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A Comparative Study of Feather and Synthetic Badminton Shuttlecock Aerodynamics

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Abstract

Badminton is a high drag game. The aerodynamic properties of badminton shuttlecocks are complex. As a bluff body, the shuttlecock generates high aerodynamic drag and steep flight trajectory. Although a series of studies on aerodynamic behaviour of spherical and ellipsoidal balls have been reported in the open literature, scant information is available in the public domain about the aerodynamic behaviour of badminton shuttlecocks. The primary objective of this work was to evaluate aerodynamic properties of a series of shuttlecocks under a range of wind speeds. The non-dimensional drag coefficient was determined and compared. The natural feather shuttlecock displayed lower drag coefficient at low speeds and significantly higher drag at high speeds. On the other hand, the synthetic shuttlecock demonstrated the opposite trends.

Introduction

Badminton is one of the oldest and popular sports in the world and believed to be originated from ancient Greece and China. The modern badminton game was imported by the British from India to Great Britain in the middle of 19th century and spread to other parts of the world. Although the modern Badminton rules and regulations were introduced in 1887, the first Badminton World Championship was held only in 1977. Previously the Badminton game was popular in Europe and America, currently the game is progressively becoming popular in Asia and Africa especially in China, Indonesia, Malaysia, Japan and Singapore. The popularity of game is so immense that over 160 countries have officially joined the Badminton World Federation (BWF) - a governing body of the game. Its initial name “International Badminton Federation” (established in 1934 with it’s headquarter in England) was renamed as BWF in 2006 and it’s headquarter has been moved to Kuala Lumpur in Malaysia in 2005 from England. Currently, according to BWF estimates, the game is played by over 200 million people worldwide and over thousands of professional players participate in various competitions and tournaments around the world. Badminton has been introduced for the first time as an Olympic sport in 1992 Barcelona Games.

The centre piece of the badminton game is no doubt the shuttlecock which is made of either natural feathers or synthetic rubber with an open conical shape (described and shown later). The cone is comprised of 16 overlapping goose feathers embedded into a round cork base which is covered generally with a thin goat leather or synthetic material. Most amateur players use a synthetic shuttlecock as it lasts longer and costs less (cheaper) compared to feather shuttlecock which is predominantly used by the professional players and have high initial velocity. Generally, three types of synthetic shuttlecocks (distinguished by color code) are available in the market. They are: a) Green shuttlecock (for slow speed), b) Blue shuttlecock (for middle speed), and c) Red shuttlecock (for fast speed). Frequently, the red shuttlecock is used in colder climatic conditions and the green shuttlecock is used in warmer climatic conditions.

Being a bluff body, the shuttlecock generates high aerodynamic drag and steep flight trajectory. A typical flight trajectory of a badminton shuttlecock is shown in Figure 4. The aerodynamic properties of badminton shuttlecocks significantly differ from other ball, racket or projectile sports.

Despite the enormous popularity of Badminton game, the aerodynamic behaviour of the shuttlecock (regardless of feather or rubber made) is not clearly understood. Its flight trajectory is significantly different from the balls used in most racquet sports due to very high initial speeds (highest speed is 332 km/h by Chinese player Fu Haifeng in 2005) that decay rapidly due to high drag generated by feathers or rubber skirts. While some studies by Alam et al. [4-6], Mehta et al. [7-9], Smits and Ogg [10] and Seo et al. [11] were conducted on spherical and ellipsoidal balls, no study except Cooke [3] and more recently by Alam et al. [1-2] was reported in the public domain on shuttlecock aerodynamics. The knowledge of aerodynamic properties of shuttlecocks can greatly assist both amateur and professional players to understand the flight trajectory as player requires considerable skills to hit the shuttlecock for the full length of the court. The parabolic flight trajectory is generally skewed heavily thus its fall has much steeper angle than the rise. The understanding of aerodynamic properties can significantly influence the outcome of the game. Therefore, the primary objective of this work is to experimentally determine the aerodynamic properties of a series of shuttlecocks (synthetic and feather made) under a range of wind speeds, and compare their aerodynamic properties.

Experimental Procedure

A brief description of badminton shuttlecocks, experimental facilities and set up is given in the following two sub sections.

Shuttlecock Description

As mentioned previously, the feather shuttlecock is made of 16 goose feathers with a skirt diameter of 65mm, mass is around 5.2 grams (g) and total length is approximately 85mm. Figure 1 shows general features of a standard feather shuttlecock. A typical feather shuttlecock and synthetic shuttlecock are shown in Figures 2 and 3 respectively.

As part of a larger study, twenty new shuttlecocks were initially selected. However, only 10 shuttlecocks (five feather shuttlecocks and five synthetic shuttlecocks) were used in this study. These 10 shuttlecocks are, a) Grays nylon, b) Grays plastic, c) Grays volante, d) Mavis – Yonex 500, e) RSL standard, f) Grays volant en plumes, g) Yonex mavis 350, h) RSL silver feather, i) Arrow 100, and j) RSL classic tourney. The dimensions of all these shuttlecocks are shown in Table 1.

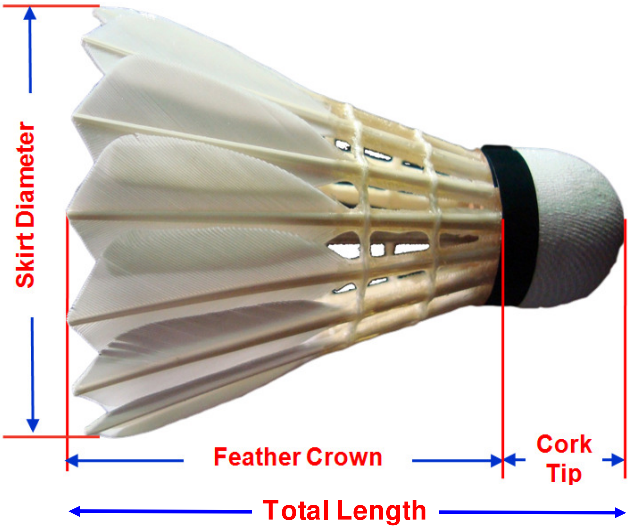

Figure 1. Nomenclature of a typical standard feather shuttlecock

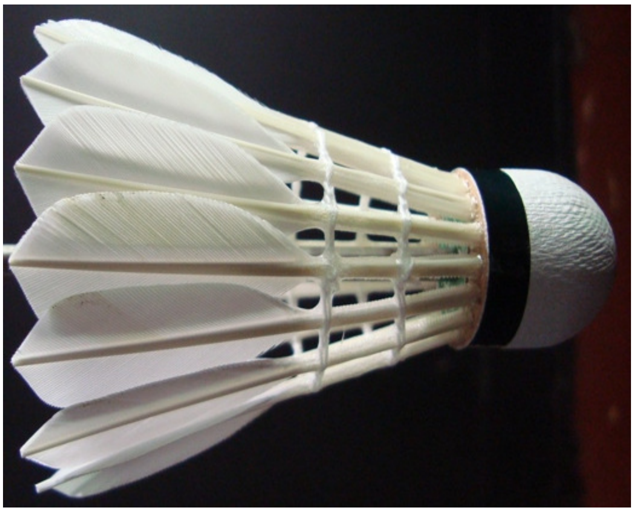

Figure 2. Feather shuttlecock

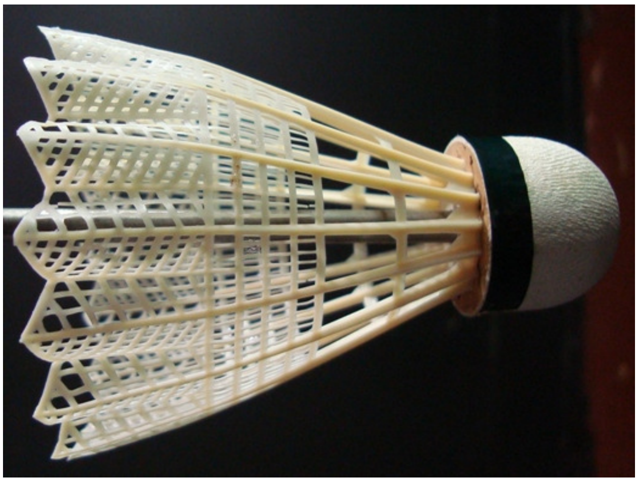

Figure 3. Synthetic shuttlecock

Table 1. Physical parameters of shuttlecocks

		Total Length	Length of Cock Tip	Skirt Diameter	Mass
ID	Type	(mm)	(mm)	(mm)	(g)
S-1	Synthetic	84	25	65	5.215
S-2	Synthetic	82	25	63	4.867
S-3	Synthetic	83	25	66	6.231
S-4	Synthetic	78	25	68	5.26
F-1	Feather	85	25	66	4.959
F-2	Feather	86	25	65	4.913
S-5	Synthetic	80	25	65	5.244
F-3	Feather	85	25	66	5.12
F-4	Feather	85	25	65	5.181
F-5	Feather	85	25	65	4.891

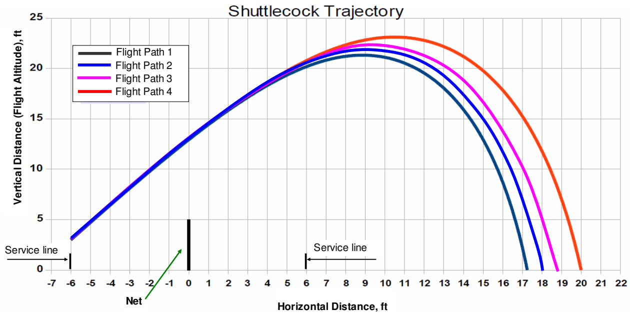

Figure 4. Typical flight paths of a shuttlecock

Wind Tunnel Testing

The study was conducted in RMIT Industrial Wind Tunnel. It is a closed return circuit wind tunnel with a turntable to simulate the cross wind effects. The maximum speed of the tunnel is approximately 150 km/h. The dimension of the tunnel's test section is 3 m wide, 2 m high and 9 m long and the tunnel's cross sectional area is 6 square meter. The experimental set up in the test section of RMIT Industrial Wind Tunnel is shown in Figures 5 & 6. The tunnel was calibrated before conducting the experiments and tunnel's air speeds were measured via a modified NPL ellipsoidal head Pitot-static tube (located at the entry of the test section) connected to a MKS Baratron pressure sensor through flexible tubing. More details about the tunnel can be found in Alam et al. [2].

A sting mount was developed to hold the shuttlecock on a six component force sensor. The mounting gear and experimental set up in the test section are shown in Figures 5 & 6. The aerodynamic effect of sting on the shuttlecock was measured and found to be negligible. The distance between the bottom edge of the shuttlecock and the tunnel floor was 420 mm, which is well above the tunnel boundary layer and considered to be out of significant ground effect.

The aerodynamic drag coefficient (C_D) is defined as: $C_D=D/0.5\rho V^2 A$, where A is calculated as projected frontal area of shuttlecock without any deformation. The Reynolds number (Re) is defined as: $Re=Vd/\nu$. Here d is the skirt diameter of the shuttlecock. The lift and side forces and their coefficients were not determined and presented in this paper. Only drag and its coefficient are presented here.

Figure 5. Wind tunnel testing of shuttlecock (experimental rig only)

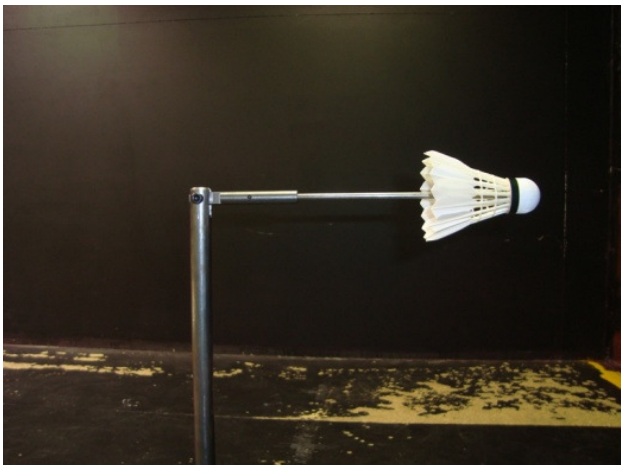

Figure 6. Wind tunnel testing of shuttlecock (experimental rig with shuttlecock)

The aerodynamic properties (drag, lift and side force and their corresponding moments) at wind speeds of 60 km/h to 140 km/h with an increment of 20 km/h) at two pitch of 0° and 15° with the mean direction of winds were measured. However, the data for 0° pitch angle is shown in this paper. The aerodynamic forces acting on the shuttlecock were determined by testing shuttlecocks with the supporting gear and then subtracted from the forces acting on the supporting gear only. A shuttlecock with the mounting device on a six component force sensor is shown in Figure 5. The influence of the sting on the shuttlecock was checked and found to be negligible. The repeatability of the measured forces was within ±0.1 N and the wind velocity was less than 0.5 km/h.

Results and Discussion

The aerodynamic force was converted to non-dimensional parameter (drag coefficient, C_D) using equation 1.

$$C_D = \frac{D}{\frac{1}{2}\rho V^2 A} \qquad (1)$$

The C_D variations with Reynolds numbers for feather and synthetic shuttlecock are shown in Figures 7 & 8 respectively. The C_D versus Reynolds number plots for the highest and lowest drag generated feather shuttlecocks and synthetic shuttlecocks are shown in Figures 9 and 10 respectively.

The average C_D value for all shuttlecocks is lower at low Reynolds number initially and increases with an increase of Reynolds numbers. The drag coefficient is almost constant at speeds over 80 km/h for the feather shuttlecocks. However, the C_D value drops for the synthetic shuttlecocks at speeds 80 km/h and above (see Figure 8). The figure also indicates a significant variation in drag coefficients among the synthetic shuttlecocks which is believed to be due to varied geometry of skirts and deformation at high speeds. On the other hand, less variation of drag coefficients was noted for feather shuttlecocks as shown in Figure 7. As expected, the variation in C_D is minimal for the feather shuttlecock due to less deformation at high speeds and also less variation in skirt geometry. The average C_D value for feather shuttlecocks is higher at low speeds compared to synthetic shuttlecocks. In contrast, the average C_D value for the synthetic shuttlecock is higher at high speeds compared to the C_D value of the feather shuttlecock.

Figure 9 displays relatively less variation in C_D value for the feather shuttlecock compared to the value of synthetic shuttlecocks (see Figure 10). The maximum and minimum variations in C_D for feather shuttlecocks are approximately 50% and 7% at low and high speeds respectively. On the other hand, the maximum and minimum variations in C_D for synthetic shuttlecocks are approximately 40% and 27%. The data clearly shows that both feather and synthetic shuttlecocks have variable drag characteristics at low speeds. The data also indicates that all feather shuttlecocks display almost similar drag characteristics at high speeds. Therefore, the flight trajectory of feather shuttlecocks will be more stable and predictable compared to synthetic shuttlecocks at high speeds (high Reynolds numbers).

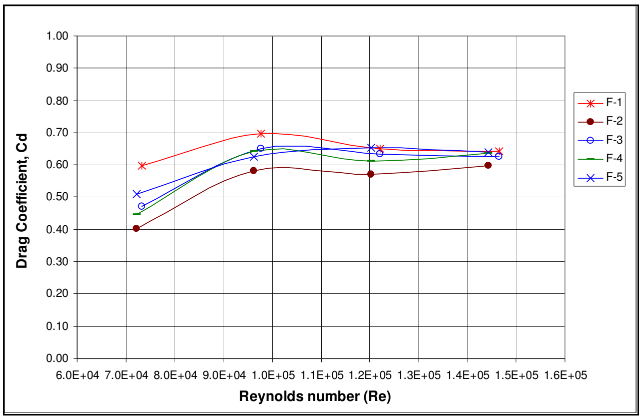

Figure 7. C_D as a function of Reynolds numbers (Feather shuttlecock)

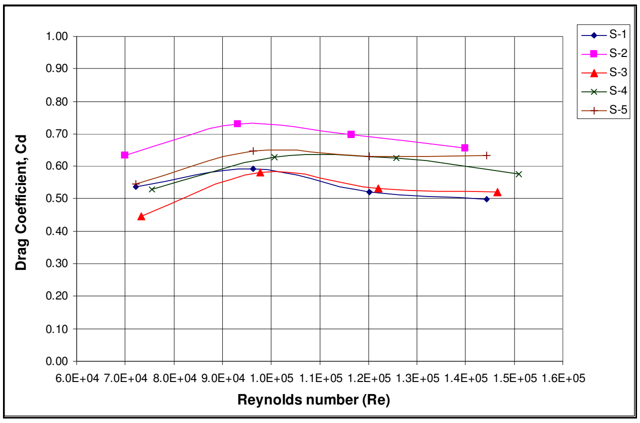

Figure 8. C_D as a function of Reynolds numbers (Synthetic shuttlecock)

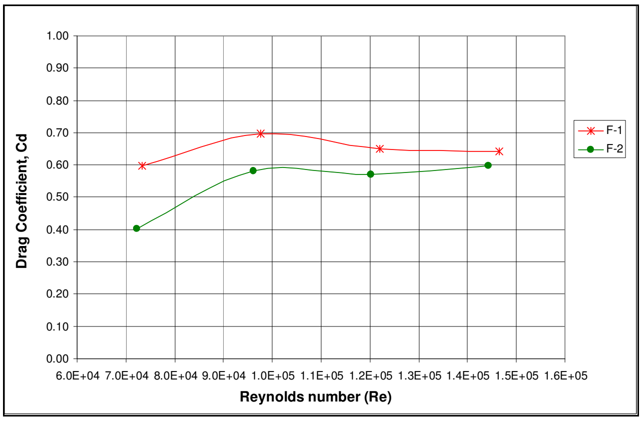

Figure 9. C_D variation between two high and low drag feather shuttlecocks

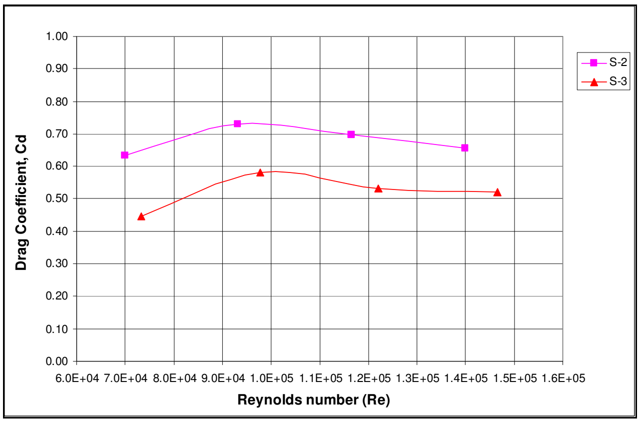

Figure 10. C_D variation between two high and low drag synthetic shuttlecocks

The degree of structural deformation of synthetic shuttlecocks was not considered in this study. However, work is underway to address this issue.

Conclusion

The following concluding remarks have been made based on the experimental study presented here:

- The average drag coefficients for all shuttlecocks tested are approximately 0.61 over 100 km/h and 0.51 at 60 km/h.
- The average drag coefficients for feather shuttlecocks are approximately 0.62 over 100 km/h and 0.49 at 60 km/h.
- The average drag coefficients for synthetic shuttlecocks are approximately 0.59 over 100 km/h and 0.54 at 60 km/h.
- The synthetic shuttlecocks have widely scattered drag coefficients at all speeds tested.
- The feather shuttlecocks have relatively higher drag coefficient variation at low speeds. However the variation is significantly lower at high speeds.
- The synthetic shuttlecock is subjected to higher deformation at high speeds compared to feather shuttlecock and becomes more streamlined. Hence it produces less aerodynamic drag.

Acknowledgments

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