The effect of baseball seam height on the Magnus Force

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Many people do not know that Major League and College/High School baseballs are different. The difference in the two is the height of the seams that hold the ball together. In this experiment, two baseballs, one with raised seams and the other with lower seams, were investigated to explore how much that the seam height effects the motion of a pitched baseball through the air. I investigated the effect that the seam height of the balls effected the Magnus force. The Magnus force is the effect in which a spinning ball curves away from its principle or expected flight path. The ball with raised seams had a larger Magnus force by about 0.25 N, so the effect of seam height is significant in the effect it has on the Magnus force.

I. INTRODUCTION

For many Americans, the game of baseball is more than watching a batter smash the ball out of the infield and slide safely into second base. The first sign of the game dates back to the mid 1800's, where amateurs played the game with few rules and a baseball constructed out of rubber wrapped with strings covered by horsehide [1]. The baseball did not start out as the beautiful combination of form and function as it is today. The baseball started out as a rubber core wrapped in yarn and a leather cover in a lemon peel type of stitching. Those balls were much livelier than the balls used today, that is that they could be hit much further resulting in very high scoring games. Throughout the 1850s and 60s, the ball and rules continued to evolve into what were familiar with today.

The study of sports ball's aerodynamics dates back before the game of baseball was even created. Isaac Newton decided to scientifically explore the path of a sphere's flight through the air after noticing a tennis ball curve. This interest carried through the years and as technology improved, experiments could be conducted with greater accuracy. A more thorough understanding of a sphere's flight, such as a tennis ball, golf ball or baseball, has been developed and researched by many. Even now, the aerodynamics of spheres are still being studied. With all that being said, some sports ball types, like the baseball, still have uncertainty in explanations of its flight phenomena.

Most people may not know that from Little League all the way through collegiate leagues, the seams are markedly higher than the balls used in professional leagues. The height of the seams directly affects how well pitchers can throw. There is not as much grip on the balls with lower seams, and the ball moves differently when thrown or hit. The NCAA has even committed to changing to flat-seamed baseballs in 2015 due to testing showing that they fly farther than their raised-seam counterpart [2]. The NCAA tested raised seamed and flat seamed balls by putting each through a pitching machine set at a constant angle and velocity for each ball for over 100 tests for each ball. The flat seamed baseball traveled farther than the raised seam ball on average.

Athletes and strategists value knowing equipment behavior for their respective sports. In baseball, aerodynamic ball properties like lift and drag are important to understand to know what pitches may be hit better with more velocity so that they travel further from a batter's perspective. From a pitcher's perspective, knowing which pitch to throw and how each pitch moves can aid in reducing big hits.

In this experiment, I inspect how the height of the baseball seams affects the Magnus force on the ball when it is pitched. Pitchers use different types of pitches when facing batters in hope to get them to miss their swing. To do this, pitchers grip the baseball in different ways, which affects the way that the ball spins during its path to the catcher. The most common pitch in baseball is the fastball. A fastball pitched from an ideal overhand pitcher will have a backspin with respect to the pitcher. Pitches usually want to simply drop due to the force of gravity pushing the ball downward, but for fastballs, the backspin causes a force that opposes the gravitational force. The direction of the curve can always be found by following the simple rule that the ball will follow its nose [3]. In other words, the direction that the front of the ball is spinning with respect to the batter is the direction that it wants to move. For fastballs, the front part of the ball is spinning upward, which makes it want to travel up and oppose the gravitational force, which makes the ball appear to float. (Pitchers throw the ball with different spins to influence the movement of their pitches in different ways in attempt to successfully win matchups with batters.)

The origin of the force which makes spinning baseballs curve may be appreciated once we recall that the drag force acting on a baseball increases with increasing speed. This force, which is known as the Magnus force, after the German physicist Heinrich Magnus, is the dominant spin-dependent force acting on baseballs [4].

In this experiment, I investigate how the seam height of baseballs affects the Magnus force during a pitch using baseballs with lower seams from the professional level and baseballs with raised seams from the college level. The baseballs were mounted onto a motor that is attached to a board which is attached to a frictionless rotating wheel. The board was placed in front of a high powered

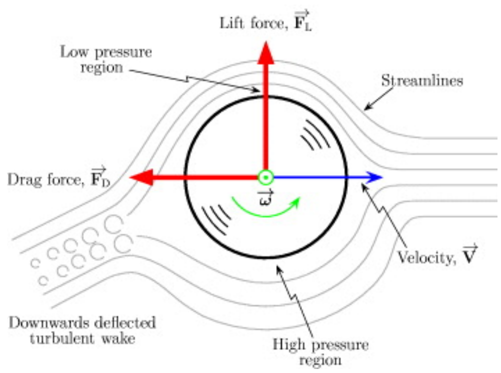

FIG. 1: A simplified schematic diagram showing the streamlines around a rotating sphere under the conditions of a laminar boundary layer. For the case shown of counter-clockwise spin, there is a high fluid velocity and thus a low pressure region above the sphere, and a low fluid velocity, hence a high pressure region below the sphere leading to a lift force (Image is reproduced from Reference [6]).

fan. As the ball spun, the Magnus force took effect, causing the board to rotate. This rotation would continue, stretching a spring which provided a restoring force, until equilibrium was reached. Afterwards, the restoring force was calculated, which was also the value for the Magnus force for the test.

II. THEORY

Understanding the flight of a baseball invloves two major aerodynamic properties, life and drag. Lift can be described as the forces on a ball which are directed perpendicular to the ball's trajectory, where drag is described as a force opposite of the direction of the ball's flight path. The lift force was first studied by Isaac Newton, but later explained and credited to G. Magnus in 1852, having the force named after him. When a spinning ball curves away from its principal flight path, the Magnus force or Magnus effect is responsible. In Fig. 1, it is shown that while the ball is spinning, the pressure surrounding the ball is affected. This is due to a combination of the angular velocity of the projectile ω, the translational velocity of the projectile v, and the drag of the projectile s [3]. The Magnus force acts perpendicular to the direction of motion of the spinning object. It is defined as the cross product of ω and v with some drag variation. The role of drag is not currently mathematically certain. For the purposes of this experiment, we will consider both the drag and surface roughness to be represented by s and use

$$\vec{F} = s(\vec{\omega} \times \vec{v}). \tag{1}$$

For the way that the apparatus is set up in this experiment, the Magnus force creates a torque τ on the board so that

$$\vec{\tau} = \vec{r} \times \vec{F}, \tag{2}$$

where r is the distance from the point where the force is applied to the center of the board. This torque force was balanced by another torque force acting as a restoring force created by a spring that was connected to the opposite end of the same wooden board similarly shown in Fig. 2. We can use the spring constant of the spring as well as the distance the spring stretches in order to find the restoring force and consequently find the Magnus force. The spring constant can be found by Hooke's Law, which states

$$|F| = kx, \tag{3}$$

where k is the spring constant of the spring and x is the distance the spring stretches. After finding the spring constant of the spring, Hooke's Law can also be used to calculate the Magnus force, because the spring force is equal to the Magnus force at equilibrium.

III. PROCEDURE

An apparatus was constructed where the Magnus force could be measured in order to look at the effect of seam height on that force. As mentioned earlier, the Magnus force only affects projectiles that are spinning. Because of this, the apparatus was required to controllably and consistently simulate a spinning ball in constant atmospheric conditions. The motor that spun the ball was connected to an adjustable DC power supply held at approximately 4 V, which translated to approximately 3600 RPM. The motor was placed in front of a high-powered fan that

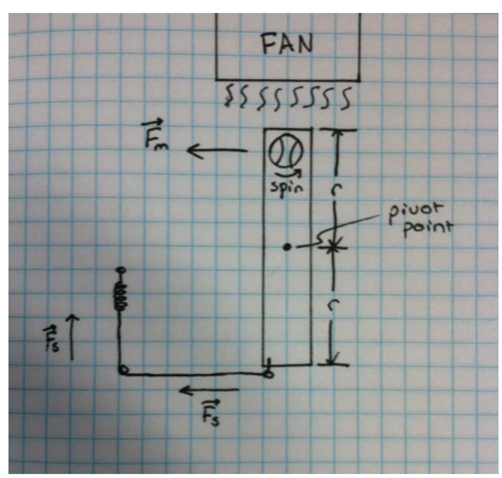

FIG. 2: A simplified schematic showing the forces acting on the board as the ball spins with the fan on. $\vec{F_m}$ is the Magnus force rotating the board, $\vec{F_s}$ is the restoring force due to the spring, and r is the distance from each force to the pivot point of the board.

blew air at speeds of roughly 46 miles per hour, a design inspired from Ian Wilson's modifications to an apparatus used by J. J. Thomson [5]. Once the baseball's motion was properly simulated, I once again used Ian's modifications to Thomson's original apparatus. The hanging board used in Ian's experiment presented a problem when the fan blew on it. The whole board was blowing backwards, which made it hang at an angle that was not perpendicular to the Plexiglas top, which may have affected measurements. Instead, I had the motor attached to a frictionless rotating disk, seen in Fig. 3 which allowed for free rotation due to Magnus force whilist stopping the balance problem the hanging board had. Using the rotation board also provided a more stable base for testing and it eliminated the need for counterbalance masses. The motor was mounted to the board as seen in Fig. 4, and it was mounted a large enough distance from the rotation board so that it had a free range of motion. Test runs were performed to ensure that the apparatus worked properly. When the motor was turned on, the ball spun at a high speed. The ball was then oriented so that it was directly in front of the fan so that it was being hit directly by the air. As the ball spun with the fan on, the Magnus force took effect causing the board to rotate until it could no longer overcome the force of the spring. When the fan was turned off, the board returned to its starting position due to the springs restoring force.

The method that I used to measure the Magnus force involved a spring being used to create a restoring force that worked against the Magnus force when everything was turned on seen in Fig. 5. The spring hung vertically from a screw that was in one of the table legs, and was connected to a string that was guided around another screw and tied to the board that the ball motor was mounted on as seen in Fig. 6. When the ball was spinning and the fan was turned on, the board would rotate until reaching a distance at which the spring and the Magnus force acting on the ball would equal out. It was at this point that measurements could be taken and analyzed. Once the fan was turned off, but the ball was left spinning, the board would return back to its starting position due to the spring.

Once the apparatus was completely set up, two baseballs with different seam heights as seen in Fig. 7 were used to investigate the effect that the seam height has on the Magnus force. Each baseball had similar weights and diameters. The first baseball was a ball with raised seams. The second ball had lower seams than the first ball. I attempted to use a third ball that had no seams at all, but it began falling apart at testing speeds so it was not used for analysis.

The experiment began by placing the first ball onto the aluminum rod and onto the motor. Then, I adjusted the board's initial placement so that it was in front of

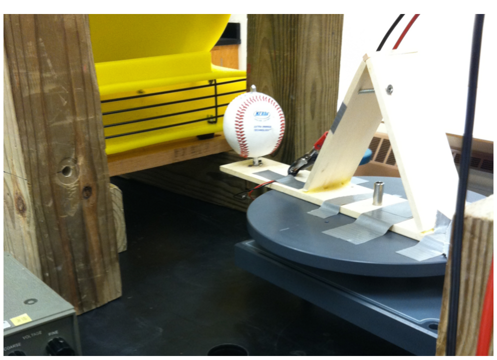

FIG. 3: A picture of the baseball and the board mounted onto the frictionless rotational disc, which allowed for less interference in measurements.

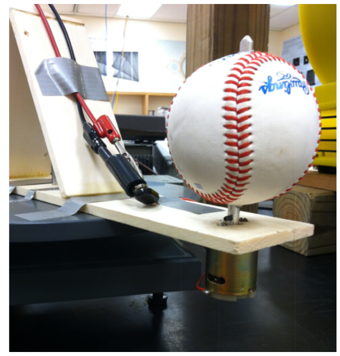

FIG. 4: Each baseball had a hole drilled entirely through its diameter, allowing the aluminum rod to slide through, making the balls mountable. The motor was screwed to the board from underneith and the board was placed on the rotation disc such that there was enough clearance for the motor to rotate freely without bumping. The motor is powered by a DC power supply, whose wires were hung up to avoid any interference.

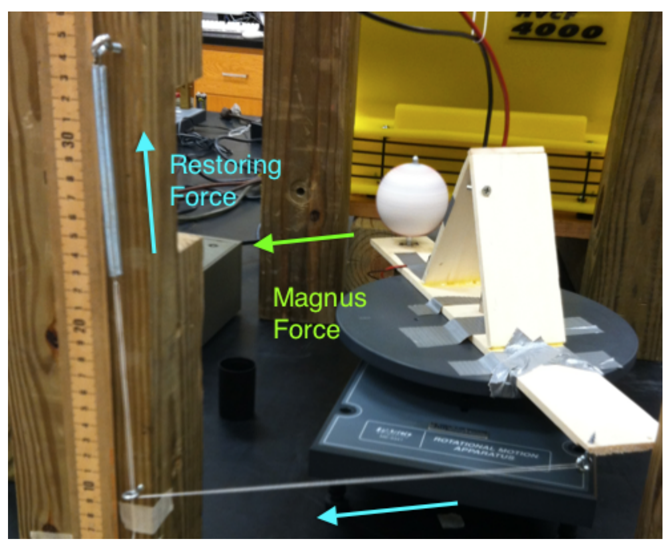

FIG. 5: An image showing the forces at work. The blue arrows represent the restoring force provided by the spring, and the green arrow represents the Magnus force rotating the board.

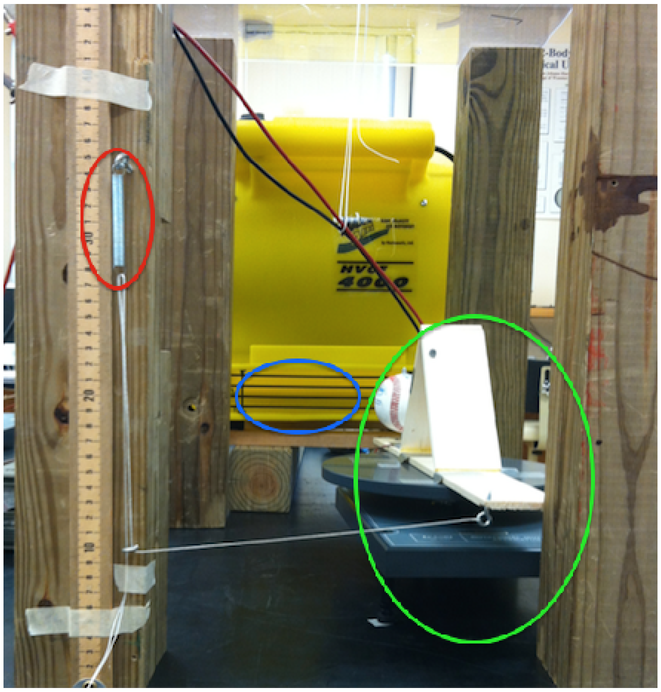

FIG. 6: The entire assembled apparatus. The blue circle is the fan that was set on the first setting, blowing air at roughly 46 mph. The green circle is the ball mounted on the motor, which is screwed to the board that is bound to the frictionless rotating disc. The string is tied to a screw and routed around another screw to be tied to the spring, represented by the red circle, which is hung above from another screw. As the board would rotate, the string tied to the spring would be pulled, stretching the spring a certain distance until equilibrium was reached; that distance could then be measured and recorded using the meter stick.

the fan and the string attached to the spring was taut. The motor was turned on first, rotating the ball at 3616 ± 20 RPM, then the fan was turned on, blowing air at 46 ± 1 miles per hour. I measured the rotations per minute of the ball by holding a smart pulley to the rotating baseball, measuring tangential velocity at different voltages. I then graphed the tangential velocity versus voltage shown in Fig. 8 , using the annotated ″a" and ″b" values given by the graph for the equation $a + bx = v$, where x is the voltage value, to calculate the tangential velocity at any given voltage since the graph is linear. I used the tangential velocity and the radius of the baseballs in an online converter to calculate the revolutions per minute of the balls. I measured the wind speed with a Pasco interface anemometer, taking the average of three different tests measuring the wind speed in miles per hour. Once everything was turned on, the board rotated until it reached equilibrium with the spring. Once equilibrium was reached, a high definition photograph was taken of the spring. This process was repeated three times, taking pictures of the spring when the fan was off and again when it was on for comparison.

FIG. 7: The two balls that were used in testing. The left ball is the college/high school baseball with raised seams. The ball on the right is a Major League Baseball with flat seams.

IV. RESULTS AND ANALYSIS

For each run, the photograph was analyzed using Logger Pro for accurate measurements of the placement of the spring on the meter stick, seen in Fig. 9. To measure the distance that the spring stretched, a straight line was added to the graph and orientated in such a way so that it was parallel to the lines on the meter stick. This was done for the top and bottom of the spring and repeated for each photograph. The data collected from each ball can be seen in Fig. 10, where the difference between the red and blue dots represents how much the spring stretched. An average stretch distance was taken

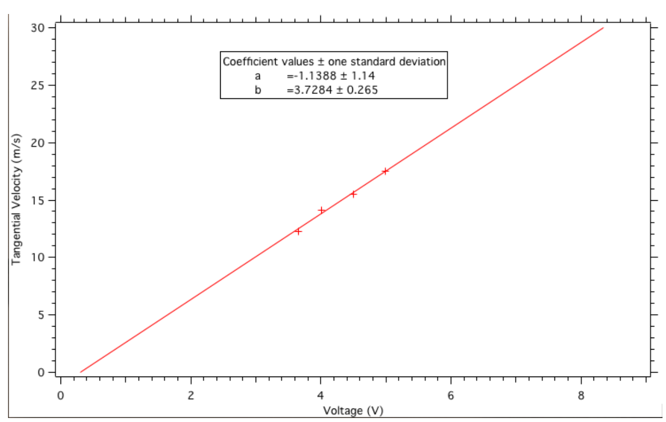

FIG. 8: Tangential velocity measured with a smart pulley vs. the voltage applied to the motor. Since the plot is linear, the equation $a + bx = v$ can be used to calculate the tangential velocity at any voltage.

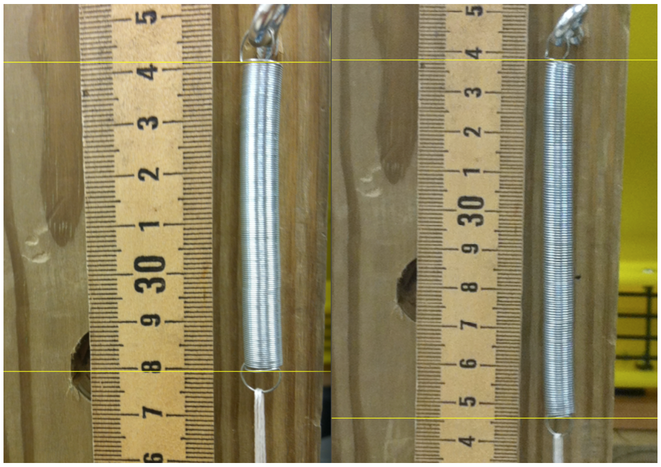

FIG. 9: An image of one of the ball's initial and final positions being analyzed. Some of these images were viewed in this manner in order to find the distance that the spring stretched for each test.

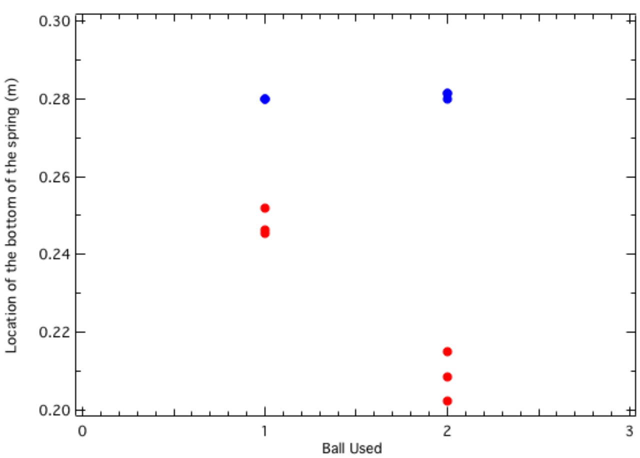

FIG. 10: A graph of the raw data collected for the two balls. The first ball is the ball with the lower seams, and the second ball is the one with raised seams. The blue dots represent the initial starting positions relative to the bottom of the meter stick. The red dots represent the points at equilibrium relative to the bottom of the meter stick. The change in location was calculated and used to find the Magnus force.

from the data and used with the spring constant of the spring to find the force. The lower seamed ball stretched the spring 3.175 ± 0.01 cm on average and the ball with the raised seams stretched the spring 7.23 ± 0.01 cm on average.

In order to calculate the Magnus force that caused the ball to stretch the spring, the spring constant k was needed. This was found by placing a 50 kg mass onto the spring and measuring how far it stretched with the previously mentioned method. Since the force due to gravity is known and the distance the spring stretched was measured, Hooke's Law could be used to find the spring constant. The spring that was used in this experiment had a spring constant of 6.17 N/m. After finding the spring constant, Hooke's Law was once again applicable in finding the Magnus force for each ball. After everything was calculated, I found the Magnus force on the ball with the lower seams to be $F = 0.196 \pm 0.001$ N and I found the Magnus force on the ball with the raised seams to be $F = 0.446 \pm 0.002$ N. The baseball with the raised seams has a larger Magnus force acting on it than the ball with the lower seams as expected. These results support the studies done by NCAA DI baseball labs wanting to use flat seamed baseballs in the future for the fact that they travel further.

The results from both balls vary quite a bit, as the raised seam ball had over twice the amount of Magnus force acting on it. Measurements were as accurate as my placements of the lines during photograph analysis. The sources of error that the apparatus itself presented was the angle that the air was blowing, possible frictional forces, and possible air resistance from the board itself being hit by the air. These results were found using a fan blowing at half the speed of a professional pitcher, and ball spinning nearly 600 RPM faster than that of the top Major League pitcher. At higher speeds, I would expect the Magnus force to be even greater on both of the balls.

V. CONCLUSION

The goal of this experiment was to investigate the effect of a baseball's seam height on the forces it experiences during flight. Through testing with an apparatus that allowed me to measure the Magnus force of the two subjected baseballs, I was able to investigate and analyze two different baseballs with varying seam height. The ball with lower seams had a smaller Magnus force of 0.196 ± 0.001 N. The ball with the raised seams had a Magnus force of 0.446 ± 0.002 N acting on it. The difference was relatively significant, as the higher seamed ball had over twice the amount of force due to the Magnus effect acting on it. To put things into perspective, a raised seam curveball thrown at 90 mph will drop roughly 0.62 feet more than a flat seam curveball thrown at the same speed compared to a spinless ball thrown at the same speed.

VI. ACKNOWLEDGEMENTS

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