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AERODYNAMIC PROPERTIES OF BADMINTON SHUTTLECOCK

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ABSTRACT

Unlike projectiles, the shuttlecock generates significant aerodynamic drag and complex flight trajectory. Despite the popularity of the game, scant knowledge is available in the public domain about the aerodynamics of shuttlecocks. The primary objectives of this study were to experimentally measure the aerodynamic properties of a series of natural feather and synthetic shuttlecocks under a range of wind speeds and pitch angles. The drag coefficients for shuttlecocks were determined and compared. The natural feather shuttlecock indicated lower drag coefficient at low speeds and significantly high value at high speeds. On the other hand, the synthetic shuttlecocks have shown opposite trends. The average drag coefficient for shuttlecocks found in this study was between 0.5 and 0.6.

Keywords: Aerodynamics, Shuttlecock, Wind Tunnel, Drag Coefficient

1. INTRODUCTION

Badminton is one of the oldest and popular games in the world and believed to be originated from ancient Greece and China. However, the modern version of 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 not taken place until 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. Today, the game is so popular that over 160 countries are now the official members of 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. According to BWF estimates, at present, the game is played by over 200 million people worldwide and over thousand players participate in various competitions and tournaments around the world. One of the exciting moments of the game is shown in Figure 1. The centre piece of the game is shuttlecock which is made of either natural feathers or synthetic rubber with an open conical shape (shown later). The cone comprises of 16 overlapping goose feathers embedded into a round cork base which is covered generally with a thin leather or synthetic material. Unlike most racquet sports, a badminton shuttlecock is an extremely high drag projectile and possesses almost parabolic flight trajectory. Most amateur players use synthetic shuttlecock as it lasts longer, costs less (cheaper) and exhibits less aerodynamic drag 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 colour 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.

Figure 1 An exciting moment in Badminton game [4]

Despite immense 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 many studies by Alam *et al.*, 2008, 2009, Mehta *et al.*, 2008, Smits and Ogg, 2004 and Seo *et al.*, 2004 were conducted on spherical and ellipsoidal balls, no study except Cooke, 1992 and more recently by Alam *et al.*, 2009 was reported to 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.

2. EXPERIMENTAL PROCEDURE

2.1 Shuttlecocks

Ten new shuttlecocks were selected for this study. These shuttlecocks are: Grays nylon, Grays plastic, Grays volante, Mavis – Yonex 500, RSL standard, Grays volant en plumes, Yonex mavis 350, RSL silver feather, Arrow 100, RSL classic tourney. The dimensions of all these shuttlecocks are given in Table 1. All shuttlecocks are shown in Figures 2-6.

2.2 Experimental Set Up

A sting mount was developed to hold the shuttlecock on a six component force sensor in the test section of RMIT Industrial Wind Tunnel. The mounting gear and set up in the test section are shown in Figures 7 (a, b, c & d). 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) F-1


b) F-2

Figure 2 Natural feather shuttlecocks


a) F-3


b) F-4

Figure 3 Natural feather shuttlecocks


a) F-5


b) S-1

Figure 4 Natural feather shuttlecock (a) and synthetic shuttlecock (b)


a) S-2


b) S-3

Figure 5 Synthetic shuttlecocks

Table 1 Physical parameters of shuttlecocks

		Length of Suttle	Length of Cock	Width at the end of skirt	Mass
ID	Type	mm	mm	mm	mm
S-1	Synthetic	84	25	65	5.2
S-2	Synthetic	82	25	63	4.9
S-3	Synthetic	83	25	66	6.2
S-4	Synthetic	78	25	68	5.3
S-5	Synthetic	80	25	65	5.2
F-1	Feather	85	25	66	5.0
F-2	Feather	86	25	65	4.9
F-3	Feather	85	25	66	5.1
F-4	Feather	85	25	65	5.2
F-5	Feather	85	25	65	4.9

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 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 digitise and record all 3 forces (drag, side and lift forces) and 3 moments (yaw, pitch and roll moments) simultaneously.

a) S-4

b) S-5

Figure 6 Synthetic shuttlecocks

A plan view of the tunnel is shown in Figure 8. More details about the tunnel can be found in Alam *et al.*, 2003.

The aerodynamic drag coefficient is defined as:

$C_D = \frac{D}{\frac{1}{2}\rho V^2 A}$, where D, ρ, V & A are the drag, air density, wind speed and un-deformed projected frontal area of shuttlecock respectively. The Reynolds number is defined as $\mathrm{Re} = \frac{VD}{\nu}$, where V, D & ν are the wind speed, skirt diameter and kinematic viscosity respectively. 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 7(a) Experimental setup of the sting on a six component force sensor

Figure 7(b) Sting with shuttlecock (side view)

Figure 7(c) Sting with shuttlecock (top view)

Figure 7(d) A complete setup (sting & shuttlecock)

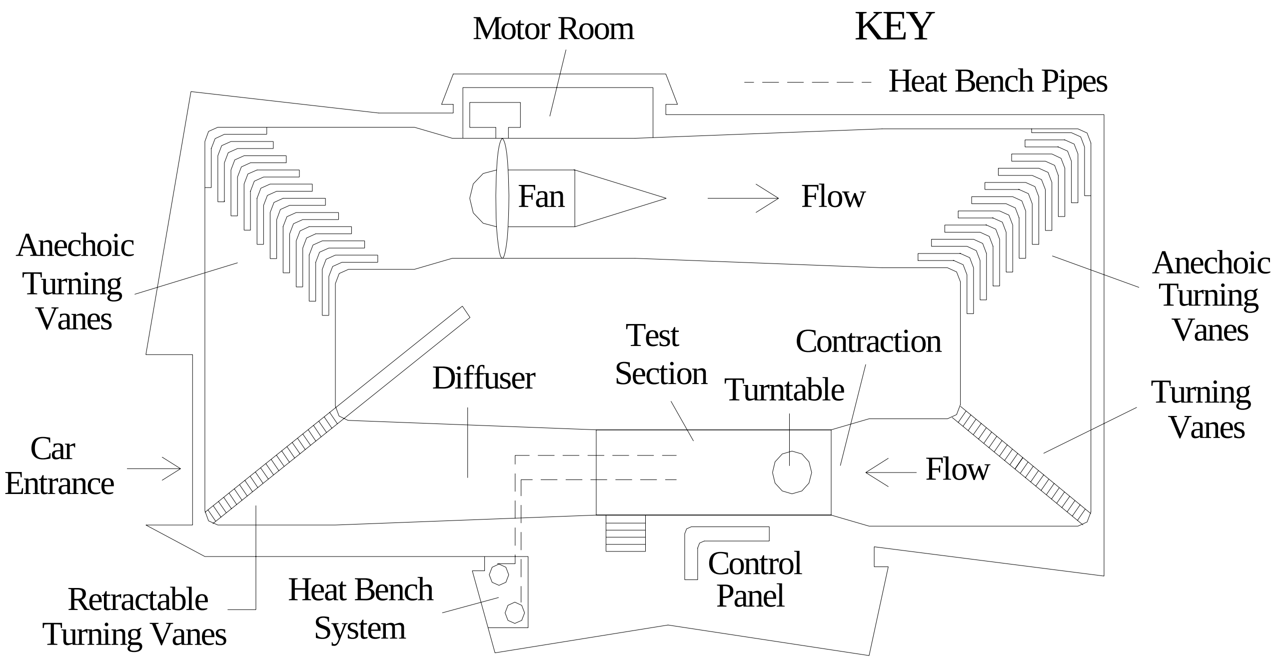

Figure 8 A plan view of RMIT Industrial Wind Tunnel (Alam *et al*., 2003)

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 drag coefficient (C_D) variation with Reynolds number (varied by velocity) for all shuttlecocks is shown in Figure 9. The Reynolds number is defined as $\mathrm{Re} = \frac{\rho V d}{\mu}$

Where, ρ, V, d & μ are the air density, wind velocity, shuttlecock effective diameter and dynamic (absolute) viscosity of the air.

The C_D variations with Reynolds numbers for feather shuttlecock and synthetic shuttlecock are shown in Figures 10 and 11 respectively. The C_D value was calculated using un-deformed projected frontal area of the shuttlecock.

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 9). Figure 11 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 (see Figure 9). 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 shuttlecock 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 for feather shuttlecock.

As mentioned earlier, two types of shuttlecock have been studied here. The experimental results indicate that there is notable variation in drag coefficients between the natural (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 are significantly different from their counter part, feather shuttlecocks. As a result, the airflow behaviour around the synthetic shuttlecocks differs notably compared to natural (feather) shuttlecocks. The degree of structural deformation of synthetic shuttlecocks was not determined in this study. However, work is underway to address this issue.

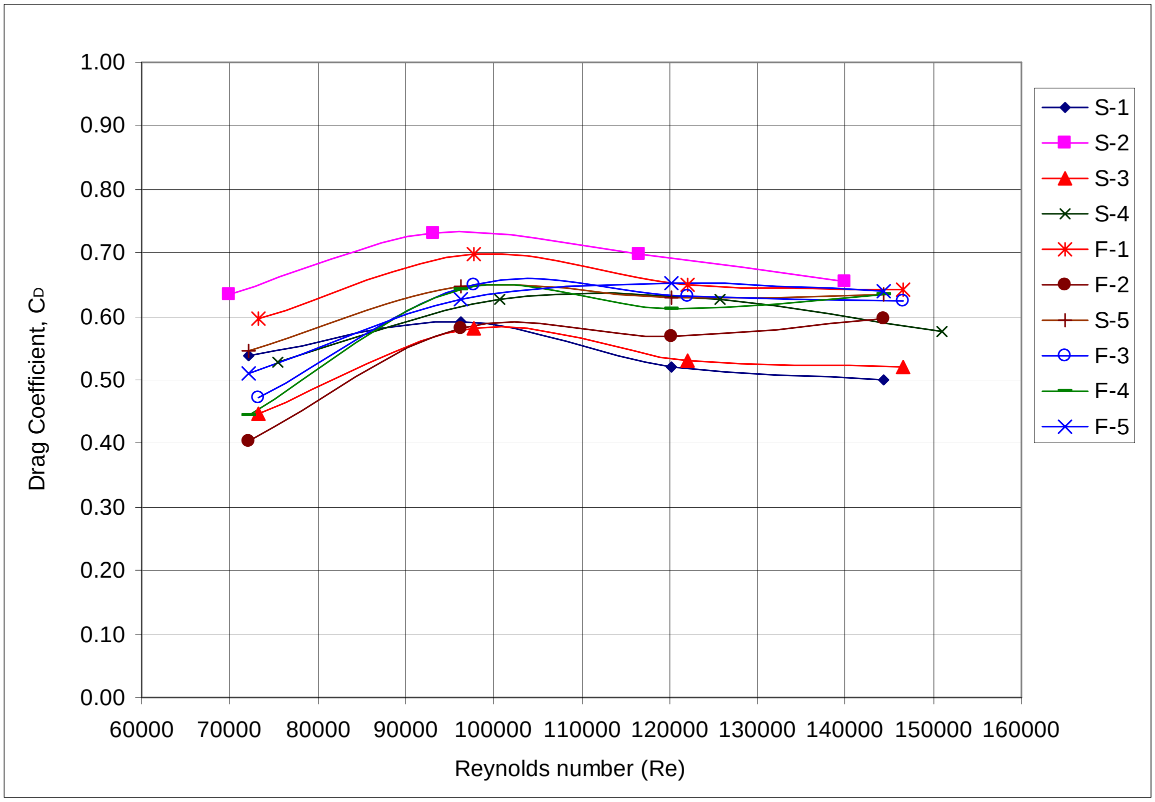

Figure 9 Drag coefficient variations with Reynolds number

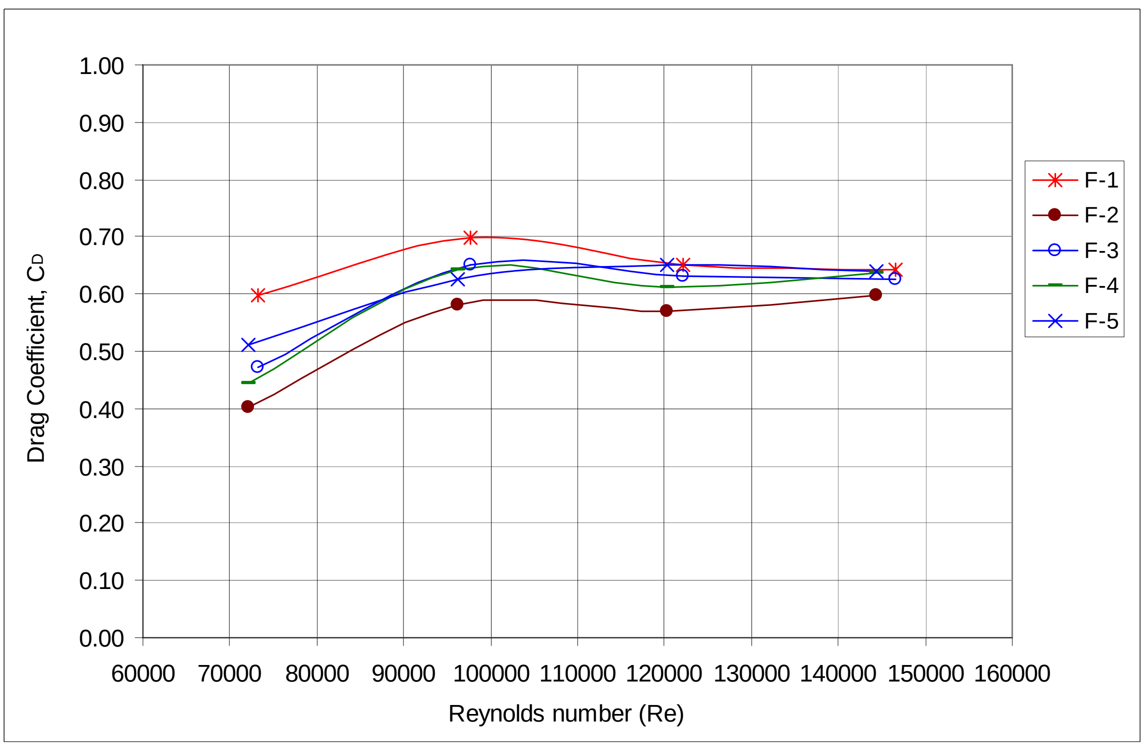

Figure 10 Drag coefficient variation with Reynolds number for feather made shuttlecocks

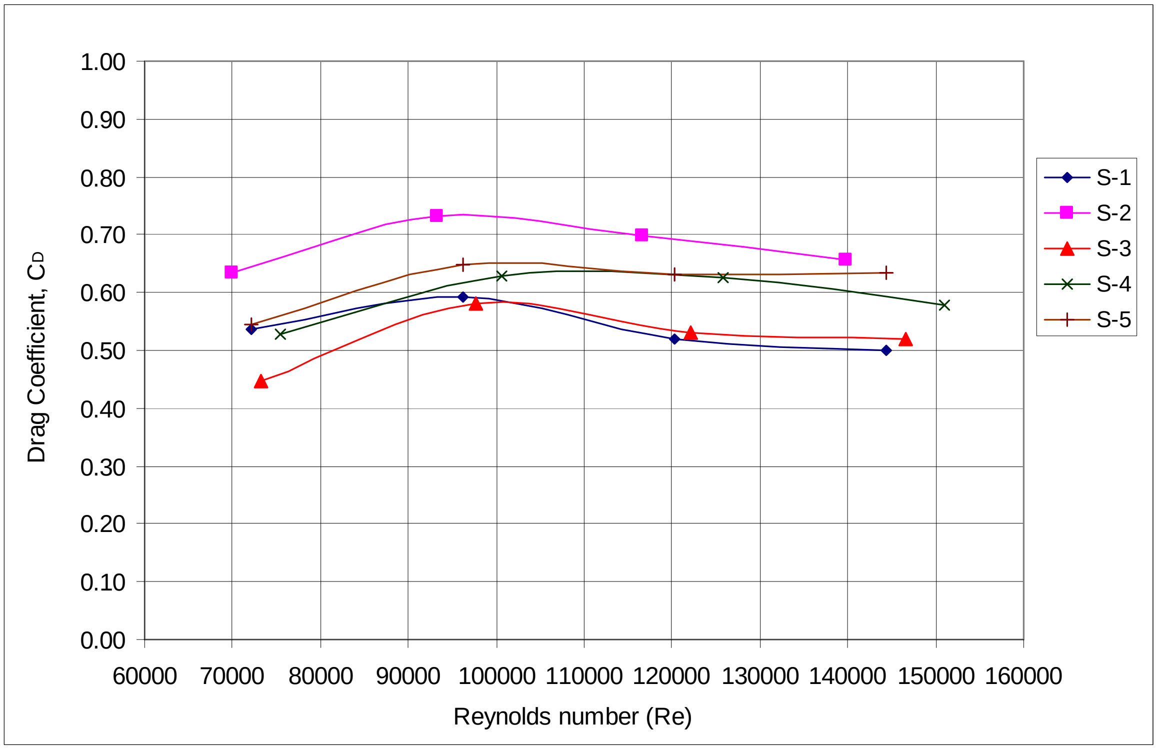

Figure 11 Drag coefficient variations with Reynolds number for synthetic shuttlecocks

4. CONCLUSION

The following conclusions have been made from the work 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 resulting in lower drag coefficients.

5. FUTURE WORK

The effect of pitch angle is important and worthwhile to investigate.

The skirting design is believed to have effect on aerodynamic properties. Further study is required to quantify the effects.

Although Badminton is predominantly played in door, the effects of yaw on aerodynamic properties can be detrimental. Further investigation on this would be useful.

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NOMENCLATURE

Symbol	Meaning	Unit
D	Drag Force	(N)
L	Lift Force	(N)
C_D	Drag Coefficient	-
C_L	Lift Coefficient	-
Re	Reynolds Number	-
V	Velocity of Air	m/s
ρ	Density of Air	kg/m^3
ν	Kinematic Viscosity of Air	kg/m^3
A	Projected Area	m^2
d	Shuttlecock diameter	m