

Master Thesis

Application of Aerodynamic Force Estimation Method using Geometry of Trajectory to Sports Ballistics

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Abstract

A body in flight receives the aerodynamic force from air flow around it. Since this force has a large influence on its flight trajectory, aerodynamic studies of a body in flight have been carried out for a long time. These studies mainly use wind tunnel experiments. In wind tunnel experiments, the force is measured by fixing a body in a uniform flow, and the experiments are carried out under certain conditions. The conditions, however, do not sufficiently correspond to actual flight conditions. In fact, sports ballistics reports that aerodynamic coefficients vary along its trajectory. Therefore, in order to clarify the aerodynamic characteristics of a body in flight, the effect of acceleration/deceleration of the body is important.

In this study, we propose an estimation method for aerodynamic force by relating geometrical quantities of flight trajectory such as curvature and torsion with mechanical quantities included in the equation of motion such as aerodynamic coefficients and rotation axes. The characteristic values in aerodynamics of sports balls are estimated using the proposed method from time-series data of flight trajectory measured actually, and the unsteadiness in aerodynamics of balls in flight is examined from the obtained results.

In order to confirm the effectiveness of the proposed estimation method, the mechanical quantities are estimated back from a sample trajectory calculated by presetting the aerodynamic coefficient and the axis of rotation as initial conditions. The estimated result reproduces successfully the initial conditions, and we can confirm the effectiveness of the present method.

The proposed method is applied to three-dimensional trajectories of golf ball actually measured. The obtained results show that the aerodynamic coefficients, their time derivatives and also the rotation axis can be estimated at each moment on the trajectory. At the same time, it is found that all the estimated quantities varied along its trajectory. In the drag coefficient of the straight trajectory, in particular, the time

derivatives increase as the trajectory approaches to the apex where the ball gradually decelerates. On the other hand, in the result of the slice trajectory, the time derivative of the drag coefficient has negative values. These results suggest that the change in the drag coefficient during the deceleration in ball motion is affected by the inclination of the axis of rotation. In addition, the axis of rotation is varying along the trajectory and it shifts towards the backspin rotation in the straight trajectory.

Moreover, we estimate the aerodynamics of three types of golf ball with different specification from two-dimensional trajectory data, and attempt to clarify the unsteady characteristics of each ball. The time derivative of the aerodynamic coefficient is mainly determined by the launch speed, and the rotation speed at launching has little effect. This suggests that the launch speed of the balls affects significantly the change of the drag coefficient and Magnus force coefficient. These results show that the present estimation method is able to assess in detail the unsteadiness of golf balls with different characteristics using their flight trajectories.

We present the estimation method of the aerodynamic characteristics of a body in flight from time-series data of its flight trajectory. In this method, it is possible to estimate the aerodynamic coefficients and the axis of rotation along the trajectory, and it is shown that this method is effective for investigating the unsteadiness of the aerodynamics in flight experiments.