SPINNING SPORTS BALLS

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INTRODUCTION

Ball spin significantly affects how sports balls move. The production of spin, its evolution during impact and flight and its effects on the ball paths are discussed for two popular American ball sports; baseball and basketball. In baseball, the spin in flight is important because it generates substantial lift forces. These can add substantial range to that achievable with no spin and cause large lateral deviations of the path from the vertical plane. As a result a curve ball can be hit farther than a fastball, even though its pitched and batted speeds are less than those of the fastball. Furthermore, the effect of spin has implications on how different pitches should be batted optimally. In basketball free throws, aerodynamic forces are small compared to spin-generated friction contact forces that dominate. This talk examines the mechanics of spin generation and its effects on the two games.

METHODS

Improved models for the pitch, batting impact, and post-impact flight phases of a baseball can be used in an optimal control context to find bat swing conditions that produce maximum range [1]. An improved batted flight model incorporates experimental aerodynamic lift and drag force profiles (including the drag crisis) and their dependence on spin and velocity. The rigid-body model for bat-ball impact includes the dependence of the coefficient of restitution on the approach relative velocity and the dependence of the incoming pitched ball angle on speed. Undercut distance and bat swing angle are chosen to maximize range of the batted ball. Post-impact conditions are found to be independent of the ball-bat coefficient of friction. The lift force is enhanced by spin produced by undercutting the ball during batting. Contrary to popular opinion, an optimally hit curve ball will travel farther than an optimally hit fastball or knuckleball as a result of increased lift during flight. Because the curve ball has pitched topspin, less undercut is required to produce optimal batted backspin, and smaller batted ball speed and launch angle penalties must be incurred to generate backspin than when hitting a fastball optimally. Changing spin during flight is likely not important since the characteristic spin decay time is of the order of 30 s [1]. The sensitivity of maximum range can be calculated for all model parameters including bat and ball speed, bat and ball spin, and wind speed.

In contrast, the flight of a basketball is much less affected by aerodynamics but spin is important during rim and backboard contact. Friction forces caused by spin-induced relative motion of the ball contact point are important and largely determine the ball path. A dynamic model [2] is discussed for basketball motion that may contact the rim, the backboard, the bridge between the rim and board, and possibly the board and the bridge simultaneously. The model is used to investigate free throw success near the sagittal plane. Non-linear ordinary differential equations describe the ball angular velocity and ball center position. The model includes radial ball compliance and damping and contains sub-models describing slipping and non-slipping contact and purely gravitational flight. Switching between the sub-models depends on contact point velocity and friction forces. Interesting limiting dissipation-free families of trajectories allow the ball to enter and pass below the rim plane before being ejected rather than being captured. These rely importantly on continuously changing spin and precession of the consequent angular momentum by the contact forces. The dynamic models of basketball-rim and basketball-backboard interaction allow simulations for a single point ball-rim or ball-board contact, as well as the possibility of two-point contact on both board and bridge. The model can be used to study release angles, velocity, and angular velocity that maximize the probability of success. In basketball free throws in which contact forces dominate, backspin can scrub more energy from the ball in shots that hit the rim and can aid in capture, increasing the number of successful shots by about 10%, all other conditions held constant.

Generation of appropriate spin by the athlete during impact (baseball) or launch (basketball) relies on contact forces normal [3] and tangent [4] to the ball surface. Simple rigid-body models of the ball may not accurately predict post-impact spin. Although large normal compliance is obvious in high-speed images of batted balls, models including tangential compliance of the ball surface lead to two-degree-of freedom oscillations and predict significantly different post-impact spin and translational velocity than do models assuming rigid-body ball motion. Experimental measurements of baseball and basketball contact forces [5] show the possible influence of tangential compliance. Present research efforts search for the least complex model of the 1 ms baseball-bat and 11 ms basketball-rim impacts that can adequately describe these processes.

CONCLUSIONS

Accurate description of the paths of sports balls must rely on a complete understanding of the aerodynamic and contact forces caused by the interaction of the spinning ball with its environment.

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