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In situ lift measurements of sports balls

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Abstract

Aerodynamic lift on sports balls is typically measured in wind tunnels. Wind tunnel measurements may have measurable differences with ball drag occurring in play. Measurements under game conditions have been attempted, but are difficult to interpret from the data scatter and are not controlled. The following considers lift measurements from a ball propelled through static air in a laboratory setting. High speed light gates were used to measure lift. Lift was observed to depend on the ball speed, roughness, stitch height, and orientation.

Keywords: lift; sport ball aerodynamics; magnus effect, lift measurements.

1. Introduction

Understanding the flight of a ball involves two aerodynamic properties, lift and drag. Drag is the force, F_d, in the direction opposing the ball's flight path. Lift can be described as the force, not including gravity, on a ball that is directed perpendicular to the ball's trajectory. [1]. The lift coefficient, *Cl*, is found from [2]

$$C_l = \frac{2F_l}{\rho A V^2} \tag{1}$$

where ρ is the density of air, A is the cross sectional area of the ball, and V is the speed of the ball. Lift is a function of surface roughness, rotation, velocity, and orientation of the ball.

It is convenient to describe the ratio of translation velocity to angular velocity by the non-dimensional spin factor, S, defined by [3]

$$S = \frac{\omega r}{V} \tag{4}$$

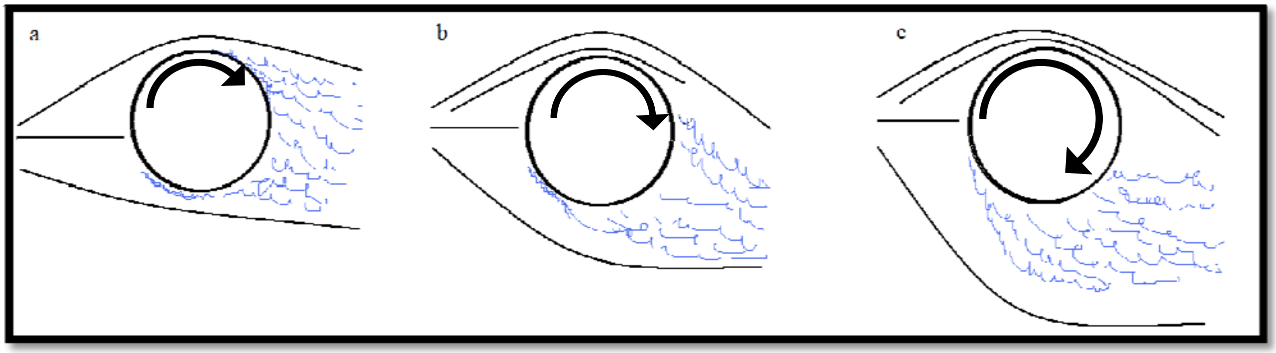

Figure 1 - Flow from left to right over a rotating smooth cylinder. Angular velocity, in the clockwise direction, increases in speed from a) to b) to c).

where ω is the angular velocity, r is the radius, and V is the linear speed. Prandlt [4], intrigued by the Magnus effect, analyzed how rotation of a cylinder or sphere caused lift. He found that as rotation increased, lift increased. As rotation was introduced on the 2-D cylinder, as seen in Figure 1, the flow separating off the backside (right side of the cylinder) begins to move to the lower side. When the air flow and ball surface move in the same direction, the air particles will have increased momentum which moves the flow separation point away from the upstream stagnation point [5]. When the air flow and cylinder surface move in opposite directions, the air particles will have decreased momentum, which moves the flow separation point toward the upstream stagnation point. A difference in pressure perpendicular to the free stream airflow is observed creating a net force perpendicular to the ball path (the sum of the forces on the ball no longer directly appose its path). Thus, balls thrown with back spin (the airflow and the ball surface at the top of the all act in the same direction) will have a lift force that resists the effect of gravity.

The effect of speed and rotation on lift can be described by a bilinear trend, as illustrated in Figure 4. Nathan[3], Watts and Ferrer[6], Alaways [7], Bearman and Harvey[8], Jinji and Sakurai[9], and Briggs [10] found similar bilinear trends in their research. Most recently, Nathan projected balls in a laboratory setting and used a motion tracking system using ten Eagle-4 cameras and found similar results.

The following considers the effect that surface roughness, velocity, orientation and rotation will have on the lift force. The study was conducted in a laboratory setting to improve the accuracy of lift measurements over that achievable in game conditions. Balls were projected through static air to avoid interaction with ball support devices.

2. Methods and experimental setup

The change in ball vertical displacement was found using two light boxes that measured both the position and speed of the ball. The study examined three different sports balls. The translational velocity ranged from 26.8 m/s to 40.2 m/s.

A three wheeled pitching machine (HomePlate, Sports Tutor) was used to project balls with controlled angular velocity. The three wheels were oriented 120° apart with the lower wheel aligned in the vertical direction. A high speed video camera (1000 fps, 10^{-4} s shutter speed) was used to record each shot to verify correct orientation, flight path, and angular velocity. Tracking software was used to determine the angular velocity of each pitch.

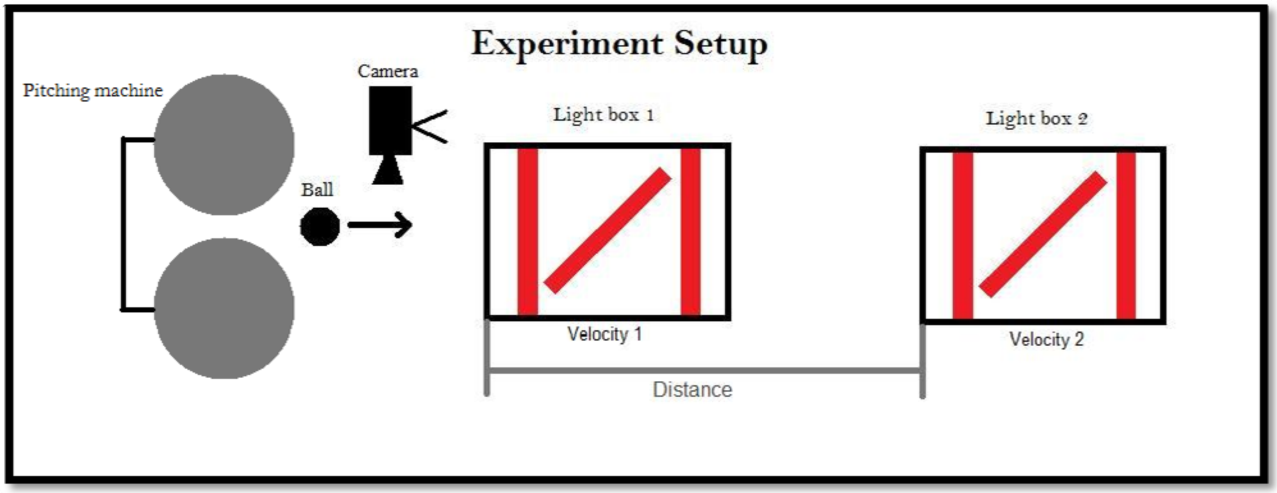

Figure 2. Diagram showing arrangement of pitching device and light boxes used to measure ball speed, rotation, and location.

Once the ball was released from the pitching device, it began its path through the light boxes. Each box had an opening of 0.3675 meters by 0.4953 meters to allow enough room for a ball to enter and exit without contacting the inner walls as it passed through. Each light box consisted of three pairs of light gates (Ibeam, ADC) as shown in Figure 2. Each light gate was rigidly mounted and levelled inside the light box. Velocity was found from the two vertical gates placed 0.4191 meters apart. Lift was found from change in the ball's vertical position, which was measured from the light gates mounted at 45°.

The light boxes were placed between 5 meters apart. The change in velocity between the boxes ranged from .5-1.75 m/s. The light boxes were squared to each other and the pitching machine using a laser level. The lift force, *Fl*, was found from [11]

$$F_{\mathrm{L}} = m\frac{2(\mathrm{D}_{\Delta\mathrm{y}} - \mathrm{V}_{\mathrm{Ay}}\mathrm{t}_0)}{\mathrm{t}_3{}^2} - \mathrm{g} \tag{3}$$

where $D_{\Delta y}$ is vertical difference in ball position from Light box 1 and 2, V_{Ay} is the V_{Ay} is the initial vertical velocity at Light Box 1, t_0 is the time taken from the release of pitching machine to Light Box 1, t_3 is the time the ball takes to travel between the light boxes, g is gravity, and m is the ball mass.

3. Samples

The three wheeled pitching machine allowed ball orientation to be controlled and rotation was imparted only in the vertical plane. The study comprised of major league baseballs, collegiate baseballs and dimpled pitching machine balls. Two different orientations of the collegiate ball were used. As shown in Figure 3, a normal orientation positioned stitches perpendicular to airflow and a parallel orientation positioned stitches parallel to air flow.

Figure 3. Diagram showing the normal/2-seam (a) and parallel/4-seam (b) orientations. Black arrows indicate the airflow direction, white arrows indicate the ball rotation axis.

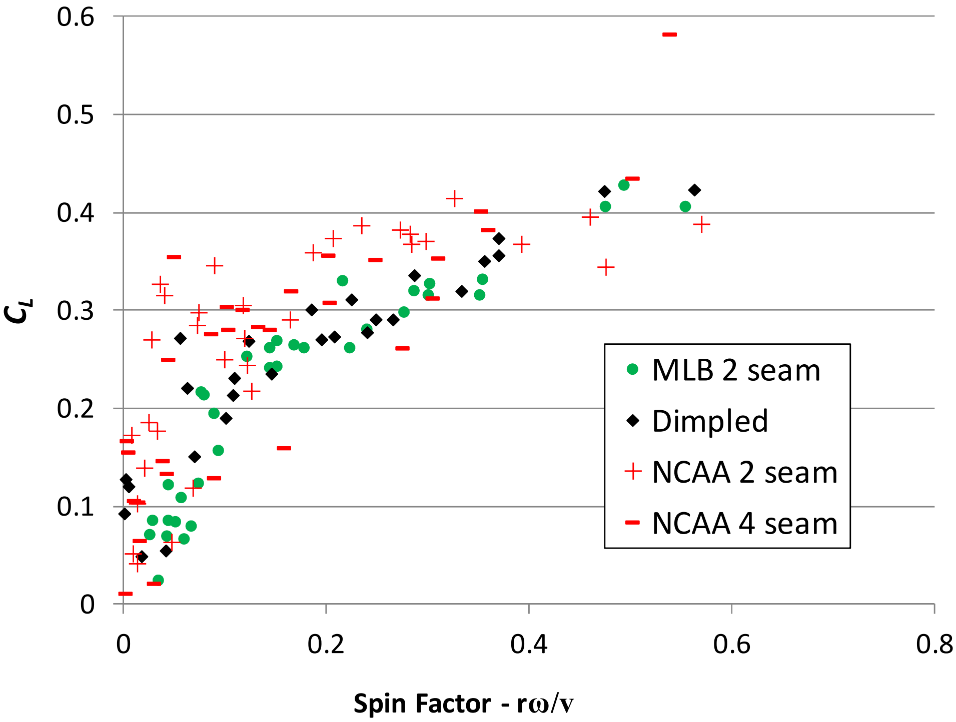

Figure 4. Coefficient of lift for all test balls.

4. Results

The lift coefficient is shown for all the sports balls from this study as a function of spin factor in Figure 4. All balls show a bilinear trend with a rapidly increasing coefficient of lift from C_L of 0.0 to 0.28 and then changing to a less aggressive increase from 0.28 to 0.6. The lift curve for the MLB and dimpled pitching machine ball had the least amount of scatter. The lift on the collegiate ball showed greatest lift. Lift increased with increasing spin factor. Lift also increased with increasing stitch height. The data did not show a definite increase in coefficient of lift when switching from a 2-seam to a 4-seam orientation, contrary to the general understanding of players and coaches.

Scatter in lift was larger for the collegiate baseball than the other ball types. The stitch height plays a definite roll in this scatter. Because the stitches are taller, the slightest variation in stitch orientation will affect the lift for that particular shot. Variation in the orientation of stitched balls was difficult when releasing from a wheeled pitching machine. It is not surprising, therefore, that the dimpled pitching ball showed the least amount of scatter.

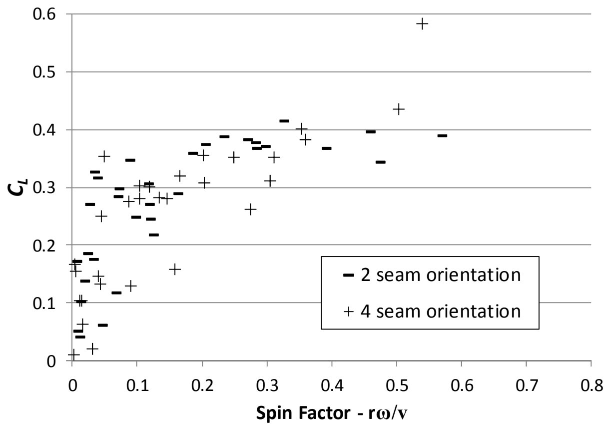

Figure 5. The lift coefficient of the collegiate baseball in the normal and parallel orientations.

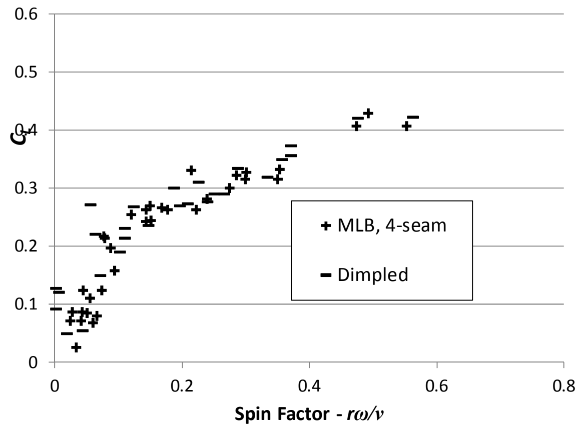

Figure 6. The lift coefficient of MLB in 4 seam orientation and the dimpled ball.

5. Concluding remarks

The preceding has considered the lift of sports balls obtained by projecting the balls through still air. The collegiate baseball, MLB, and dimpled balls were tested. The lift trends on all balls and orientations were comparable to previous experiments in that a bilinear lift trend was observed. The three wheeled pitching machine controlled orientation with rotation, revealing the sensitivity to stitch height and orientation. The average C_L on a baseball increased by 15%-20% from the collegiate to MLB. It is difficult to pitch baseballs with exact orientation. Hence, scatter in the data was observed for some ball types.

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