Finding the Spin of a Softball Pitch

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When a rise ball softball pitch was examined by using a high-speed camera, it was found that the rise ball had a constant angular velocity of 65 ± 10rad/s and velocity of 3.1m/s for the seam of the ball. The velocity for the center of mass was also found to be $9.69 \pm 0.49 m/s$. Three forces that affected the flight of the ball were the Magnus force of 0.396N, the gravitational force of -1.94N and the viscous force of $1.6 \times 10^{-4} N$.

INTRODUCTION

The arm motion in softball is the same for every pitch. What changes the pitch is how the wrist finishes when the ball is released and the resulting spin of the ball. Different grips also help to enforce the correct form of the wrist motion and ensure the desired spin. There are a number of phenomena that will determine the flight of a softball. While the angular velocity, linear velocity and the angle of the rotational axis relative to the ground can be easily measured, other quantities such as the Magnus force, Bernoulli effect, Reynolds number (R), drag coefficient (C_d), and drag force (F_d) are more difficult to determine.

The Magnus force, named after an engineer named G. Magnus, gave the first explanation for the lateral movement of a spinning ball.[7] In his report it said, "A spinning ball induces the air around it a kind of whirlpool of air in addition to the motion of air past the ball as the ball flies through the air."[1] Bernoulli's theorem becomes effective when the circulating air slows down the flow of air on one side of the ball but speeds it up on the other. Thus the kinetic energy of the fluid increases and its pressure decreases. Therefore, the side that the air speed is slower will have a higher pressure, and the imbalance will create a force moving the ball laterally toward the lower pressure side. The spinning affects a thin layer of air next to the surface of the ball and therefore it will affect the general flow field around the body.[7] Along with the flow of the air, the Magnus force will also increase when the flow travels farther around the curved surface side with the wind rather than side. From the article by Watts and Ferrer, the Magnus force is created when the flow is turbulent on one side and not the other and results in a lift force. The amount of lift (F_L) depends on the seam orientation, a constant (K), velocity (v) of the ball and its angular velocity (ω). Thus[13], $F_L=2KV^2\omega$. Another way to calculate the lift force was done by Watts and Ferrer.[13] They used a lift coefficient and their conclusion found the drag coefficient was a function of the ratio of the rotational speed of the equator and the center of mass speed. This provided a way to calculate the lift force without knowing the constant *K*.

In addition to the Magnus force, the Reynolds number also has an impact on how the ball spins. Frohlich concluded from his study of the importance of aerodynamic effects that softballs are affected more strongly at higher speeds by aerodynamic forces than a baseball, but at lower speeds softballs are affected less.[3] This is one reason the seams of a softball are higher than the seams on a baseball.

While this object is rotating about some axis there has to be an original force that provided the rotation (in this experiment it is the wrist). The tendency of a force to rotate an object about some axis is measured by torque. The torque acting on an object is proportional to the object's angular acceleration and the moment of inertia. Since in this experiment a spherical ball is being used, the moment of inertia is then

$$I = \frac{2}{5}mr^2, \qquad (1)$$

where m is the mass of the object and r is the ball's radius.

Therefore when an object is spinning about an axis and its center of mass is traveling along a certain vector, an angular momentum ($\vec{L}$) will exist. Since there is no external force (except the viscous force which is very small) acting on the spin of the ball, then the angular momentum (L) is constant and thus,

$$L = I\omega . \qquad (2)$$

Specific forces that act upon a ball can be calculated and compared to see which affects the flight of the ball the most. The first force that can be found is the force of gravity on the center of mass. Two other forces that are important to the flight of a ball are the viscous force and the Magnus force. The viscous force is a force that depends on how smooth or rough the surface is and how on the specific fluid. It can then be calculated

$$F_v = 6\pi\eta R V_{cm}, \qquad (3)$$

where η is the viscosity of air, R is the radius of the object and V_{cm} is the velocity of the center of mass.

The next force to be considered is the Magnus force or lift force. In an article written by Watts and Ferrer[13], they used a technique to find the lift force. Instead of using the equation[13]

$$F_L = 2KV^2\omega, \qquad (4)$$

they used the equation[13]

$$F_L = C_L \frac{1}{2}\rho V^2 A. \qquad (5)$$

Here, A is the cross sectional area, V is the velocity of the center of mass and ρ is the density of air.

EXPERIMENT

The time for one rotation for a rise ball was found by an Olympus Encore high-speed camera running at 250 frames per second and connected to a Macintosh laptop via a video bridge. It was captured using iMovie. After editing a QuickTime version showed how the ball spins upon the axis of rotation as can be seen in figure 1.1. Picking a point such as the top of the ball to follow as time passes made it possible to calculate the time for one full rotation of the ball to be 160ms.

The angular velocity of the seam of the ball was first estimated by following a point on the seam throughout the time it could be seen on the film. Then by dividing the amount of rotation by the time elapsed time, the angular velocity was found to be

$$\omega_{seam} = \frac{\frac{1}{2}\pi}{24ms}$$
$$= .065 \text{ rad/ms} .$$
$$= 65 \pm 10 \text{ rad/s}$$

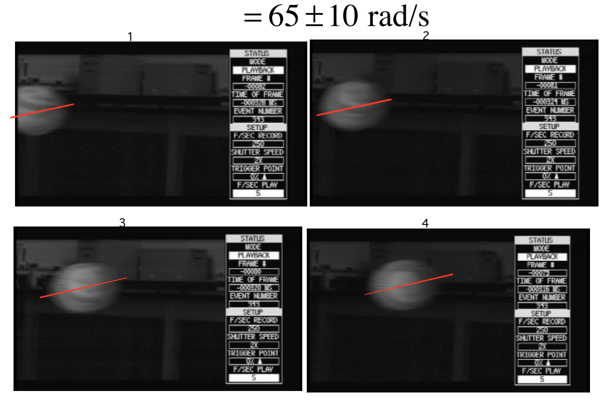

Figure1.1: Consecutive frames over a time of 12 ms. Notice how the seam rotates about the line representing the axis of rotation.

A more quantitative method was used by locating a point on the seam relative to the center of mass of the ball using VideoPoint software. Figures 1.2 and 1.3 show the path of the seam of the ball in the x and y directions. These graphs show how the seam rotated about an axis as time passed.

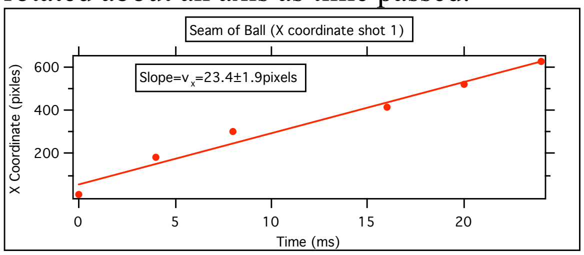

Figure 1.2: A graph of the path of the seam of the ball in the X-direction relative to the center of mass.

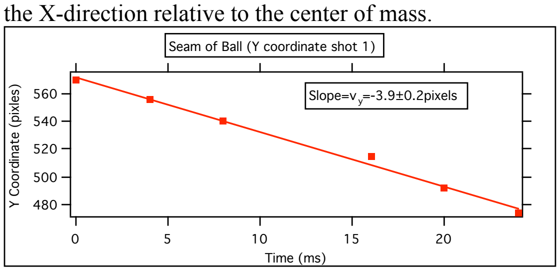

Figure 1.3: The Y-direction of the seam with the path of the ball.

The average diameter from vertical and horizontal distance measured in pixels from the images determined the scale. This gave the diameter in pixels to be 311 ± 22. Then by knowing what the circumference[2] was it was possible to convert to centimeters. The angular velocity was then found by taking the magnitude of the velocities in figures 2 and 3 and dividing by the radius.

$$v = \sqrt{(.00721)^2 + (.0012)^2}$$
$$= 7.3 \pm 0.02 \times 10^{-3} m/s$$
$$\omega = \frac{7.3 \pm 0.02 \times 10^{-3} m/s}{.048m}$$
$$= 152 \pm 5 \times 10^{-3} m/s$$

This gave two angular velocities of the seam of the ball one in radians, $65 \pm 10 rad/s$, and one in meters, $152 \pm 5 \times 10^{-3} m/s$. The velocity of the center of mass was $9.69 \pm 0.49 m/s$.

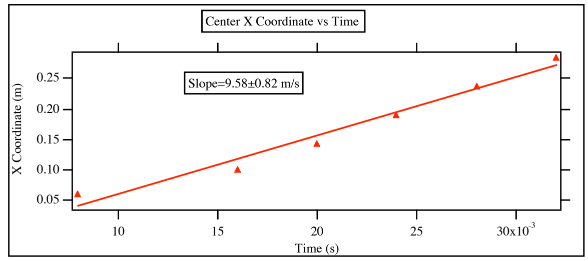

Figure 1.4: Graph of the X-coordinate of center of mass versus time.

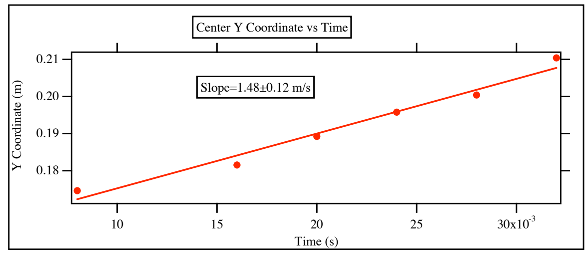

Figure 1.5: Graph of the Y-coordinate of center of mass versus time.

In addition to finding the velocity and angular velocity of the edge and center of mass of the ball that affect the ball, forces such as the Magnus force, force of gravity and viscous force were found. The Magnus force was found by using Eqn.(5) and Fig. 5 that Watts and Ferrer[13] used. For my $\frac{\pi D\omega}{V}$ value of 2.01, it was then possible to find the corresponding C_L of 0.92. Once C_L was determined, it was used in equation 5 to calculate the Magnus force of 0.396N.

$$F_L = (0.92)(\tfrac{1}{2})(1.29kg/m^3)(9.6m/s)^2(\pi \times (0.048m)^2)$$
$$= 0.4N$$

The force of gravity was -1.94N. Finally, the viscous force was calculated by equation 3 to be $1.58 \times 10^{-4} N$.

$$F_V = 6\pi(1.8 \times 10^{-5} kg/ms)(0.048m)(9.69m/s)$$
$$= 1.58 \times 10^{-4} N$$

ANALYSIS AND INTERPRETATION

It is possible that the high-speed camera's rotation time of 160ms is off some, because the calculation was done by estimating how much the ball rotated in the elapsed time. The time was definite but how much the ball actually rotated could change depending on the viewer's line of sight and how much the ball was distorted. Lighting issues in the video and slight disfiguring of the image caused the distortion.

The angular velocity found for the seam of the ball was 65 ± 10rad/s. This result was based on viewing the video of the high-speed camera and had the same problems as the previous calculation had. Therefore, an angular velocity of 65 ± 10rad/s was reasonable result when taking into effect the error. This showed that the high-speed video camera data is more reliable for the best angular velocity data.

Before the angular momentum could be calculated, the diameter of the ball and the angle the seam made with the axis of rotation needed to be determined. This was difficult because the movement of the center of mass of the ball had to be separated from the actual spin of the ball. Each time data were taken from an image in VideoPoint the distance in pixels was needed to be determined and then converted to cm. The average distance was then $311 \pm 23 pixels$ and when it was converted to cm using the distance was 9.6cm, which is the diameter of the ball; a scale was set[15].

Another important factor that needed to be found before the angular momentum could be found was the angle between the seam and the axis of rotation. This would be essential if the angular momentum was changing, but as our results showed and by seeing that the angle changes at a constant rate with time, the angular momentum is constant. The angular momentum could still be calculated though, because the moment of inertia could be calculated and by using equation 2, the angular momentum could be calculated. The angular velocity of the seam was calculated to be 65 ± 10rad/s, therefore, the angular momentum was 0.25kgm^2/s.

From all of the information needed to calculate the angular momentum, the velocity of the seam of the ball and of the center of mass was easy to calculate. Thus, the velocity of the seam was 3.14m/s and the velocity of the center of mass was $9.69 \pm 0.49 m/s$.

The comparison of the forces acting upon the ball was very consistent with what was expected. Due to the size of the softball and the raised seams, the lift force would be expected to be larger than a baseball's lift force of about $0.08N$ when thrown at the same speed.[13] The softball's lift force was larger with a force of $0.4N$. The gravitational force was the largest out of the three forces observed. Thus, the gravitational force was -1.94N. The last force that was calculated was the viscous force and it was also the smallest force. This is because it has been found from previous experiments[13] that the Reynolds number, which depends on how smooth or rough a surface is, does not have a large effect on the flight of the ball. Therefore, a force that depends on the Reynolds number would also not have a large effect on the flight of the ball. Thus, the calculated viscous force of $1.58 \times 10^{-4} N$ was reasonable.

CONCLUSION

From the results, it is concluded that the measured rise ball has a constant angular momentum of 0.25kg*m^2/s. There is an angular velocity of 65 ± 10rad/s on the seam of the ball. Also, there is a velocity of 3.1m/s at the seam and $9.69 \pm 0.49 m/s$ at the center of mass for the measured rise ball. When the forces acting on the ball were compared, the Magnus force was 0.4N, the gravitational force was the -1.94N, and the viscous force was $1.58 \times 10^{-4} N$.

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