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Relating baseball seam height to carry distance

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Abstract

Past work has shown large variation in the drag of baseballs. Little is known concerning the causes of variation in ball drag. Ball diameter, weight, seam height, surface roughness, and shape influence lift and drag, and therefore carry distance. The aim of this work was to quantify the effect of seam height and roundness on ball lift and drag, which, to our understanding, has never been done outside of a wind tunnel. A bespoke, non-contact, ball surface profiler, was used to measure ball radius, including seam height. The profiles were analyzed to describe ball roundness and seam height separately. Balls with three different seam heights were projected in an enclosed stadium 102-122 m (describing a typical fly ball). Redundant radar devices were used to measure launch angle, speed, and flight paths. High speed video was used to confirm launch angle and ball spin rate. Hit distance was verified with a physical tape measure. The ball's roundness influenced the effective height of a seam. Measurements of the non-seam area of a ball were necessary to characterize the seams of a ball. A strong correlation was observed between seam height and a ball's drag coefficient. Lift, however, was not sensitive to seam height or ball shape.

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Keywords: drag, lift, sports ball aerodynamics, surface roughness, drag crisis, seam height

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1. Introduction

Characterizing the flight of a baseball after it has been hit involves two aerodynamic properties, lift and drag. Drag is the force, F_d, in the direction opposing the ball's flight path. Lift, also known as the Magnus Effect, can be described as the force, not including gravity, on a ball that is directed perpendicular to the ball's trajectory. Both the coefficient of lift, C_l, and drag, C_d, are dimensionless and describe the lift and drag forces on a shape or

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object in a fluid, such as air [1]. After a ball is hit from a bat, it travels through air where only gravity and aerodynamic forces are present. Hit baseballs travel at high speed and long distances making scientific observations difficult. Wind tunnels and controlled in situ laboratory experiments are chosen to characterize the aerodynamic properties over short distances and controlled airflow [2-5]. Major league baseball games are now recorded with video tracking systems, such as HITf/x, allowing ball tracking. Lift and drag coefficients can be found using these methods, but often display low reproducibility due to experimental error.

Wind tunnels measure aerodynamic forces, but the ball must be rigidly mounted to load cells that can interfere with airflow. In situ analysis involving speed gates or motion tracking measurements receive scrutiny due to the short distance used to characterize the response of the ball. Video tracking is also limited to camera resolution and recording frame rate.

Recent aerodynamic studies [8] have shown that the raised seam baseballs have a higher variation in drag and lift than the low seam balls. Even for low seam balls, large discrepancies between the predicted and measured hit distances, nevertheless, persist. The work presented here considers the effect of seam height on ball lift and drag by analysing full flight baseball trajectories in a controlled environment.

2. Methods and experiment

The aim of this study was to understand how the surface of the ball affects its aerodynamic properties. Relatively little data exists characterizing the surface geometry of a ball. The baseball's surface is commonly accepted as a non-uniform roughened sphere [6] with unpredictable aerodynamic movement when traveling with no rotation [7]. The location of the seams relative to the airflow cause these "knuckling" effects. The surface geometry created by the seams is complex and not readily characterized using standard commercial profilometers.

The following considered baseballs with three seams heights: high seam (Rawlings R1NCAA), medium seam (Rawlings FSR1NCAA), and low seam (Rawlings Official Major League Baseball). The ball surfaces were measured with a contact and non-contact ball profiler (see Figure 1).

The contact profiler was designed to measure seam height relative to the adjacent ball ear (leather surfaces between the seams or stitches, Figure 1a). The profiler has three posts equally spaced with a dial indicator at the center. Seam height was defined as the average radial distance from the seam to the ear, 3 mm left and right of the seam.

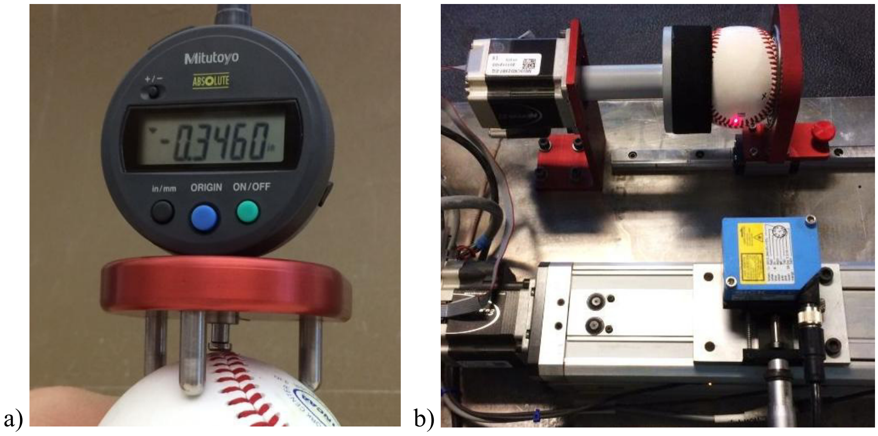

Fig. 1. a) Contact ball profiler b) Non-contact laser ball profiler

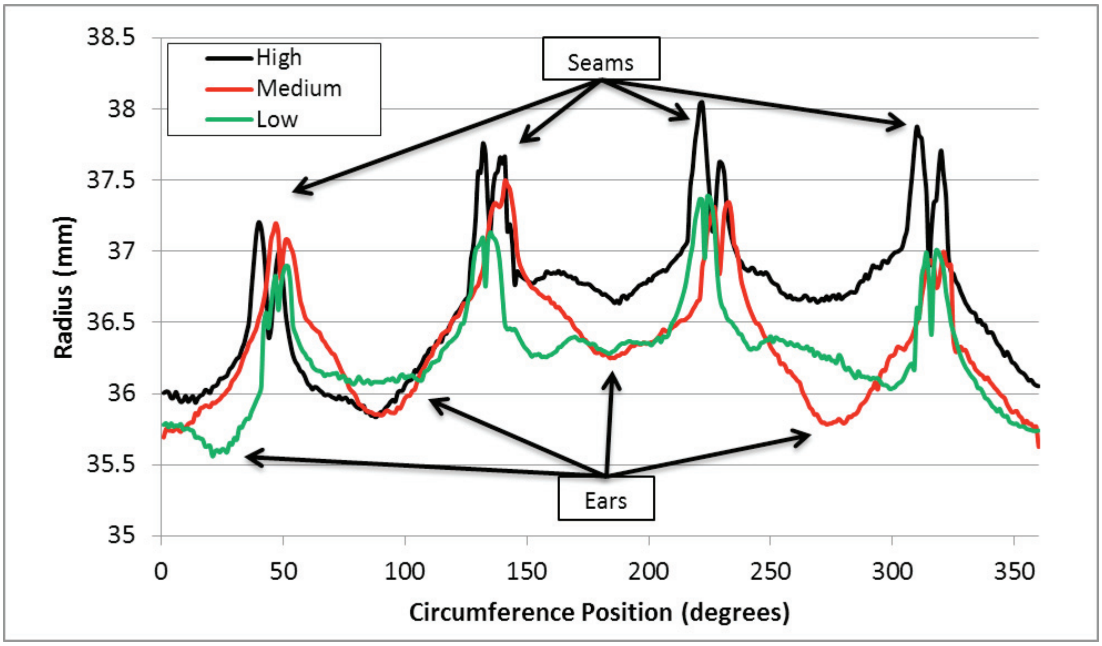

Fig. 2. Example output from non-contact laser profiler. Three ball models included are high, medium, and low seam baseballs.

A non-contact profiler was used to measure the surface profile of the ball with high accuracy (±.0254mm). The ball was supported between a motor controlled spindle and low friction bearing allowing the ball to rotate about a fixed axis. The ball was rotated in a 2-seam and 4-seam orientation (see Figure 3b) one full revolution, while measuring the radius in one degree increments. The output was a surface profile about a single cross section of the ball, as shown in Figure 2. The ball can be thought of as having two radii: an ear radius, R_E, and a seam radius, R_S (see Figure 3a). Note: The vertical scale in Figure 2 was magnified to show the differences in surface radius.

The experiment was conducted in the Houston Astros closed roof stadium to eliminate uncontrolled wind conditions from affecting the ball trajectories. Balls were projected with a bespoke pitching machine (Figure 4). The machine accelerated the ball with a controlled seam orientation in a piston style pneumatic cannon prior to. Once the ball was accelerated, it entered two spinning wheels to impart rotation. The accelerator allowed for a higher exit speed, spin rate, and prevented damage to the surface of the ball from friction with the spinning wheels [9].

One dozen balls of each model were projected in the 4-seam orientation from home plate in the direction of Centre Field. A total of 52 pitches were analysed. Redundant radar devices (Portable and Stadium version of Trackman) were used to measure launch angle and ball exit speed. High speed video recorded each shot and confirmed exit speed, spin rate, and launch angle. The landing point was marked with a small flag and measured manually. The projected balls had an average launch angle of 28 (±1) degrees, exit speed of 42.9m/s (±.9m/s), and spin rate of 1680rpm (±275rpm).

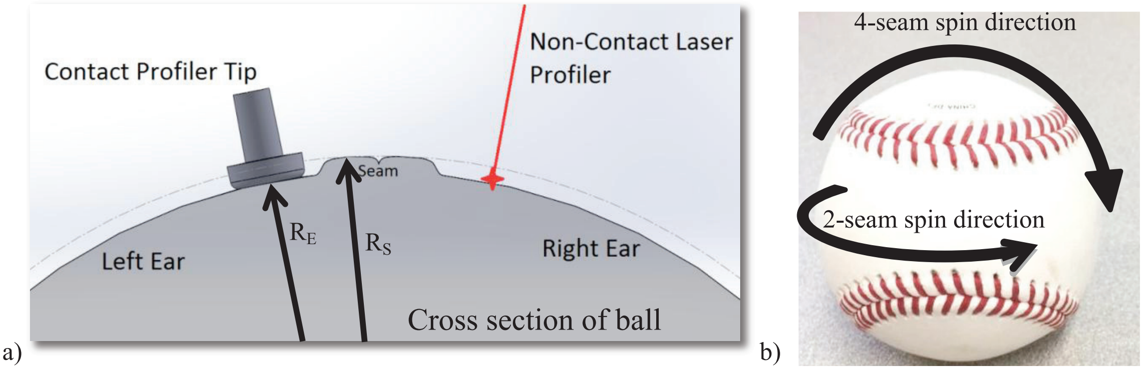

Fig. 3. a) Cross section of ball depicting the different types of profiler methods; b) 4-seam and 2-seam spin direction.

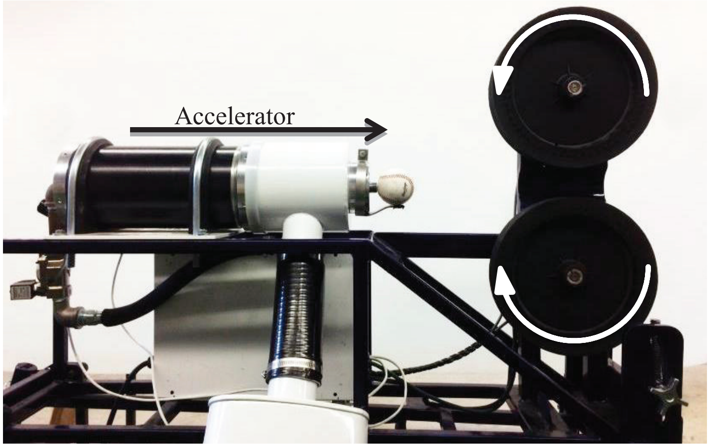

Fig. 4. Pitching machine.

3. Results and Discussion

The average lift and drag coefficients for each ball were found using the measured launch conditions by adjusting C_d and C_l until the predicted flight time and carry distance matched experiment. Carry distance was normalized using the C_d and C_l for each ball with a nominal launch angle of (28°) and exit speed (42.9m/s). The reported carry distance here refers to the normalized carry distance, *D*.

Surface profiles for all balls were obtained with the contact and non-contact profiler in the 4-seam and 2-seam orientations. As seen in Figure 2, the ear radius will vary from the edge of the seam to the centre of the ear. Five methods of seam height measurement were considered. The four methods using the non-contact profiler were: (1) Surface Deviation – The standard deviation of the ball's radii (2) Seam to Minimum Ear – the minimum ear radius was subtracted from the adjacent maximum seam radius, RS (averaged from four ears). (3) Seam to Maximum Ear – same as (2) but using the maximum ear radius. (4) - Seam to Average Ear – the average of the four ear radii were subtracted from the four seam radii, then averaged. A fifth method used the contact profiles. (5) Contact Profiler – seam height was relative to ear height on both sides of seam measurement location. Seam height was the average of four locations in the 4-seam orientation and two locations in the 2-seam orientation.

The five seam height measurement methods were regressed against the ball coefficient of drag. A linear regression or correlation strength, R^2, was calculated for each case and is reported in Table 1. The Max Seam to Max Ear yielded the lowest correlation. The highest correlation occurred with the Seam to Average Ear method.

Interestingly, the relatively simple measure using the contact profiler method was only 6% weaker than the highest correlation.

As observed in Figure 5, carry distance depended strongly on the drag coefficient. Low seam balls travelled the furthest, with an average distance of 116.8 (2.62)m and C_d of 0.34 (0.01). Here and elsewhere, values in parenthesis indicate the standard deviation. The medium seam average distance was 110.2 (2.23)m with an average C_d of 0.39 (0.02). The high seam average distance was 107.7 (3.43)m with an average C_d of 0.42 (0.02). The average C_l was .26 (0.02) and was not sensitive to seam height. While there were clear differences in average carry distances between each seam height, a wide range in carry distance for each seam height was also observed.

A single high seam ball and single low seam ball were projected eight times each. The raised seam, short distance, ball had an average carry distance of 100.0 (0.6)m. The low seam, long distance ball had an average carry distance of 112.4 (0.8)m. The good experimental repeatability of these results, suggested that the largest contributing factor in carry distance variation was the ball.

A carry distance, D_p, was found from the drag coefficient of each ball using the regression in Fig. 5a. The carry distance, D_p, is compared with the measured carry distance, D, in Fig. 6, where the average difference was 0.05 (1.40)m. A carry distance, D_p, was also found from the seam height. This was done by finding a drag coefficient from the seam height of each ball using the regression of Fig. 5b. Carry distance was found using this drag coefficient in the regression of Fig. 5a, where the average difference was 1.1 (3.3) m, as shown in Fig. 6. The seam height is shown to be a strong indicator of ball drag, and in turn, carry distance. It is clear, however, that factors other than seam height affect ball drag. One possibility not considered here is the effect of ball center of mass. An off mass center would cause oscillations in flight that were not captured in the surface roughness measurements performed in this work.

Table 1. Seam height measurement method and its corresponding linear regression strength

Method Name	Description of Seam Height Method	Ball Orientation Analyzed	Linear Regression Strength (R^2)
Surface Deviation	Standard deviation of ball radii	4-seam	.504
Seam to Max. Ear	Max. seam less max. adjacent ear	4-seam	.406
Seam to Min. Ear	Max. seam less min. adjacent ear	4-seam	.573
Seam to Average Ear	Max. seam less average adjacent ear	4-seam	.596
Contact Profiler	Measured seams 8 seams - 4 and 2 seam orientation	4-seam and 2-seam	.563

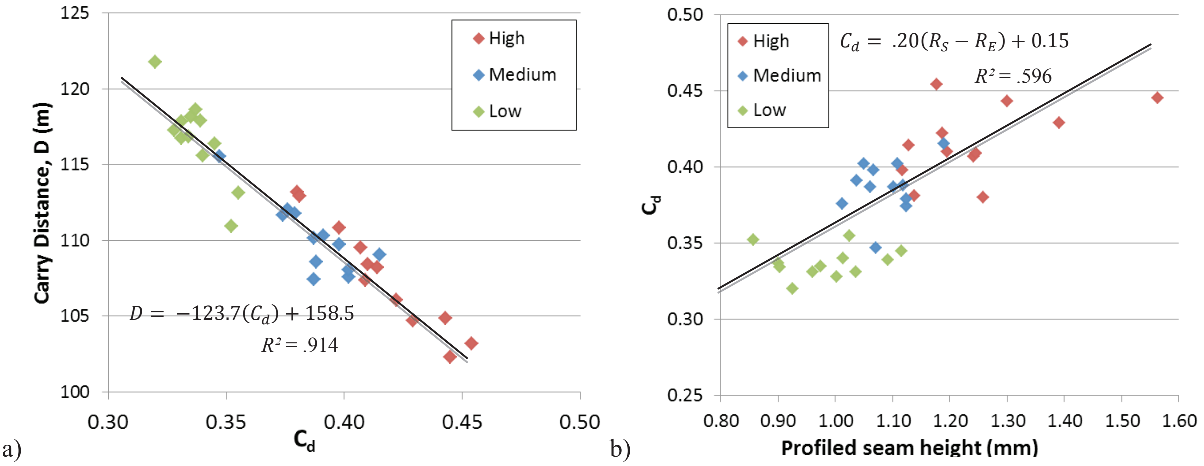

Fig. 5 a) Coefficient of drag versus nominal carry distance, D. Baseballs were projected at exit speed 42.9m/s, 1600 rpm spin rate, and 28° launch angle; b) Coefficient of drag versus seam height. Seam height was calculated using the Seam to Average Ear method.

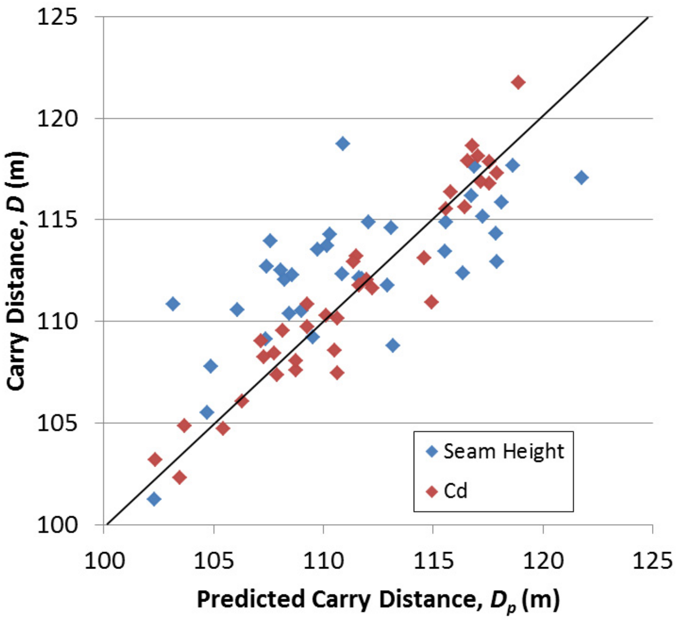

Fig. 6. Measured carry Distance, *D*, compared to carry distance found from the regressions in Fig. 5. The concordance coefficient, r_c, was 0.71 and 0.96 for Seam Height and C_d respectively.

4. Summary

A full field in situ baseball aerodynamic study was conducted in a controlled environment to study how baseball coefficient of drag and carry distance is affected by surface geometry. Baseballs with low, medium, and high seams were compared. The largest seam heights yielded the shortest carry distance and highest drag. The smallest seam heights yielded the longest carry distance and highest drag. The coefficient of drag was repeatable and showed good correlation to seam height. The coefficient of lift was not sensitive to seam height. Carry distance can be predicted if drag or seam height is known.

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