Measuring Shuttlecock Drag in Free Flight

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Badminton is a major recreational and professional racket sport played throughout the world. Shuttlecock aerodynamics depend on its mass, size, and material (feathered or synthetic). Shuttlecock drag is often measured in a wind tunnel, where a stationary support measures the drag force from a controlled airflow. There is a surprising disagreement in shuttlecock drag, even for the case of feathered shuttlecocks with rotation, where the drag coefficient has been found to be as high as 0.73 and as low as 0.48 [1-6]. The following compares the drag of synthetic and feathered shuttlecocks by tracking their motion in free flight. The method avoids some of the complexities encountered with wind tunnels and provides a novel means of measuring drag.

Three feathered shuttlecocks (AS-50, Yonex) were projected at 25, 45, 50, 58, and 62 ± 2m/s, while two synthetic shuttlecocks (Mavis 2000) were projected at 25, 50, and 63 ± 2 m/s. The shuttlecocks were projected over a 7 m distance using a pneumatically actuated piston and assumed to travel in a 2D plane, as transverse motion was less than 0.15 m. This avoided turn around disturbances, as occurs from racket impact, and the effect of projection air blast, as occurs with "burp" style air cannons. Shuttlecock trajectory was recorded using two high speed cameras at a 2048x1952 pixel resolution and 2500 fps (Phantom v1840). The shuttlecock position was tracked in 3D space using commercial software which reported an average calibration point location accuracy of 2.2 mm (Pro-Analyst, Xcitex).

The measured trajectory must be differentiated twice to obtain acceleration and drag, making this method sensitive to measurement noise. The first derivative, or velocity, was obtained from the distance and time between sequential video images. The velocities from each trajectory were assembled into a master curve as a function of time, for the feathered and synthetic shuttlecock. Acceleration was found from the derivative of an empirical fit to each mastercurve. To identify a suitable means creating the fit, a trajectory was created from a known time varying drag coefficient to which 2 mm (standard deviation) of noise was added. A rational 4/4 fit provided the best agreement, where ten repeated fits with different noise provided a maximum difference to the known drag coefficient of 0.02.

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The drag coefficient of the feathered and synthetic shuttlecocks is shown in Fig. 1 over the length of their trajectories. As has been observed elsewhere, the free flight measurements do not show a large sensitivity to speed [3,6]. The drag of the feathered shuttlecock increased with speed slightly, as observed by others [1,3,5]; while drag of the synthetic shuttlecock tended to decrease with increasing speed, as observed by others [1,3]. The drag coefficient of both the feathered and synthetic shuttlecock was between 0.5 and 0.55, which is within the range, and toward the lower end of wind tunnel measures. The sensitivity of the drag coefficient to speed in sports balls is generally attributed to changes in the locations of the flow separation points. The shuttlecock's cone shape tends to fix the flow separation points, and is likely responsible for the relatively constant drag coefficients.

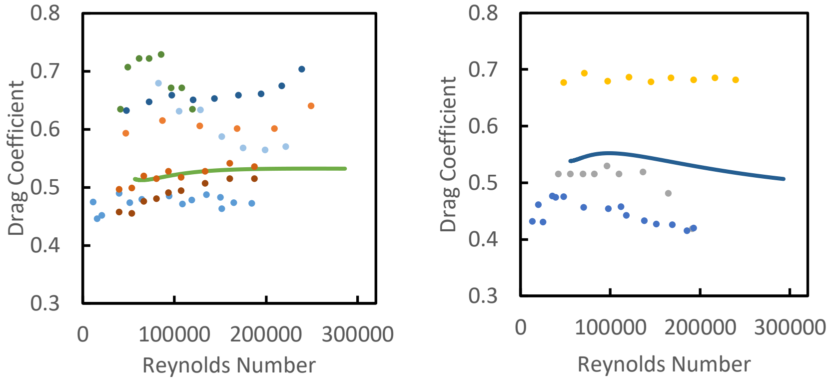

Figure 1. Drag coefficient as a function of speed for feathered (left) and synthetic shuttlecocks (lines are free flight results, circles are wind tunnel results, where each study is represented by a unique color).

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