SPIN, TRAJECTORY, AND MOTION
- IN THE CASE OF BASEBALL AND SOFTBALL PITCHERS –

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Using mechanical principles as the basis, the trajectory of a pitched ball is determined by its initial linear and rotational velocities, the angle of release, the direction of the ball's axis of rotation, and the air density. Among the parameters required to determine the pitched baseball trajectory, ball velocity has attracted the most attention from biomechanics researchers. However, ball velocity is only one aspect of the factors for evaluating the pitching performance. In order to make hitting more difficult for batters, the pitcher introduces spin and alters the trajectory from a simple parabolic trajectory to one in which aerodynamic forces play a significant role. In this paper, relationship between spin, trajectory and the motion will be discussed for fastball and curveball in baseball pitch. In the presentation, softball pitching will be also referred to, so far as time permits.

KEY WORDS: fastball, curveball, aerodynamic force, pitching machine

TRAJECTORY AND BALL SPIN OF BASEBALL PITCHES: Many different types of pitches are thrown in baseball. The fastball (FB) is said to be the most important pitch in any pitcher's arsenal, and a curveball (CB) is recommended as best used to supplement the pitcher's ability to throw a fastball (Jordan, 1988). In the early 1870's an argument, "Are baseball's curveballs optical illusions, or real curves?" stormed the world of baseball (Drury, 1953). Even after the reason of the curvature of the baseball was interpreted physically (Brown, 1913), the long debate and experiments have continued.

Figure 1 shows an example of the trajectories for FB (left) and CB (right) in transverse (top) and saggital (bottom) planes. The dashed line shows the theoretical spin-free trajectory. The deflections of the X and Z axes (horizontal and vertical direction, respectively) between the actual and spin-free trajectories at Y = 18.440 m are represented as ⊿X and ⊿Z, respectively.

We can recognize that not only CB but also FB does curve, and the deflections of these two pitches are in opposite directions with each other in both planes. From this fact we can presume that the ball spin in two pitches are also in opposite directions.

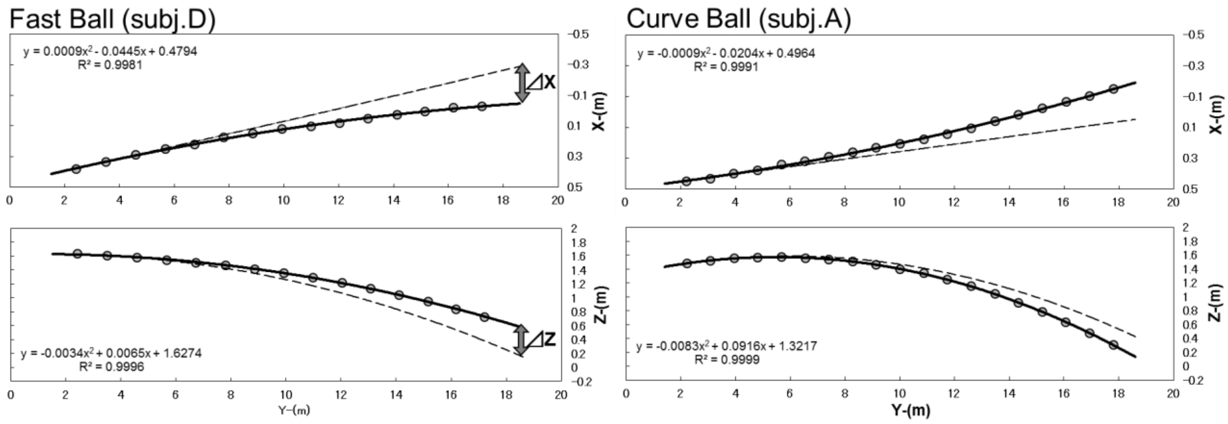

Figure 1: Trajectories for fastball (FB, left) and curveball (CB, right) pitches in transverse (top) and saggital (bottom) planes. The circles indicate measured position. The solid line is the fitted curve by the method of least squares. The dashed line is the theoretical spin-free trajectory (Sakurai et al, 2002, Jinji and Sakurai, 2006).

JOINT KNEMATICS OF THROWING ARM IN FB AND CB: The difference of the ball trajectories (and thus ball spins) means that there is a difference of the throwing motion between two pitches. Figure 2 shows the stick pictures of the FB (left) and CB (right) pitches of six collegiate pitchers when the motion was projected on the vertical plane including the pitching direction. Although variations in motion were recorded between subjects, the general movements for the FB and CB pitches were similar.

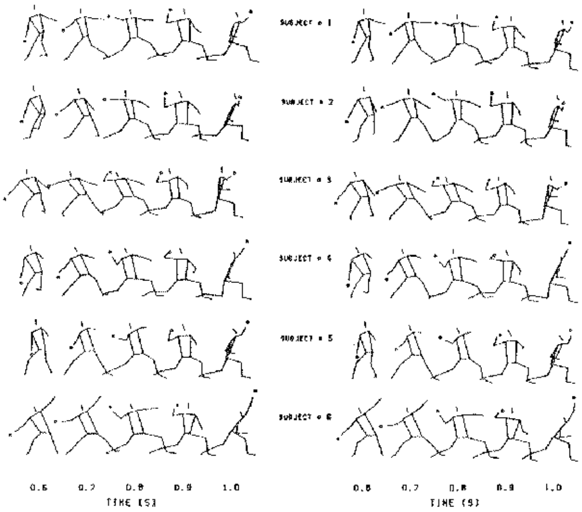

Figure 2: Stick figures for FB (left) and CB (right) pitches thrown by six collegiate pitchers (Sakurai et al, 1993).

The seven joint angle changes as shown in Figure 3 were calculated for the throwing arm. In anatomical sense, the throwing arm has seven degrees of freedom of joint motion apart from the fingers; three at the shoulder, one at the elbow, one at the radio-ulnar or forearm, and two for the wrist. For example, shoulder joint motion is defined by three angles, namely, horizontal abduction / horizontal adduction, abduction / adduction, and internal rotation / external rotation. These angles are corresponding to all the anatomical degrees of freedom of throwing arm.

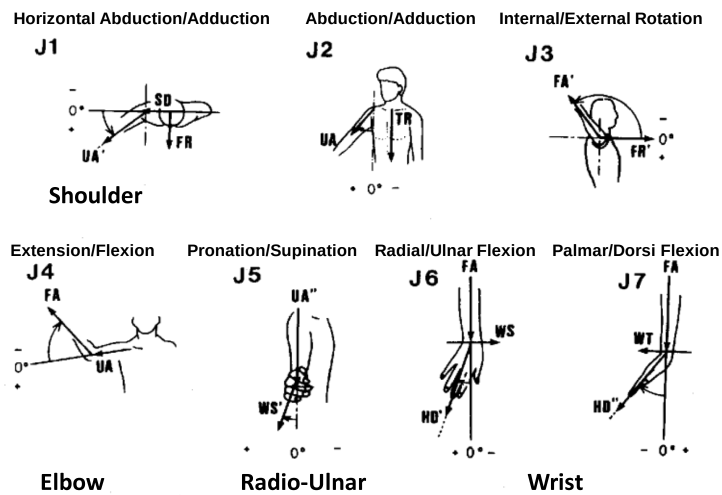

Figure 3: Seven joint angles corresponding to all the anatomical degrees of freedom of throwing arm apart from the fingers for the throwing motion analysis (Sakurai et al, 1993).

Figure 4 shows the changes of mean values of joint angles (J1-J7) of the throwing limb for both FB and CB pitches synchronized with the ball release time for the six collegiate pitchers. The patterns of joint kinematics of two pitches were generally very similar, and most of the peak values of the joint angles showed no significant differences between two pitches, except angles of radio-ulnar supination (J5) and wrist dorsiflexion (J7) values during the late-cocking and acceleration phases leading to the ball release.
Several writers have stated that supination of the forearm occurs as the ball is released, especially when throwing arm injuries are discussed in medical literature in relation to the CB pitching motion. However the supination of the forearm and the dorsiflexion of the wrist reached their maximum levels at almost the same time for both FB and CB pitches, and pronation and palmar flexion occurred at the instant of the ball release. These findings suggest that the ball rotation (and thus the deviation) of CB in the opposite direction to FB was not caused by the motion of the supination or palmar flexion around the ball release.

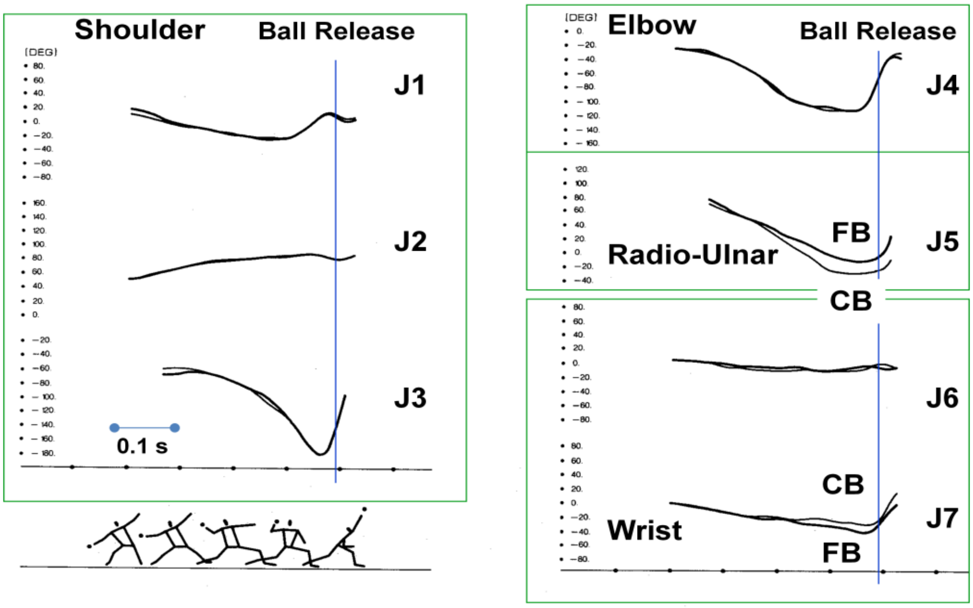

Figure 4: Seven joint angle changes of throwing arm for FB and CB pitches. Difference between two pitches were only found in Radio-Ulnar Supination/ Pronation angle (J5) and Palmar/Dorsi Flexion angle of the wrist (J7) (Sakurai et al, 1993).

SPIN CHARACTERISTICS OF PITCHED BASEBALLS: A spinning baseball in flight is subject to gravitational forces as well as drag and lift forces, and these forces determine its trajectory. The trajectories of pitched baseballs were obtained to estimate the aerodynamic forces acting thereupon. In addition, the effects of the spin axis direction and spin rate on the trajectory of a pitched baseball were evaluated.

The trajectories of FB and CB pitched by both a pitcher and a pitching machine were recorded using four synchronized video cameras (60 Hz) and were analyzed using DLT procedures (Figure 5). The baseball was filmed immediately after ball release using a high-speed video camera (250 Hz), and the direction of the spin axis and the spin rate were calculated based on the positional changes of the marks on the ball (Figure 6).

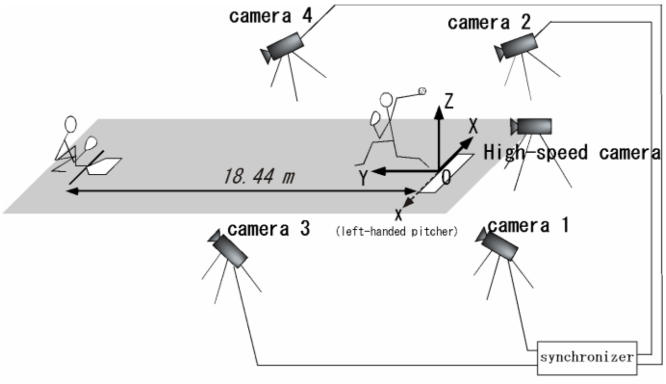

Figure 5: Experimental setup for determining the ball trajectory and the ball spin of the pitched baseballs

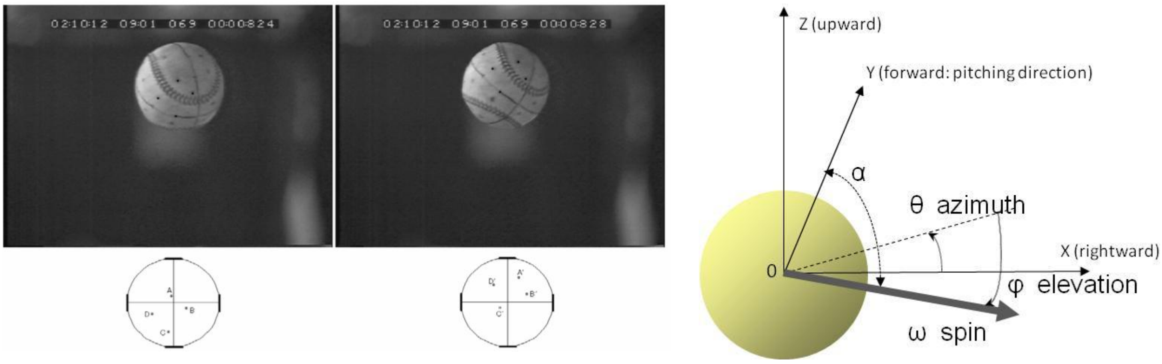

Figure 6: [Left] Video images used for calculating the direction of spin axis and spin rate (above) and schematic diagram of digitized points on the ball (below). [Right] The orientation of the angular velocity vector ω is defined by θ (azimuth), φ (elevation) and α (angle between axis of rotation and pitching direction).

The mean values of θ, φ and α for FBs were 30.5 ± 13.2°, -26.4 ± 10.8° and 66.7 ± 8.1°, respectively. The mean values of θ, φ and α for CBs were -48.3 ± 14.0°, -27.0 ± 6.5°, and 57.0 ± 6.8°, respectively. No significant difference was observed between the mean spin rates of FBs and CBs, which were 31.4 ± 2.7 rps and 31.0 ± 4.2 rps, respectively.

In the pitching machine, the mean value of α, which is the angle between the pithing direction and the ball spin axis, was 86.4° for FBs and 84.9° for CBs, which means the spin axis of the balls from the pitching machine were primarily orthogonal to the pithing direction regardless of the types of the pitches. Contrary to the case of the pitching machine, the values of α ranged widely (30-85 degrees) for the actual pitchers.

Watts and Ferrer (1987) and Bearman and Harvey (1976) suggested that, in the wind tunnel experimentl, the lift coefficient was proportional to the spin parameter rω/V, where r is the radius of the ball, ω is the angular velocity, and V is the velocity of the ball. However, in this experiment, the lift coefficient did not depend on rω/V (r=0.023) and instead was correlated closely with ωsinα (r=0.860), where α is the angle between the spin axis and the pitching direction (Figure 7). The term ωsinα represents a component of the angular velocity vector perpendicular to the pitching direction. The lift force, which is a result of the Magnus effect occurring due to the rotation of the ball, acts perpendicular to the axis of rotation. The Magnus effect was found to be greatest when the angular and translational velocity vectors were perpendicular to each other, and the break of the pitched baseball became smaller as the angle between these vectors approached 0°. Balls delivered from a pitching machine broke more than actual pitcher's balls. It is necessary to consider the differences when we use pitching machines in batting practice.

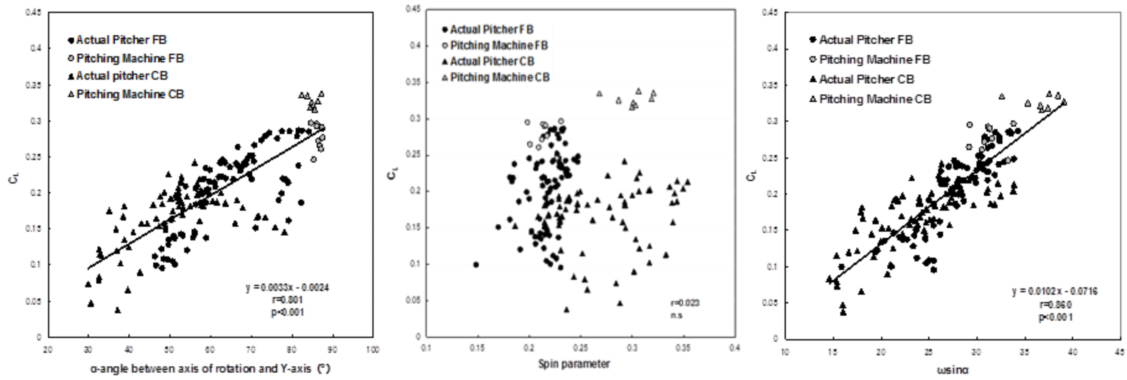

Figure 7: Relationships between aerodynamic lift coefficient (vertical axis: C_L) and angle α (left), spin parameter (rω/V, middle), and ωsinα (right), for FB and CB pitches thrown by nine collegiate pitchers and a pitching machine.

FACTORS DETERMINING THE SPIN AXIS OF FB PITCH: The factors that determine the direction of the spin axis of a FB pitch were investigated. Nineteen male baseball pitchers were recruited to pitch fastballs. The pitching motion was recorded with a three-dimensional motion analysis system with 1000 Hz data collection. Reflective markers were attached to the ball, and the direction of the spin axis was calculated on the basis of their positional changes. The orientations of the hand segment in a global coordinate system were calculated using Cardan rotation angles.

The hands of all participants showed similar kinematic patterns with some variations in angle values (Figure 8). The angle of the spin axis, θ, exhibited correlation with the angle of the right/left rotation of the hand after t = 0.983 s; the highest correlation with θ was observed at t = 0.994 s (r = 0.840). The angle of the backward/forward tilt of the hand exhibited correlation with θ after t = 0.989 s, and the highest correlation was observed at t = 0.997 s (r = 0.711). The angle of the right/left sideways of the hand exhibited correlation with θ after t = 0.996 s, and the highest correlation was observed at ball release (r = 0.709). The angle of spin axis, φ, showed correlation with the angle of hand sideways after t = 0.970 s (r = –0.725), and the highest correlation was observed after t = 0993 s.

The spin axis directions thus significantly correlated with the orientations of the hand just before the ball release. The ball is released from the fingertip and rotates on a plane that is formed by the palm and fingers; the spin axis of the ball is parallel to this plane. The lift force (Magnus effect) of the pitched baseball is largest when the angular and translational velocity vectors are mutually perpendicular. Further, in order to increase the lift forces for the fastballs, the palm must face the home plate

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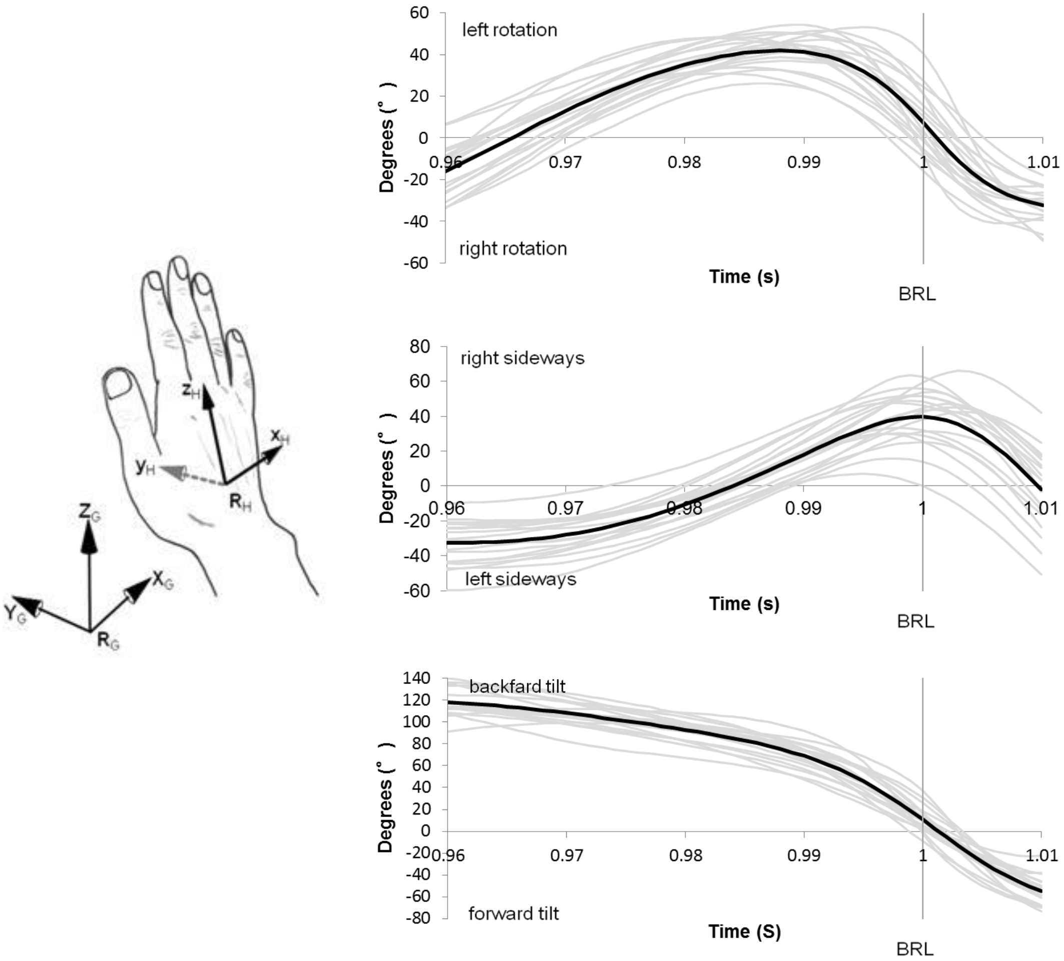

Figure 8: (Left) Definition of the global and local reference frames. R_G is the global reference frame, and R_H is the hand reference frames. (Right) Angle changes of right/left rotation (top), right/left sideways (middle), and backward/forward tilt (bottom) of the hand around FB release. The thick line is the mean value of nineteen participants, while the thin line is the data for each participant. The time of ball release (BRL) is assigned as t = 1.000 s.

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