Physics Extended Essay

Investigation Of The Factors That Affect Curved Path Of A Smooth Ball

Oğuz Kökeş

D1129-063

School: TED Ankara Collage Foundation High School

Supervisor: Mr. Özgül Kazancı

Word Count: 3885

Abstract

This essay is focused on an investigation of spin(revolution per second) of a ball and its effect on the ball's curved motion in the air. When a ball is hit and spinning in the air, it leaves its straight route and follows a curved path instead. In the following experiment the reasons and results of this curved path (deflection) is examined.

In the experiment, the exerted force on the ball and its application point on the ball is changed. The ball was hit by 3 different tension levels of a spring mechanism and their deflection values were measured. Spin of the ball was also recorded via a video camera. Likewise, the location of the spring mechanism was also changed to hit from close to the end and the geometric center of the ball. The spin of the ball was also recorded and its deflection was measured.

By analysing this experiment, one can see that the spin of a ball is an important factor in its curve. The curve of a ball can be increased by spinning it more in the air. So to create more spin one can increase the exerted force on the ball or apply the force close to the end of the ball. By using this information on the exerted force and its location one can shoot a ball while adjusting its spin to make it curve as desired.

Word Count: 232

Table Of Contents

1-Introduction

1.1 Purpose Of The Experiment

Football is the most popular sport in the world. Hundreds of thousands of matches are played every week within the world. As football is very popular it is also ever expanding. Players always try new tactics and ways to score the goals or to cheer up the crowd. One of the most popular moves of football these days is curved shots. They are preferred as they both look nice and are useful to score goals.

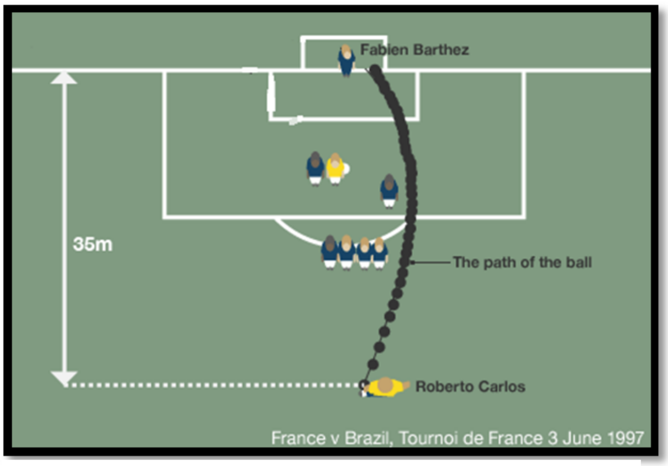


Figure 1: This figure represents the famous free - kick taken by Robert Carlos in 1997. The shooter, Roberto Carlos, uses a curved shot to pass the ball around the wall of players and hit the goal behind them.

Apart from football, curved shot are also used in baseball, golf and tennis. The main reason for using this method is to trick the opponent as the location of the ball dramatically changes or pass an object that is between the thrower and the desired place.

While this technique of shooting is often used, it is actually hard to perform a successful curved shot. For a successful curved shot the hitter must a take several factors into consideration. For example, when the free-kick by Roberto Carlos is taken into consideration (Figure 1), he had to balance the power of shot and also where he should hit the ball to perform this shot. As there are limitless possibilities to modify a curved shot it is interesting to see how the power and placement of the shot changes the flight of the ball.

As one can see, although curved shots are frequently used in football as well as other branches of sports, how to hit the ball or what to do to perform a successful shot is not known by majority. These shots are usually taken by using instincts or videos from different matches and done without thinking. The purpose of this experiment is to scientifically examine the factors that affect a curved shot. To do this variable angular velocity values and disorientation of the ball will be taken into consideration.

1.2Background Information

To execute the experiment, one should know the reasons and factors that cause the curve of a ball. Regardless, which sport or way a curved shot is used, the most important factor for a curved shot is spinning the ball. Spinning the ball is the reason a ball takes a curved path along its way. For example, in baseball, when the pitcher is throwing a curved shot, he spins the ball from his rest to make the ball spin in the air, thus curving it. The reason of this spin and curve relation is examined in Bernoulli's Principle and Magnus Effect.

1.2.1 Bernoulli's Principle

The Bernoulli's Principle actually examines fluid dynamics and not solid objects or specifically balls, but still explains the reason of the curve and its relation to pressure difference. Basically as the relative speed of a fluid (or in this experiment the ball) increases, the pressure decreases.

When this principle is applied for solid objects, on the other hand, if the objects is spinning, the pressure is different for two sides of the ball. This difference causes a resulting force which also curves the ball. This process is called the Magnus Effect.

1.2.2 Magnus Effect

The Magnus Effect is simply is a force created because of the difference in velocities between two sides of a spinning object. As the ball is spinning in the air; one side of the object moves with the same motion as the wind steam exposed, whereas the other side motions are opposed causing one side of the ball spin faster than the other. This unbalance in velocity creates a force. This force is called the Magnus Force.

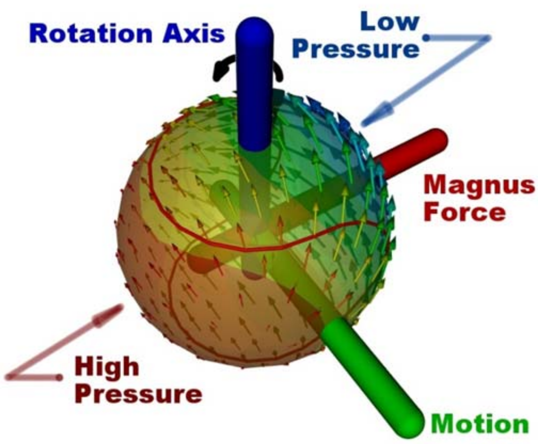


Figure 2: This figure shows how the Magnus force is formed. As one can see, the difference of pressure in two sides of the ball causes a resulting force, Magnus Force, to change the direction of the ball.

"The commonly accepted explanation is that a spinning object creates a sort of whirlpool of rotating air about itself. One the side where the motion of whirlpool is in the same direction as that of the wind steam to which the object is exposed, the velocity will be enhanced. On the opposite side, where the motions are opposed, the velocity will be decreased. According to the Bernoulli's Principle, the pressure is lower on the side where the velocity is greater, and consequently there is an unbalanced force at the right angles to the wind. This is the Magnus Force."

1.3 Research Question & Hypothesis

Although the reason for a ball to curve can be answered by using Bernoulli's Principle and Magnus Effect, how to create different curves on an object is still unanswered. This brings up the question:

"How does changing the angular frequency of a rotating ball affect the curved path of the ball?"

In this experiment this will be obtained in two ways, by changing the magnitude of applied force and place of application point of the exerted force.

1.3.1 Changing the Exerted Force:

For changing the exerted force one can guess that as the force exerted on the ball increases, the ball will have a bigger velocity after the interaction. Due to this increase in velocity of the ball, the deflection of the ball will be greater

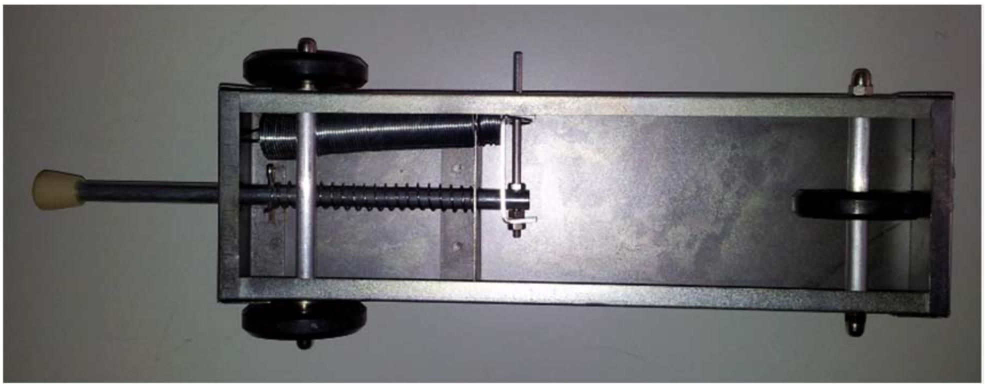
1.3.2 Changing the Place of Application Point of the Exerted Force:

When the place of application point is changed the spinning rate of the ball will change as well. In order to obtain maximum spinning rate the force should be applied to the point on which it will create the greatest moment. When the spinning rate increases it is expected for the ball to have a greater deflection.

2 - Materials and Setup of The Experiment

2.1 Materials

- Spring Mechanism
- Plastic Ball (51.461±0.002g)
- Cardboard (dimensions are not important as it will be used only to create a curved path so that the ball will gain angular speed.)
- Video Camera (Brand in this experiment: Sony DCR-SX30)
- Coloured Pencils (Black-Red)
- Duct tape (9,837±0.001g)(It will be used to stabilize the ball before the force is applied)
- Ruler (100.0±0.1cm)
- Digital Scale for measuring the mass
- Spirit Level to stabilize the camera at right angle to experimental setup(it is embedded in the tripod)
- Tape Measure (300.0±0.1cm) (It is used to calculate the range of the ball)



Picture 1: This picture shows the spring mechanism used in the experiment. As one can see, two springs are used to create bigger forces and thus curves.

As measuring the ball alone was not easy, the ball was measured on the tape, also used in the experiment, and mass of the ball was calculated afterwards. Also, the video footage from the camera will be used for calculations in later stages of the experiment; a high quality video camera should be used.

2.2 Setup of the Experiment

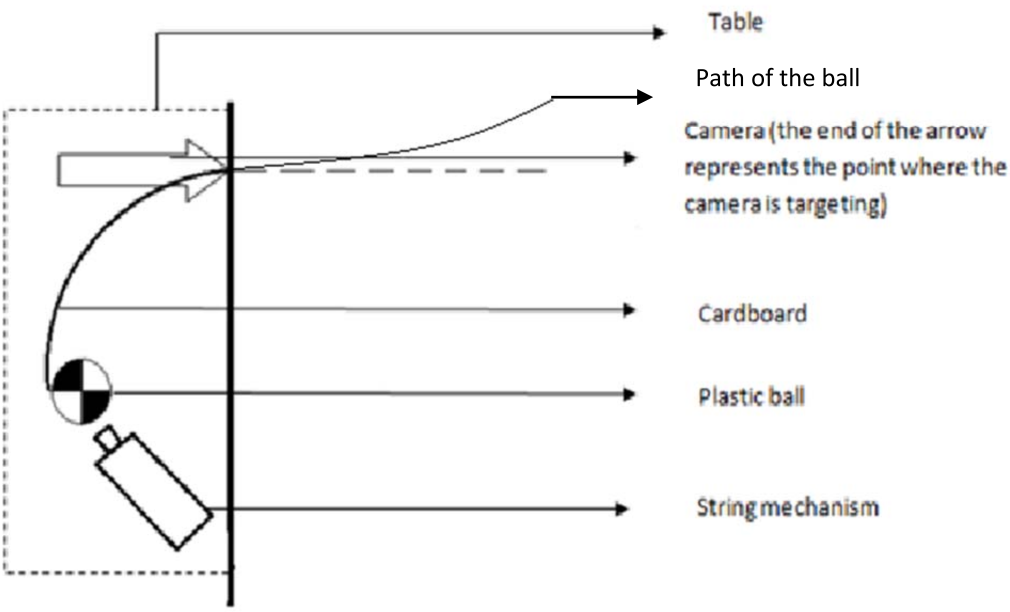


Figure 3: This figure shows the mechanism that is used in the experiment from top view. One can see that the steps to set up this mechanism above.

As the experiment consists two parts, first the main system for the experiment should be set up. One should also note that as the ball should be in the air to spin and curve, the experiment is done at the edge of a bridge facing a 350.0±0.1cm fall.

1) The cardboard is bent in a semi circular shape and fixed on the bridge. As it was mentioned before, one end of the cardboard is facing towards the fall.
2) The tape is fixed near the cardboard so that direction of the cardboard points the expected path of non-spinning ball thrown horizontally from the same place. (The dashed line in Figure 3)
3) A camera is placed over the experiment, targeting the end of the cardboard to record the outrun of the ball.
   It is important to note that the camera should record its target with an angle of 90^o, as angular speed of the ball is measured via the footage from the camera. This is done by placing a flat surface (table in this experiment) over the system and fixing the camera on it via a tripod. Also, a spirit level is used to adjust the angle of the camera.
4) A straight line is drawn to the surface to measure the deflection of the ball. This is done by hanging a mass from the end of the cardboard, and drawing a straight line from there.
5) Range values for every trial are measured.

After this system is completed, depending on which part of the experiment is conducted, the setup of the experiment varies.

For changing the exerted force;

After the ball is placed on the tape, spring mechanism is placed 1.5±0.1cm away from the ball and fixed. The force is changed by changing the tension of the springs. One can see the levels of tension on the spring mechanism in the Picture 2 below. After the tension level is set, the spring mechanism is fired. The flight of the ball is recorded via the video camera and the point of fall is marked. The deflection of the ball is measured and noted. This is done 5 times for each tension level totalling 15 trials.

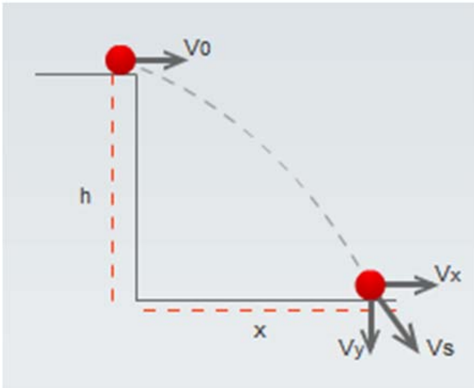


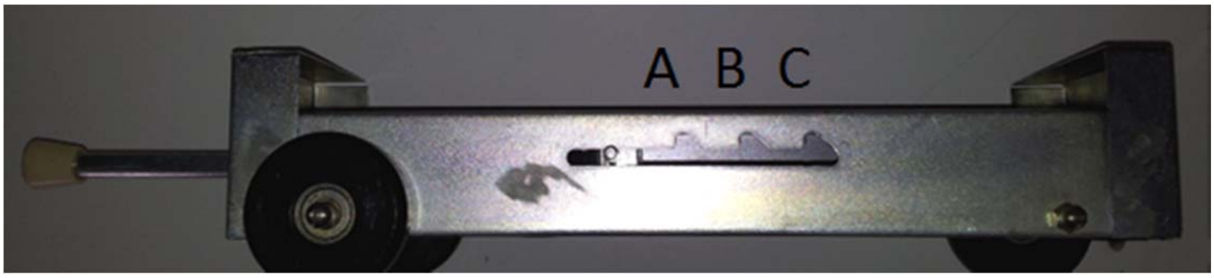
Figure 4: The throw in the experiment is actually a horizontal throw as seen in the figure above.

For changing the location of the force exerted on the ball;

The mechanism is taken to the right side of the ball to change the location of the force. One should note that the distance between the ball and mechanism should be kept constant. The angle between the ball and the mechanism is not significant as only the difference in number of spins and deflection is significant which are recorded by the video camera. The spring mechanism is fired and the flight of the ball is recorded via the video camera and the point of fall is marked. The deflection of the ball is measured and noted. The location of the ball is changed after 5 trials for 4 time resulting 20 trials. However, the distance between these locations must be kept constant to have balanced values. Also one should note that the tension of the spring is at maximum during this part of the experiment to get the maximum possible deflection and to have more significant measurements as a result.

3 - Data Collection & Processing

3.1 Changing The Exerted Force



Picture 2: This picture shows the spring mechanism sideways. As one can see there are 3 levels stretch the springs. As a result, 3 different forces were exerted on the ball. Also, as one can see from the picture these levels are named and will be referred as A, B and C throughout the experiment.

3.1.1 Raw Data Table

Tension Level	Trial	Number of Spins	Deflection (±0.1cm)	Range (±0.1 cm)
A	1	2	0.9	160.2
	2	3	0.7	164.6
	3	2	0.8	168.5
	4	3	1.0	165.7
	5	3	0.9	163.4
B	1	6	1.6	171.3
	2	4	1.3	170.8
	3	5	1.5	171.5
	4	5	1.5	174.3
	5	5	1.8	172.6
C	1	9	3.1	178.4
	2	8	3.0	180.3
	3	8	2.7	179.6
	4	8	2.9	177.4
	5	7	2.6	178.7

Table 1: This table shows the raw data table of the experiment. As one can see the table contains the number of spins of the ball before it hit the ground. This was counted by slowing down the video footage from the camera. How to measure the deflection and range is given below. (Figure 5)

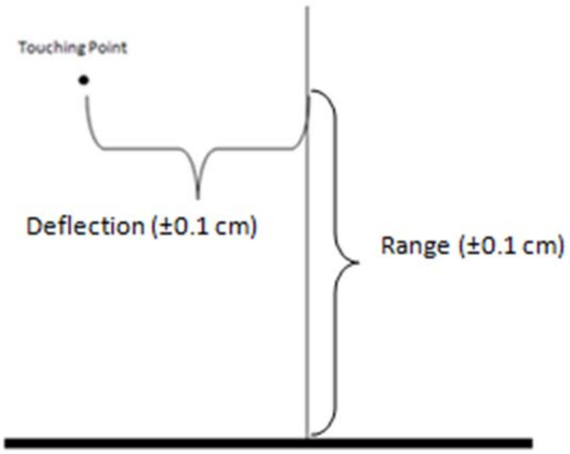


Figure 5: As one can see from the figure the disorientation of the ball is only taken sideways as the ball is expected go straight forward if it does not have a curve.

3.2 Changing the Place of Application Point of the Exerted Force:

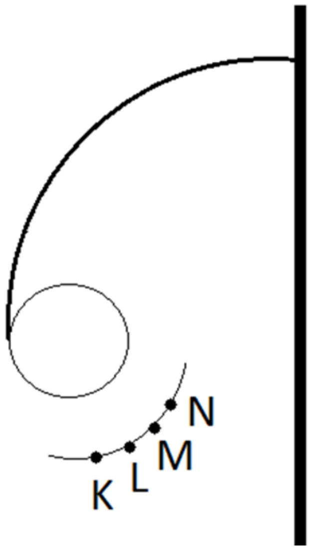


Figure 6: As it is mention above, the spring mechanism is located in four different points. As a result the same force is exerted on the ball from four different locations. Also, as one can see from the picture these points are named and will be referred as K, L, M and N throughout the experiment. The distance between those points are the same.

3.2.1 Raw Data Table

Point	Trial	Number of Spins	Deflection (±0.1cm)	Range (±0.1 cm)
K	1	5	1.3	178.4
	2	4	1.2	179.2
	3	5	1.4	178.7
	4	3	1.1	175.6
	5	4	1.2	177.3
L	1	6	2.3	175.7
	2	6	2.2	174.8
	3	6	2.1	177.4
	4	6	2.4	176.1
	5	6	2.5	177.0
M	1	8	3.1	175.2
	2	8	3.0	178.1
	3	8	3.2	175.2
	4	8	3.5	177.8
	5	8	3.1	177.7
N	1	9	4.1	174.3
	2	9	4.0	175.2
	3	9	4.2	176.7
	4	9	4.2	175.2
	5	9	4.0	173.6

Table 2: This table is the raw data table for changing the place of application point of the exerted force. It contains the number of spins, deflection and range values of the experiment which are explained above.

3.3 Fall of the Ball

Different spin rates given to the ball does not affect its vertical fall. In all trials the ball is thrown horizontally from the same height. The time of flight can be calculated by the formula:

$$h = \frac{1}{2}gt^2$$

As the height of the fall (h) is kept constant throughout the experiment and gravitational acceleration (g) is also the same for all trials (as all of them are conducted at the same environment), one can easily see the t^2 should be same for all trials. As a result, only one time of fall value is used for all trials below. To calculate this value;

$$3.50 \pm 0.01 = \frac{1}{2}9.8t^2$$

$$3.50 \pm 0.01 = \frac{1}{2}9.8t^2$$

$$t^2 = 0.71 \pm 0.01 \qquad => \qquad \mathrm{t} = 0.84s$$

As one can see, the uncertainty of the value is not taken into consideration as it is too small and accepted as insignificant for the calculations. Also to prove this value, one trial from each tension level (first of each level) is also calculated.

Trial	Time of Fall (±0.01s)
1	0.87
2	0.86
3	0.80

Table 3

As one can see from Table 3, the values from the experiment is close to the calculated value. These values are also calculated by slowing down the video footage.

3.4 Revolution per Second

Revolution per unit time is the main effect that will change the amount of deflection. Therefore it is necessary to calculate it for all trials. It can be calculated as;

$$RPS = \frac{number\ of\ rev.}{time}$$

For example for the first trial

$$RPS = \frac{2}{0.84} = 2.38 \text{ rev per second}$$

Rest of the revolution per second values of the trials can be seen below (Table 4)

Tension Level	Trial	Number of Spins	RPS (rev/s)
A	**1**	2	2.76
	2	3	3.57
	3	2	2.38
	4	4	3.82
	5	3	3.34
B	**1**	6	7.14
	2	4	5.37
	3	5	5.47
	4	5	5.95
	5	6	6.01
C	**1**	9	10.71
	2	8	9.52
	3	9	8.98
	4	10	9.54
	5	8	8.86

Table 4

3.5 Calculating the Horizontal Velocity

As the ball travels both sideways and straight, it also has a horizontal velocity. This velocity causes the ball to go further and can be calculated by the formula:

$$Vx = \frac{Range}{Time\ of\ fall}$$

So the horizontal velocity of the second trial is calculated as;

$$Vx = \frac{1.64}{0.84} = 1.95 \text{ m/s}$$

One should note that as the horizontal velocity is calculated in meters per second form the uncertainty of the range values are insignificant to include in the calculations. The rest of the horizontal velocity values are given below. (Table 5)

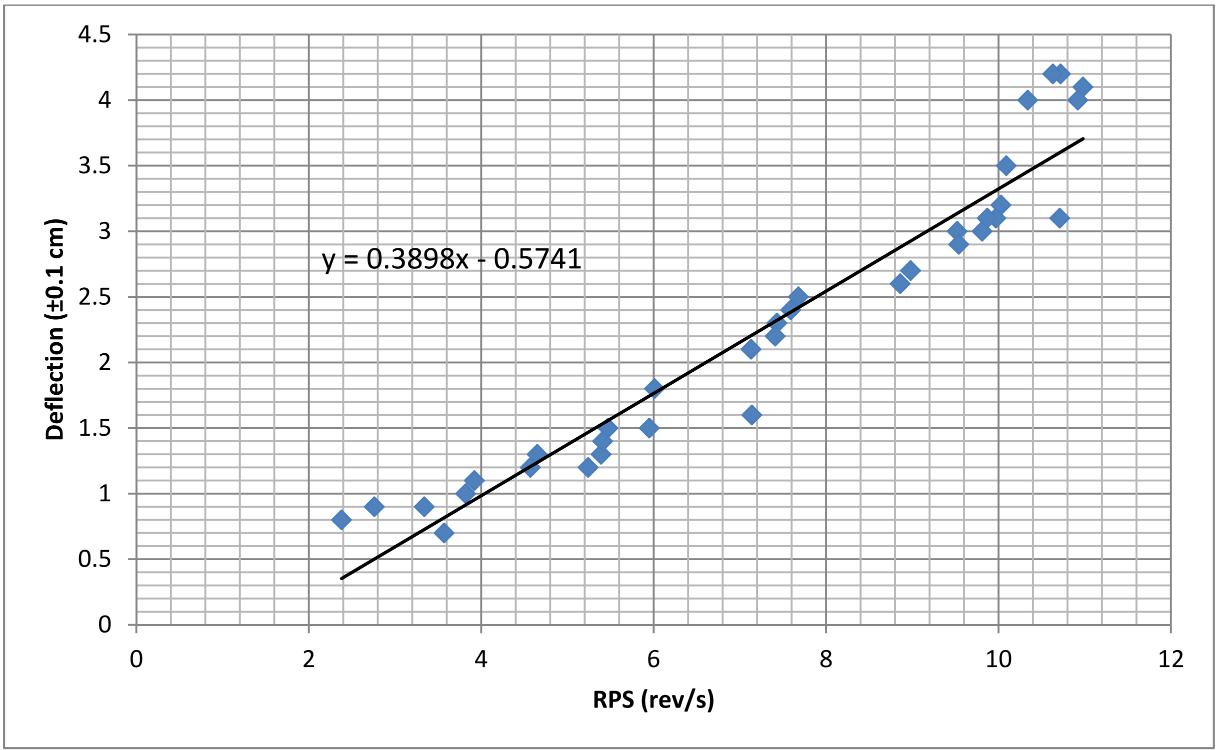
In this experiment, the external wind and Vx of the trials affect the results of the experiment but this experimental set-up does not allow to keep them at a fixed value. Therefore, only the trials that have close Vx values are taken into account and some other outliers were not considered in order to minimize the effect of its difference.

	Trial	Range (±0.001m)	Velocity (m/s)
A	1	1.602	1.905
	2	1.646	1.952
	3	1.685	2.000
	4	1.657	1.964
	5	1.634	1.940
B	1	1.713	2.036
	2	1.708	2.024
	3	1.715	2.036
	4	1.743	2.071
	5	1.726	2.048
C	1	1.784	2.119
	2	1.803	2.143
	3	1.796	2.131
	4	1.774	2.107
	5	1.787	2.119
K	1	178.4	2.124
	2	179.2	2.133
	3	178.7	2.127
	4	175.6	2.090
	5	177.3	2.111
L	1	175.7	2.092
	2	174.8	2.081
	3	177.4	2.112
	4	176.1	2.096
	5	177.0	2.107
M	1	175.2	2.086
	2	178.1	2.120
	3	175.2	2.086
	4	177.8	2.117
	5	177.7	2.115
N	1	174.3	2.075
	2	175.2	2.086
	3	176.7	2.104
	4	175.2	2.086
	5	173.6	2.067

Table 5

4 – Processed Data

4.1 Drawing the Graph



Graph 1: This graph shows the deflection of the ball as its revolution per second is changed. As one can see from the graph, RPS and deflection values can be said to be directly proportional. It is also seen that, the values are in a linear form.

5 - Conclusion & Evaluation

5.1 Analysis & Conclusion

In this experiment, the aim was to find a relation between the exerted force and where it is exerted on a ball, and the curve of the ball. To do that the exerted force and the location of the exerted force were independently changed, and the resulting deflections (due to curved path) were measured.

After the experiment, the revolutions per second (RPS) values were calculated caused by two effects, force of impact and the place of exerted force. The relation between RPS and the curved path of the ball was examined. To see the change in curved path, the ball's deflection from its axis was used.

First of all, when the change in exerted force is analysed, it is seen that when the exerted force on the ball increases, it creates a greater spinning rate and a greater deflection. This can be seen from the Table1. This increase in spinning rate also increases RPS of the ball to finally conclude that the ball's RPS caused by changing the exerted force and deflection are directly proportional.

Also, for changing the place of application point of the exerted force, it is again seen that the spin rates and deflection values differ for the application points. It can be said that when the force is applied close to the end of the ball, it creates a greater spinning rate and greater deflection. Again, by summing up this information one can conclude that the change in RPS caused by changing the place of application point is directly proportional to the ball's curve.

A similar experiment was conducted by Lyman J. Briggs and can be used to compare the results of this experiment. In his experiment, Briggs uses baseballs to spin and calculate their deflection with respect to their spin. A graph from his experiment can be seen on the right side. (Picture 3)

As one can see from the graph, the results of the experiments are similar. They both conclude that the spin of the ball has a direct effect on the balls curve and increasing the spin will cause the ball to deflect more.

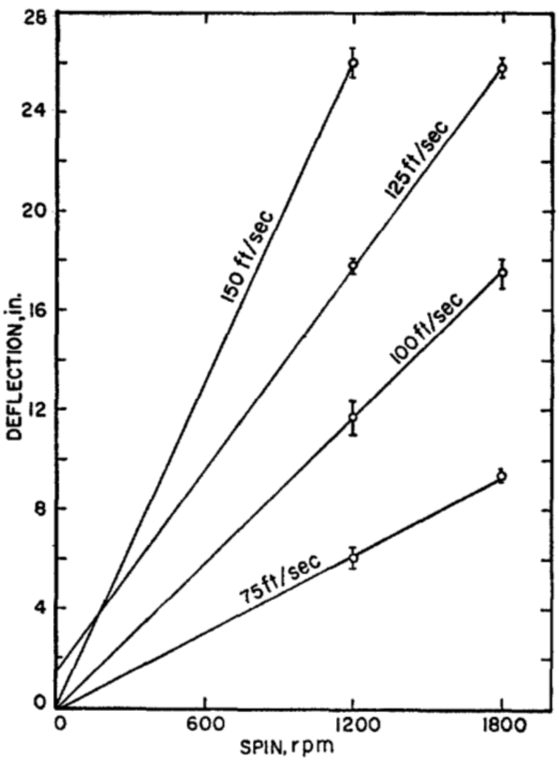


FIG. 2. Lateral deflection of a baseball, spinning about a vertical axis, when dropped across a horizontal windstream. These values are all for the same time interval, 0.6 sec, the time required for the ball to cross the stream.

Picture 3

5.2 Evaluation

Although the experiment was concluded, there are actually many sources of error that affects the result of the experiment.

- One of the major error sources in this experiment is finding the points where the ball fell after it was launched. As the ball bounced after touching the ground it was not possible to mark the exact point where the ball fell. As a result, this caused unwanted differences in the measurements.
- Also, when the graph is drawn and the experiment was concluded the horizontal velocity of the all is thought to be a constant as it is a controlled variable. However, as one can see from Table 5, although the values are close, they varied for trials. This difference affected the reliability of the experiment.
- Another factor about this experiment is the external wind. As the experiment was conducted in an open environment, the external wind changed within time, This affects the Magnus force on the ball, resulting the trials to have different deflection than they should have.

To improve this experiment;

- While improving this experiment one can use the method from Briggs' experiment. For example by using a wind tunnel the effect of the outer wind can be prevented.
- Also, the angular velocity can be calculated with a calibrated Strobotac. This way it could be calculated directly rather than calculating it afterward. Also, the result would be more precise as in this experiment the time of fall was accepted as a constant, whereas there was difference in trials.

6 - Bibliography

- Briggs, Lyman J. "Effectf of Spina and Lateral Deflection (Curve) of a Baseball and the Magnus Effect for Smooth Spheres",
- http://ffden-2.phys.uaf.edu/211_fall2002.web.dir/jon_drobnis/curveball.html
  (Date of Access: 03.10.2011)
- http://physlab.lums.edu.pk/images/f/fe/Zeldovich-spin_orbit_interaction_experiment.pdf
  (D.O.A: 08.10.2011)
- http://www.soccerballworld.com/Physics.htm
  (D.O.A: 08.10.2011)
- http://www.youtube.com/watch?v=qSAK0N1Tgrs
  (D.O.A: 01.10.2011)
- http://www.youtube.com/watch?v=ZnXA0PoEE6Y
  (D.O.A: 01.10.2011)
- http://en.wikipedia.org/wiki/Bernoulli%27s_principle#Simplified_form
  (D.O.A: 08.10.2011)
- http://en.wikipedia.org/wiki/Magnus_force
  (D.O.A: 08.10.2011)
- http://en.wikipedia.org/wiki/Angular_velocity
  (D.O.A: 08.10.2011)
- **Figure 1:** http://www.waybeta.com/uploads/img/201009/2341/201009152305417654.jpg
  (D.O.A: 10.10.2011)
- **Figure 2:** http://upload.wikimedia.org/wikipedia/commons/f/f9/Curveball-magnus-effect.jpg
  (D.O.A: 10.10.2011)