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Spin Rate and Deflection Ratio of a Ping Pong Ball

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Abstract

To investigate the effects of a spherical object's spin rate on the curvature of its flight, Ping Pong balls, of varying spin rates, were hit horizontally and recorded from above with a high-speed camera. It was shown that there was a proportional relationship between the ball's spin rate and deflection ratio. Additionally, using the results of the analyzed data, a coefficient of skin friction of the Ping Pong ball was found to be approximately 0.2 under the specific conditions of this investigation.

Introduction

When a Ping-Pong ball is hit with spin, an effect called the Magnus Force causes the ball to curve towards the direction of the spin, as seen in Figure 1. In a paper published by Grant, Sandhu, Edgington, and Rowe-Gurney in the University of Leicester's Journal of Physics [2], a theoretical model based on the theory of the Bernoulli effect was derived to model the relationship between the distance a ball travelled in the direction of motion and the perpendicular distance that it curved,

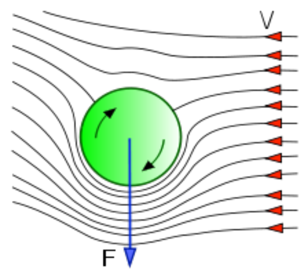

Figure 1 Diagram of the Magnus Force caused by a spherical object's spinning motion in the air. [1]

$$D = \frac{\pi R^3 \rho \omega}{vm} x^2 \tag{1}$$

where D is the distance the ball travelled in the direction of the Magnus Force, R is the radius of the ball, ρ is the density of the air in the room, ω is the spin rate, v is the forward velocity of the ball, m is the mass of the ball, and x is the distance travelled. Equation 1, however, includes three variables v, ω, and x; therefore, could not be tested without the use of professional tools such as a wind tunnel. Thus, for the purposes of this investigation, Equation 1 was rearranged to the following equation,

$$\frac{D}{x} = \frac{\pi R^3 \rho t}{m} \omega \tag{2}$$

Equation 2 predicts a proportional relationship between the deflection ratio $\frac{D}{x}$ and spin rate ω, with a proportionality constant of $\frac{\pi R^3 \rho t}{m}$. This investigation serves to determine the effect of spin rate on the deflection ratio of Ping Pong balls, test the accuracy of the proportionality constant shown in Equation 2, and ultimately test the validity of Equation 1.

Method

The experiment was set up as shown in Figure 2. Before beginning, a line was drawn around the equator of the ball to act as a guide in detecting the ball's spin during the video analysis process. The Ping Pong ball was hit at the height of the reference ruler across the camera's field of view. Due to the difficulty of hitting the ball consistently horizontally at the height of the reference ruler, over forty hits were recorded. Twenty clips which cleanly captured the required trajectory of the ball with spin rates ranging from 0 to 164 ± 3 rad/s were selected.

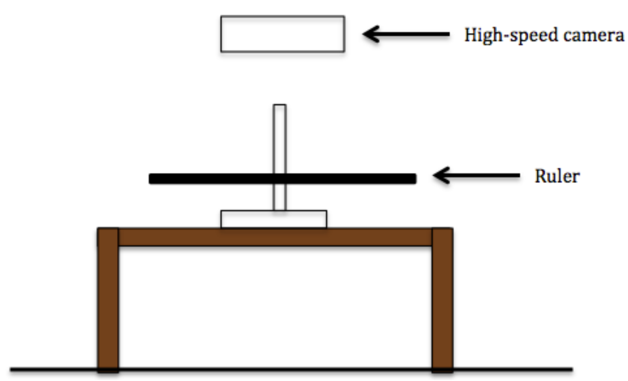

Figure 2 Diagram of the set up. A ruler was set up just inside the camera's field of vision to act as a reference height at which to hit the Ping Pong ball.

Using Logger Pro video analysis, the rotational velocity and the path of the ball was tracked for a fixed time for each hit as shown in Figure 3. The origin of the axes was set on the initial position of the ball and aligned so that the *x*-axis was parallel to the initial direction of motion of the ball, making the y-axis parallel to the acceleration of the ball due to the Magnus Force. A quadratic equation was fit to the *y*-component of the motion, with a linear fit on the x-component, as shown in Figure 4 allowing the deflection ratio, $\frac{D}{x}$, to be calculated.

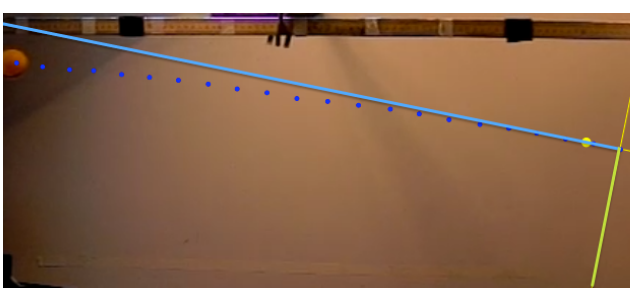

Figure 3 The green axis was used to determine *D*, the distance the ball travelled in the direction of the Magnus Force and the blue axis was used to determine *x*, the distance travelled in the direction of the initial hit. The two values were combined as the ratio of *D*/*x*, defined as the deflection ratio of the ball.

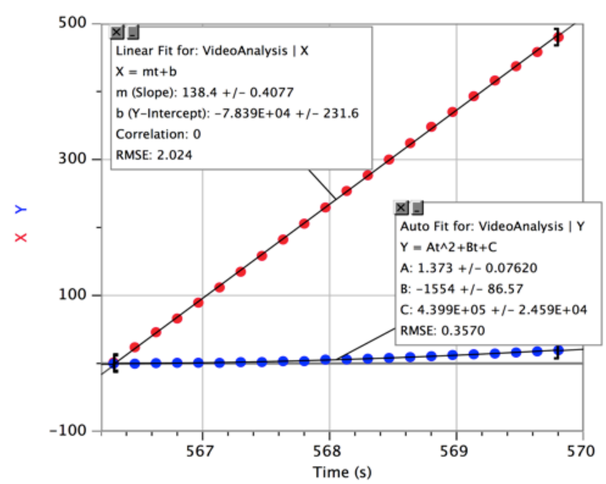

Figure 4 The *x* and *y* components of the ball's motion with curve fits. The equations were used to determine the *x* and *y* displacements, in pixels, and thus the deflection ratio.

Results and Discussion

As shown in Figure 5, the relationship between the spin rate of the Ping Pong ball and its deflection ratio can be represented as,

$$\frac{D}{x} = (0.00042s)\omega \qquad (3)$$

which shows that the relationship between the two variables is proportional. The proportionality constant found in Equation 3 was compared to the theoretical value that was calculated from equation 2 and found to be 0.002207s under the conditions of this specific experiment. Clearly, the theoretical and experimental values of the proportionality constant differ greatly. In fact, the experimental value was less than the theoretical one by a factor of about 0.2, which suggests a flaw in the theoretical model proposed by Grant et al. One assumption they made in deriving their equation was that the air at the surface of the ball was not moving relative to the surface of the ball as it spun, effectively claiming a coefficient of skin friction of 1. A coefficient of skin friction of 0 would mean that the air flow is unaffected by the relative motion of the skin, resulting in no Magnus Force on a spinning ball and thus no deflection. Conversely, a value of 1 would suggest that the air at the surface does not flow relative to the skin surface. This is clearly not a valid assumption, therefore it is suggested that a coefficient of skin friction must be included in the equation proposed by Grant et al to adequately model the deflection ratio of a spinning ball. The improved model is proposed as,

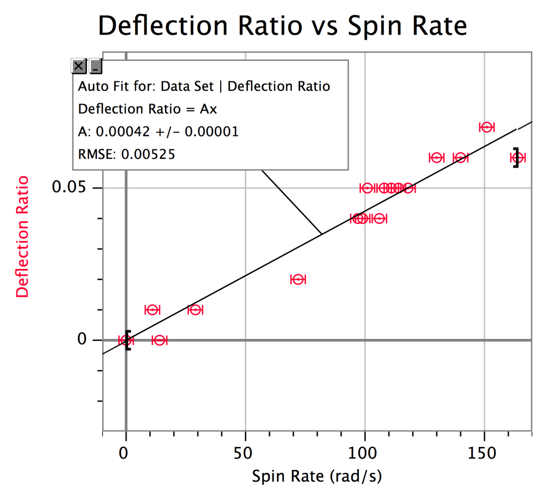

Figure 5: Proportional fit of the relationship between spin rate and deflection ratio, with a proportionality constant of 0.00042 s.

$$\frac{D}{x} = \frac{\pi R^3 \rho k t}{m}\omega \qquad (4)$$

where k is the coefficient of skin friction that is acting between the skin of the ball and the air during its flight. The coefficient of friction of the Ping Pong ball was shown to have a value of 0.2 in this investigation.

One major weakness of this investigation was the fact that the Ping Pong ball was moving in a vertical parabola during its flight. This factor could not be controlled, and thus the distance between the camera and the ball was changing slightly during its trajectory, resulting in some inaccuracies within the data. Although a wind tunnel could be used to improve the accuracy of the data points, the results of this investigation supports the claim that a coefficient of skin friction should be included in the equation to a high level of confidence.

Further research could be conducted studying a wider variety of spin rates, as this investigation mainly consisted of Ping Pong balls of relatively high spin. Various flight speeds can also be tested to see its effects on the deflection of the ball. In addition, different types of sports balls and the effects of spin rate on their deflection ratios can be studied as well. Also, an extension of the investigation could study the effects of top or back spin on the vertical component of the ball's curvature.

Conclusion

The results of the investigation show a proportional relationship between the spin rate and deflection ratio of a Ping Pong ball. In addition, the results suggest the inclusion of a constant, defined as the coefficient of skin friction, in the proportionality constant of the equation used to model this situation. It has been shown that the Ping Pong ball used has a coefficient of skin friction of 0.2 under the conditions of this investigation.

References

[1] Brandon, P., (2010). *The Magnus Force.* Retrieved from http://ffden-2.phys.uaf.edu/211_fall2010.web.dir/Patrick_Brandon/The_Magnus_%20Effect_Cover_page.html

[2] Grant, M., Sandhu, J., Edgington, A., & Rowe-Gurney, N. (2011). A4_14 How to score a goal. *Physics Special Topics, 10*(1). Retrieved from https://physics.le.ac.uk/journals/index.php/pst/article/view/458/256