but probably have never seen any actual statistics on how different brands compare. Many people play the same golf ball just because they have heard it was a good ball through clever advertising. On the PGA tour and for college teams, the most popular ball is either the Titleist Pro v1 or the Pro v1x, which are only two of many high performance balls[1]. In our study we to compared the Titleist Pro V1, Callaway Chrome Soft x and the Bridgestone BRX.

Our original goal was to test ten different balls from Titleist, Taylormade, Srixon, Callaway and Bridgestone. After we finished hitting the balls, we wanted to determine which ball produced the highest spin, and see if there was any correlation between brand and spin rate. Due to the COVID-19 outbreak, our research was cut short because we were unable to test all of the golf balls. Our focus turned to modeling the flight of the golf ball to see if we could reproduce the trajectory predictions we were getting from the simulator. We used Wolfram Mathematica to simulate the preditICted trajtory of the ball, which we compared to the predictions we collected from the simulator during testing.

THEORY

As we began testing the different balls in our study, it was important to understand the physics of the golf ball, so we would be able to better understand how the air generates lift on a spinning ball. The initial lift is created when a lofted club strikes the ball. The dimples on the golf ball help increase the lift the air imposes on the ball. Lift is proportional to the spin of an object. The initial spin of a golf ball is created by the friction between the club face and the dimples on the ball. As the ball spins, an area of high pressure forms at the bottom of the ball, and a low pressure area forms at the top. This causes the air to flow around the ball, which creates an upward force.[2]

A ball flowing through the air has smooth air flowing around it creating a wake behind the ball. A dimpled golf ball creates a turbulent boundary layer between the ball and the air above (and below) the ball. This turbulent layer allows the air move around the ball more, which reduces the wake and drag[2]. FIG 1 shows the difference between airflow over a smooth and spinless dimpled golf ball.

FIG. 1: Air flow over a smooth and a golf ball[3]

The wake on the dimpled golf ball is significantly smaller than the smooth ball, which is why the drag is less on the dimpled ball.

The spin of the golf ball induces what is called the Magnus force. The Magnus force is equal to the cross product of the angular velocity,!, and the ball's velocity, $\tilde{V}$,[4]

$$\sim F_m = S(! \rightarrow \sim V), (1)$$

Where S, which is a function of the lift coefficient C_l, is defined as 12⇢sC_l. ⇢ is the density of air and s is the projected area of the ball.

We also created a model of the flight of the golf ball that resembles the predictions

we exported from the FlightScope simulator. FIG 2 shows a free-body diagram of all the
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forces on a golf ball during flight.
FIG. 2: Forces on a moving golf ball
The drag force (equation 2) is the air resistance the ball feels as it travels through the air.

$\sim F_d = 12$⇢s$C_d V^2$. (2)

m~g is the force due to gravity that the ball feels, and C_d is the coefficient of drag.
Now that we have have defined the forces on the ball We can find the equation of motion for a golf ball from Newton's Second Law

m~a = $\tilde{F}^{(net)}$. (3)

From here we split the above equation into the x and y directions,

$mx^{00}(t) = F_m \sin$↵ $F_d \cos$↵ (4)

and

$my^{00}(t) = F_m \cos$↵ $F_d \sin$↵ mg (5)

Equations (6) and (7) are the resulting differential equations once we plug in for the drag and Magnus effect. Here ↵ is defined as the angle the ball makes with the horizontal as it travels through the air.

$x^{00}(t) =$ ⇢s

$2m^{(x_{02}} + y^{02})(C_d \cos$↵ $+ C_l \sin$↵ $)$ (6)

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and

$y^{00}(t) =$ ⇢s

$2m^{(x_{02}} + y^{02})(C_l \cos$↵ $C_d \sin$↵ $)\ g,$ (7)

Based on FIG 2 cos↵ is equivalent to $^{V_x}{}_V$ and sin↵ is equivalent to $_{V_{y_V}}$. Equations (6) and (7) now become

$x^{00}(t) =$ ⇢s

$2m^{V}\ (C_d V_x + C_l V_y)$ (8)

and

$y^{00}(t) =$ ⇢s

$2m^{V}\ (C_l V_x\ C_d V_y)\ g.$ (9)

C_l and C_d are values that vary based on spin rate and ball velocity. We can find these values from the data give by Bearman and Harvey[5] in FIG 3.

FIG. 3: C_l and C_d vs v/V from Bearman and Harvey[5]

v/V is called the spin parameter where v is the spin of the golf ball given by v= !⇡ d

$_{60}$. ! is the rotational speed of the ball in rpm and d is the diameter of the ball. The hex refers to a ball that has hexagonal dimples. The conventional ball has circular dimples. The symbols that appear on the lines is the Reynolds number. The Reynolds number is a dimensionless quantity defined as ⇢V d$_\mu$. Here μ is the fluid viscosity, which is $1.825 \cdot 10\ {}_5$ (kg/m ·s) for air at 20 C.[6] The spin and ball speed we recorded for the study were producing a spin parameter larger than the data given by the Bearman and Harvey graph, therefore we had to extend the lines of the Bearman and Harvey graph all the way to a spin parameter of 1.0. Around a spin parameter of 0.2 both the lift and drag coefficients start to straighten out, so our extension of the curves probably does not deviate from the true path. FIG 4 is the points we extrapolated from the Bearman and Harvey graph.

FIG. 4: C_d and C_l for a conventional and hexagonal dimpled ball

Once we got data from the FlightScope, we plugged the needed information into the differential equations and solved them using a numeric differential equation solver on Mathematica. We used this program to model the flight of the golf ball so that we could compare our data to the model.

METHODS

We split the research into two categories. One being the high-spin balls, and the other being the low-spin balls. Each brand usually has one for high spin and one for low spin. For the low-spin category we tested the Bridgestone BRX, Callaway ChromeSoft x, and Titleist Pro V1.

To determine the spin rates of the golf balls we used a range simulator in the indoor golf facility located in Wake field house located on campus of the University of Lynchburg. The machine is called a FlightScope which is positioned behind the person as they swing. The simulator records information such as: swing speed, ball speed, launch angle, and spin rate.

The simulator gives values for distances and swing speed, but struggles to give an accurate spin rate indoors.[7] To improve the accuracy of the spin rate, we added a metallic dot (about the size of a ball dimple) to the golf ball which acts as a reference point for the machine to read the true spin rate of the golf ball. From experience using the simulator, once the dot is added the spin rates tend to be closer to the accepted values for specific clubs. The spin rate for a 7-iorn should be around 7000 rpm.[8] This is not a concrete number because everyone's swing varies in speed and angle of attack (AOA), which is the angle the club makes with the ground at impact.

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The balls in particular we are interested in is the Callaway Chrome Soft and Chrome Soft x. These are the most visibly different than the other balls in the test because the dimples on these balls are hexagonal rather than circular dimples[9]. Their performance is probably comparable to the other balls because Callaway has been using the hexagonal dimples for awhile, and none of the other brands have changed their design. Another ball that is interesting is the BridgeStone BRX and BRXs balls. These have what is called “dual-dimple,” which physically means there is a smaller dimple inside the main dimple.[10]

After we tested the different golf balls we wanted to see if the center of mass for any of the golf balls was off-center. There was an article written stating that the center of the Callaway ball was produced off-center, which would have an impact on the flight of the ball.[11] Our original goal was to compare the flight data of all the balls to see if there was a correlation between the spin rate and the brand. If we found such a correlation we could have cut the ball open to inspect the core, but we were unable to pursue this idea because we could not test all the balls using the simulator.

Most of the balls we are studying have different compositions. That is, some balls have different numbers of “pieces”, or the core is made out of a different material. We were interested which of these combinations of materials and number of pieces that result in the best performing golf ball in our study.

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Brand Cover Material Type of Core Number of pieces Titleist Pro V1x[1] Urethane Elastomer Polybutadiene 3 Callaway Chrome Soft[12] soft Urethane Graphene 3 Srixon Z-Star[13] Urethane Energetic

Gradient Growth (E.G.G) 3 Bridgestone BRX[14] Urethane Gradational Compression 3 Taylormade TP5[15] Soft-Tough Urethane Polybutadine 5

TABLE I: High-Spin balls

Brand Cover Material Type of Core Number of pieces Titleist Pro V1[1] Urethane Elastomer Polybutadiene 4 Callaway Chrome Soft x[9] soft Urethane Graphene 4 Srixon Z-star XV[16] Urethane E.G.G 4 Bridgestone BRXS[10] Urethane Gradational Compression 3 Taylormade TP5 x[15] Urethane Polybutadiene 5

TABLE II: Low-Spin balls

Table I lists the high-spin balls, and Tab II lists the low-spin balls. Most companies used similar materials to manufacture each of the golf balls, but where the most difference comes
in is in the number of pieces each ball had. The high-spin balls tend to have fewer pieces than the low spin balls. Another difference is the number of dimples each ball had, along with the different shapes of the dimples. All the balls are similar in size, so if a ball has more dimples than another that means there are smaller dimples on the ball, but more in a given space that will be making contact with the grooves. Table III shows the number of dimples each ball in the study has.

Brand Number of dimples Titleist Pro V1[1] 352 Titleist Pro V1x[1] 328 Callaway Chrome Soft[12] 332 Callaway Chrome Soft x[9] 332 Srixon Z-star[13] 338 Srixon Z-star XV[16] 338 Bridgetone BRX[14] 330 Bridgestone BRXs[10] 330 Taylormade TP5[15] 322 Taylormade TP5 x[15] 322

TABLE III: Number of dimples per golf ball

Most of the balls have similar numbers of dimples (around 330), but the difference between the Titleist Pro V1 and Pro V1x is the largest. These balls are the most popular among tour professionals.[1] The Taylormade balls have a different design from the rest of the balls. They are the only balls that have a 5 piece design. We are not sure what the number of pieces do for the golf ball, but all of the low spin balls tend to have more pieces. When comparing the specs of the Taylormade balls, they appear to be identical, so Taylormade's cover material may be what differentiates the low-spin from the high-spin ball.

For a preliminary trial run we tested two of the balls from our project. We tested the Pro v1 (low spin) and the Pro v1 x (high spin). Each was hit 21 times by the same person. A metallic dot was placed on each ball to help the simulator pick up the ball after impact. For comparison, a ball without the dot had a spin rate of about 4000 rpm, and after the dot was applied, the spin rate jumped to 6000-7000 rpm, depending on the ball. The data we collected were very scattered, but this was expected due to the fact that repeating the same swing is very difficult.

Shot	Prov1x Spin rate (rpm)	Shot	Prov1 Spin rate (rpm)
1	5705	1	5812
2	6877	2	5978
3	6584	3	6957
4	7110	4	6864
5	6137	5	6502
6	6474	6	4276
7	6914	7	7158
8	5244	8	6847
9	6089	9	6923
10	6976	10	6778
11	4193	11	6035
12	7095	12	7397
13	5609	13	6418
14	5638	14	6849
15	6497	15	6613
16	6052	16	6355
17	7086	17	6736
18	4148	18	6350
19	4295	19	6242
20	6382	20	4643
21	6149	21	7008

TABLE IV: Prov1x (left) and Prov1 (right) data

Ball	Spin rate (rpm)	AOA ( )	V Launch ( )	Distance (m)	Launch speed (m/s)
Pro V1	6290	-3.7	16.7	173.8	57.58
Pro V1x	6957	-3.6	17.5	171.4	57.13

TABLE V: Shot comparison between a Pro V1 and Pro V1x

Table IV lists data we collected for the Pro v1 and Pro v1x balls. Once we tested the balls, we examined the data and compared which balls had the most similar shot parameters.

The parameters we compared were launch angle and angle of attack (AOA). The launch angle is the angle the ball makes with the ground as the club makes contact. Table V shows the data in which these parameters were similar. We included the distance the ball traveled and the spin rate so that we could compare the two balls.

According to the Titleist website, the Pro V1 is supposed to have less spin than the

Pro V1x[1], so we were able to see this difference using the FlightScope. The simulator we used to gather all of our data also recorded ball speed, which we needed for our model in Mathematica.

RESULTS

We were only able to test the Titleist Pro V1, Pro V1x, Bridgestone BRX, and Callaway Chrome Soft x. We only focused on the low-spin balls, so that we can compare the spin rates. We only got to hit these balls about 20 times each, so we did not have much data. Once again we were using our own swing, so we had to throw out some data that were considered bad shots. We then went through the remaining data and matched up the similar shots. Table VI lists the shots we were able to compare from the three balls we tested.

Ball Spin (rpm) AOA ( ) V Launch ( ) Distance (m) Launch Speed (m/s) BRX 5698 -4.8 17.1

167.3 55.33 Pro V1 6545 -4.7 16.2 171.4 57.14 Chrome Soft x 6141 -4.6 16.9 175 57.97 BRX 4222 -3.8 18.1 170.2 54.44 Pro V1 6290 -3.7 16.7 173.8 57.58 Chrome Soft x 6197 -3.9 17.1 170.8 56.75

TABLE VI: Shot Data from the simulator

We found that the Bridgestone BRX ball had significantly less spin than the other two. In all three of the shots the Pro V1 had the most spin. It had 6.37% more spin than the Chrome Soft x for the first shot, and 1.49% more for the second shot. The BRX, which had the least amount of spin, was 7.48% less for the first shot, and 37.9% less for the second shot.

The main difference between these three balls is the dimples. The Pro V1 has conventional dimples, the Chrome soft x has the hexaginal dimples and the BRX has the “dual dimple.” The BRX dimple is the most visibly different than the rest, which may be the reason that the ball has such a lower spin rate. Unfortunately, due to the lack of data we cannot claim that the dimples are the cause of the lower spin.

Instead of focusing on comparing the data we collected, we created a model using equations (8) and (9) so that we could compare the data we collected to the model.

FIG. 7: Trajectory model for Chrome Soft x ball

We used the spin rate and vertical launch angle from the Flightscope and plugged the information into our model on Mathematica. FIG 5-7 correspond to the position vs time graphs for the three balls we tested. Tables VII and VIII shows the simulated predictions versus the calculated data for the two balls with conventional dimples.

For the BRX ball, the distances and time of flight were less than 5% difference for the first shot. The data for the second shot had a slightly higher percent difference for both distance and time. The vertical descent, which is the angle the ball makes with the ground at impact, was less than 12% for both shots. We were not sure what caused the model to be significantly different from the simulator, but we were pleased with the results for the

FIG. 6: Trajectory model for Pro V1 ball

FIG. 5: Trajectory model for BRX ball

1

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BRX	V Descent	Distance (m)	Time (s)
Simulator	47.7	167.3	6.5
Model	43.2	166.58	6.26
% difference	9.9 %	0.43 %	3.76%
Simulator	46.2	170.2	6.3
Model	41	164.4	5.89
% difference	11.9 %	6.37%	6.73%

TABLE VII: Predicted trajectory vs modeled trajectory for the BRX ball

Pro V1	V Descent	Distance (m)	Time (s)
Simulator	49	171.4	6.8
Model	45.7	171.2	6.66
% difference	6.97 %	0.12%	2.08%
Simulator	49.5	173.8	6.9
Model	45.1	173.26	6.61
% difference	9.3 %	0.31%	4.29%

TABLE VIII: Predicted trajectory vs modeled trajectory for the Pro V1 ball

distance and time of flight.

Table VIII showed an even closer spread of the data for the Pro V1 ball. Both the distances were less than half a percent of difference, and the time of flight was within 5% difference for both as well. The vertical descent was still higher in comparison to the percent difference of the distance and time of flight. We suspect these data were much closer to each other because we were able to measure the actual diameter of the Pro V1 ball. Unfortunately we were unable to measure the diameter of the BRX or Chrome Soft x balls, so we had to use the same diameter as the Pro V1 in the model. Table IX shows the model data for the Chrome Soft x ball (hexagonal dimples).

Chrome Soft x	V Descent	Distance (m)	Time (s)
Simulator	49.8	175.6	6.9
Model	48.75	169.19	6.902
% difference	2.1%	3.7%	0.029%
Simulator	50.1	170.8	6.9
Model	49.12	164.64	6.86
% difference	1.98%	3.67%	0.58%

TABLE IX: Predicted trajectory vs modeled trajectory for the Chrome Soft x ball

The model we made for the Chrome Soft x ball used the hexagonal points for the coefficient of lift and drag, which can be seen in FIG 3. Although we did not use a measured diameter for the Chrome Soft Ball, the vertical descent, distance and time of flight were all less than 4% in difference, and the time of flight for both shots were even closer in value.

CONCLUSION/FUTURE WORK

Based on how the model's data compared to the FlightScope's, it would appear that the simulator uses similar values for the coefficient of lift and drag as we used from Bearman and Harvey. We were disappointed to only test four out of the ten golf balls, so in the future we want to test the remaining six balls and collect more data. Our original plan was to take all the predicted trajectories from the simulator and plug them into a program that would determine the statistical significance of spin rate of the ball versus the brand. If we were to find that one brand’s spin rate was significant we would then have more I. One thing that could have caused a different spin rate would be the center of mass. If the core of the golf ball was shifted over a few millimeters that could have resulted in an abnormally high or low spin rate. Since we no longer have access to the balls, there would be no way of cutting the ball open to confirm (or deny) this hypothesis. Another improvement to the project would be an automatic club swinger. While our swing produced similar distance between the balls, it would be best if we could have a repeatable swing that had the same initial conditions each shot.

[1] “Pro v1 and Pro v1x Golf Balls.” Titleist Golf. Accessed 10 October 2019. https://www.titleist.com/golf-balls/pro-v1-pro-v1xV

[2] Veilleux, Tom. “How do dimples in golf balls affect their flight?” Scientific American. https://www.scientificamerican.com/article/how-do-dimples-in-golf-ba/

[3] Hiskey, Daven. “Why Golf Balls Have Dimples.” Today I Found Out. https://www.todayifoundout.com/index.php/2010/12/why-golf-balls-have-dimples/

[4] Burgland, Brett and Street, Ryan. “Golf Ball Flight Dynamics.” May 13th 2011. Accessed 18 November 2019. http://www.math.union.edu/wangj/courses/previous/math238w13/

[5] Bearman and Harvey. "Golf Ball Aerodynamics" Imperial College of Science and Technology.

May 1976

[6] 'Viscosity of Air, Dynamic and Kinematic." Engineers Edge.https://www.engineersedge.com/physics/viscosityofairdynamic

[7] "Mevo+ Frequently asked questions." FlightScope. https://flightscope.com/help/mevo-plus-

faq/

[8] Tappin, Neil. "Launch Monitors: What do the numbers mean?" Golf Monthly.

https://www.golf-monthly.co.uk/gear/gear-blog/launch-monitors-what-do-the-numbers-mean-

14507
0

[9] "Callaway Chrome Soft x Review." Golf Info Guide. Accessed 2 October 2019. https://golf-info-

guide.com/golf-ball-tests-and-reviews/callaway-chrome-soft-x-golf-ball-review/

[10] "Bridgestone B330-RXS: Real Tour Performance for Amateur Golfers. Golf Info Guide.

Accessed 3 October 2019. https://golf-info-guide.com/golf-ball-tests-and-reviews/bridgestone-

b330- rxs-real-tour-performance-for-amateur-golfers/

[11] Shackleford, Geoff "Callaway Investing 50 million Into Its Ball Plant After MyGolfSpy Exposes Issues" https://www.geoffshackelford.com/homepage/2019/9/3/callaway-investing-50-million-into-its-ball-plant-after-mygolfspy-exposes-issues

[12] "Callaway New Chrome Soft Yellow Review." Golf Info Guide. Accessed 2 October 2019. https://golf-info-guide.com/golf-ball-tests-and-reviews/callaway-new-chrome-soft- yellow-golf-ball-review/

[13] "Srixon Z-Star Spin Skin Golf Ball Review." Golf Info Guide. Accessed 2 October 2019. https://golf-info-guide.com/golf-ball-tests-and-reviews/srixon-z-star-spin-skin-golf-ball-review/

[14] "Bridgestone B330-RX: This Revolutionary Golf Ball is still Top-Notch." Golf Info Guide. Accessed 2 October 2019. https://golf-info-guide.com/golf-ball-tests-and-reviews/bridgestone-b330-rx-revolutionary-golf-ball-still-top-notch/

[15] "TaylorMade New Tp5 and Tp5x Golf Balls Review." Golf Info Guide. Accessed 2 October 2019. https://golf-info-guide.com/golf-ball-tests-and-reviews/taylormade-new-tp5-and-tp5x-golf-balls-review/

[16] "Srixon Z-Star XV Golf Ball Review." Golf Info Guide. Accessed 2 October 2019. https://golf-info- guide.com/golf-ball-tests-and-reviews/srixon-z-star-xv-golf-ball-review/

[17] "Product Specs." Callaway Golf. Accessed 2 October 2019 https://www.callawaygolf.com/golf-balls/chrome-soft/balls-2018-chrome-soft.htmlproduct-specs