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Measurements of Aerodynamic Properties of Badminton Shuttlecocks

Firoz Alam*, Harun Chowdhury, Chavaporn Theppadungporn and Aleksandar Subic

School of Aerospace, Mechanical and Manufacturing Engineering, RMIT University, Bundoora, Melbourne, VIC 3083, Australia

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Abstract

Badminton is a high drag game. The aerodynamic properties of badminton shuttlecocks significantly differ from other ball, racket or projectile sports. Being 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.

Keywords: Aerodynamics, badminton shuttlecock, drag coefficient, wind tunnel;

1. Introduction

Originated from ancient Greece and China, Badminton is one of the oldest and popular sports in the world. The modern version of the 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. The Badminton game was initially dominated by the Europeans and Americans; however, currently the game is besieged by the Asian nations especially, 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, in accordance with the BWF estimates, the game is played by over 200 million people worldwide and over thousand players participate in various competitions and tournaments around the world. Badminton has been introduced for

* Corresponding author. Tel.: +61 3 99256103; fax: +61 3 99256108.
E-mail address: firoz.alam@rmit.edu.au

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the first time as an Olympic sport in 1992 Barcelona Games. The centre piece of the game is no doubt a shuttlecock which is made of either natural feathers or synthetic rubber with an open conical shape (described and shown later). The cone comprises of 16 overlapping goose feathers embedded into a round cork base which is covered generally with a thin goat leather or synthetic material. Unlike most racquet sports, a badminton shuttlecock is an extremely high drag projectile and possesses a highly skewed parabolic flight trajectory. Most amateur players use 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 climates and the green shuttlecock is used in warmer climates.

Despite the enormous popularity of Badminton game, the aerodynamic behavior 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. [1, 2], Mehta et al. [3], Smits and Ogg [4] and Seo et al. [5] were conducted on spherical and ellipsoidal balls, no study except Cooke [6] and more recently by Alam et al. [7] 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.

Nomenclature

D	Drag Force
C_D	Drag Coefficient
Re	Reynolds Number
V	Velocity of Air
ν	Kinematic Viscosity of Air
ρ	Density of Air
A	Projected Area
d	Shuttlecock Diameter

2. Experimental Procedure

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

2.1. Shuttlecock Description

As mentioned previously, the feather shuttlecock is made of 16 goose fathers 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 Figure 2.

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.

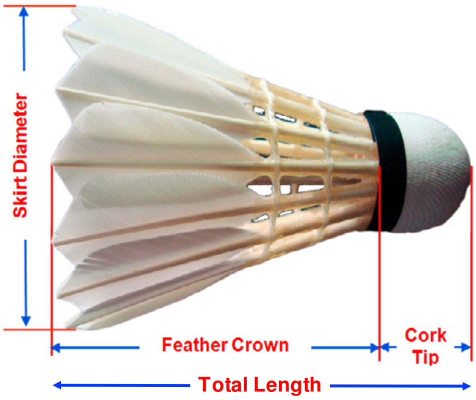
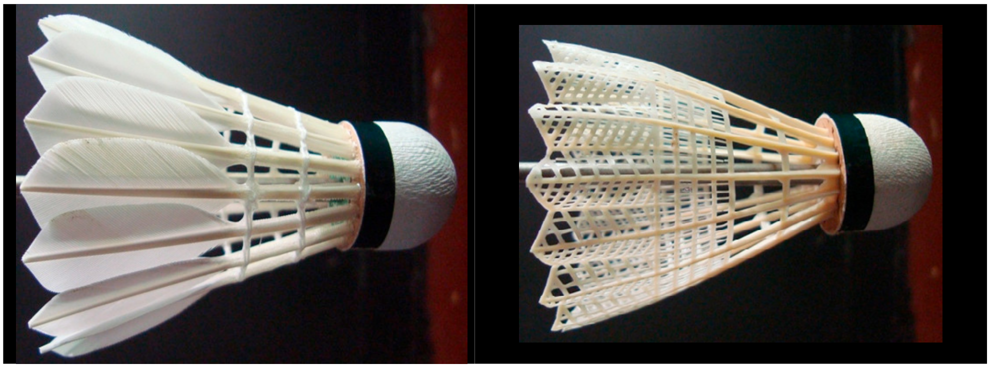


Fig 1. Nomenclature of a typical standard feather shuttlecock



(a) Feather shuttlecock (b) Synthetic shuttlecock

Fig 2. Types of shuttlecock

Table 1. Physical parameters of shuttlecocks

ID	Type	Total Length (mm)	Length of Cock Tip (mm)	Skirt Diameter (mm)	Mass (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

2.2. Wind Tunnel Testing

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 Figure 3. 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.

(a) Experimental rig only (a) Experimental rig with shuttlecock

Fig 3. Wind tunnel testing of shuttlecock

In order to measure the aerodynamic properties of the shuttlecock experimentally, the RMIT Industrial Wind Tunnel was used. The tunnel is a closed return circuit wind tunnel with a maximum speed of approximately 150 km/h. The rectangular test section's dimension is 3 m (wide) x 2 m (high) x 9 m (long), and is equipped with a turntable to yaw the model. The stud (sting) holding the shuttlecock was mounted on a six component force sensor (type JR-3), and purpose made computer software was used to digitize and record all 3 forces (drag, side and lift forces) and 3 moments (yaw, pitch and roll moments) simultaneously. More details about the tunnel can be found in Alam et al. [8].

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

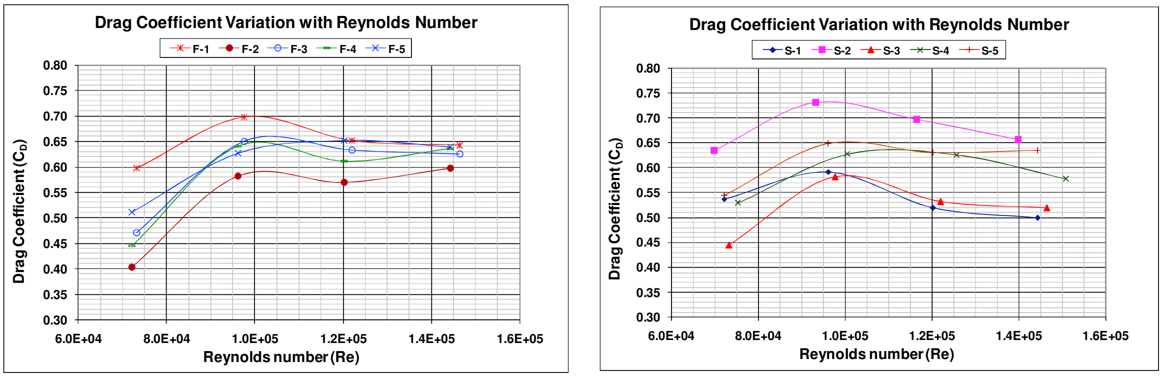
3. Results and Discussion

Shuttlecocks were tested at 60, 80, 100 and 120 km/h speeds. The shuttlecock was yawed relative to the force sensor (which was fixed with its resolving axis along the mean flow direction) thus the wind axis system was employed. The aerodynamic force was converted to non-dimensional parameter (drag coefficient, C_D) and tare forces were removed by measuring the forces on the sting in isolation and removing them from the force of the shuttlecock and sting. 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.

The C_D variations with Reynolds numbers for standard shuttlecock and synthetic shuttlecock are shown in Figure 4. Also the average values of C_D of all 5 standard (feather) and 5 synthetic shuttlecocks with wind speed variation are plotted and presented in Figure 5.

The average C_D value for all shuttlecocks is lower at low Reynolds number initially and increases with an increase of Reynolds numbers. However, the C_D value drops at 80 km/h and above (see Figure 4). Figure 4(b) shows 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 4(a). 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.

The experimental results indicate that there is notable variation in drag coefficients between the standard feather and synthetic shuttlecocks. These variations are believed to be due to structural deformation of the synthetic shuttlecocks at high speeds. Additionally, the skirt perforation and geometry of some synthetic shuttlecocks significantly different from their counterpart, feather shuttlecocks. As a result, the airflow behavior around the synthetic shuttlecocks varies notably compared to the standard feather shuttlecocks. The degree of structural deformation of synthetic shuttlecocks was not considered in this study. However, work is underway to address this issue.



(a) Standard feather shuttlecock (b) Synthetic shuttlecock

Fig 4. C_D as a function of Reynolds numbers

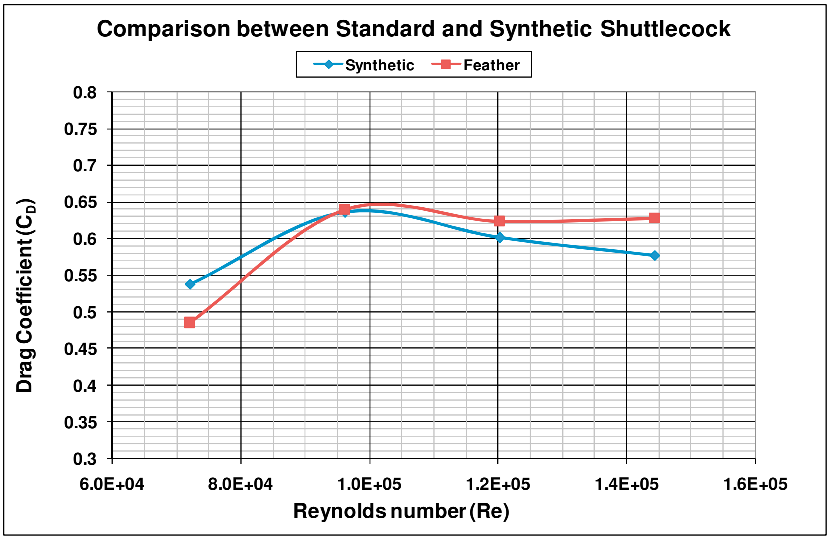


Fig 5. Comparison between Standard feather and Synthetic shuttlecocks

4. Conclusions

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

- The average drag coefficient for all shuttlecocks tested is approximately 0.61 over 100 km/h and 0.51 at 60 km/h.
- The average drag coefficient for shuttlecocks made of feathers is approximately 0.62 over 100 km/h and 0.49 at 60 km/h.
- The average drag coefficient for shuttlecocks made of synthetic rubber is approximately 0.59 over 100 km/h and 0.54 at 60 km/h.
- 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.

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