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EFFECT OF SKIRT ANGLE AND FEATHERS FORMATION ON SHUTTLECOCK AERODYNAMICS PERFORMANCE

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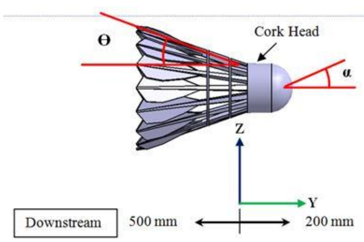
Graphical abstract



Abstract

Aerodynamic characteristics of badminton shuttlecock are significantly different from balls used in other sports. Shuttlecock can achieve a very high initial speed and at the same time, it can decelerate very fast. This is due to the significant aerodynamic drag it experiences during its in-flight motion. A computational fluid dynamics (CFD) analysis was carried out to understand the aerodynamics of a feathers shuttlecock approved by Badminton World Federation (BWF) for international tournaments. The aerodynamics performance of a standard shuttlecock at steady-state flight was investigated. The shuttlecock was assumed to be rigid and have no spin rotation; and velocity considered was 92 m/s. Effects of parameters such as angle of attack, α; angle of skirt, ϴ; and angle of feathers, β; on the shuttlecock drag coefficient, Cd; were studied. It is found that smaller ϴ leads to smaller Cd. Analysis shows that the Cd is the largest when the shuttlecock is at α = 0°. Besides that, the Cd is also influenced by β which the standard shuttlecock has fairly small Cd. Formation of feathers of the standard shuttlecock may be further twisted to the optimal value of β in order to increase its drag. As a result, ϴ and β may be considered as design parameters in order to obtain the desired aerodynamics performance.

Keywords: Aerodynamics, drag, badminton shuttlecock, computational fluid dynamics

1.0 INTRODUCTION

Badminton is a very popular racquet sport and it is the second most popular sport in the world, after soccer [1]. Different sports have different projectiles and shuttlecock is the projectile in badminton. Shuttlecock can be generally identified through its hollow conical body and semi-spherical head. There are two types of shuttlecocks used in badminton which are feathers and synthetic shuttlecocks. Feathers shuttlecock is made from feathers of goose left wing for the skirt and cork or rubber covered by a thin layer of leather for the head while synthetic shuttlecock is made from nylon [2]. Both of them are different in their designs which will undoubtedly affect the performance and trajectory.

Shuttlecock's unique aerodynamic characteristics have drawn many researchers to conduct studies on them and most of these studies except Verma *et al.* [4] were done by using experimental method of wind tunnel testing [3-6]. Only a few studies have been done on shuttlecock aerodynamics using computational fluid dynamics (CFD) analysis [7-10]. Besides that, there is barely any testing or analysis being done on shuttlecock aerodynamics by either Badminton World Federation or shuttlecock manufacturers.

Hence, a study has been conducted to investigate shuttlecock aerodynamics using entirely CFD analysis. The analysis was made through ANSYS FLUENT software (Finite Volume). Drag coefficient, Cd; of a standard feathers shuttlecock which is YONEX Aerosensa 50 at steady-state flight was investigated. Effects of parameters such as angle of attack, α; angle of skirt, ϴ; and angle of feathers, β; on the Cd were also studied. It is hoped that this study can act as a reference which provide information on shuttlecock aerodynamics that can be used by the governing body BWF, players and respective shuttlecock manufacturers to determine performance testing of the shuttlecock.

2.0 MATERIAL AND METHOD

In this study, feathers shuttlecock YONEX Aerosensa 50 has been chosen as a reference sample. It was chosen because it is approved by the Badminton World Federation (BWF) to be used in international tournaments and it is also commonly used by professional badminton players in Malaysia. Three shuttlecocks were randomly chosen from a same tube consisting of 12 units. The geometries of each shuttlecock were thoroughly measured using a profile projector Mitutoyo PH-3500. Weights of the shuttlecocks were measured using a top loading electronic balance Denver Instrument AC-400. After that, based on the measured dimensions, a standard 3D shuttlecock model was generated by using CATIA V5 R20 software. This standard shuttlecock was modelled with an angle of skirt, ϴ = 20° and angle of feathers, β = 10°. Eight other shuttlecock models with ϴ of 16°, 17°, 18° and 19° (with a constant β = 10°); and β of 0°, 5°, 15° and 20° (with a constant ϴ = 20°); were generated. Computational Fluid Dynamics (CFD) simulation has been carried out on the shuttlecock. Upstream and downstream boundaries were located at y = -200 mm and y = 500 mm respectively from the cork head of the shuttlecock (Figure 1). The diameter of the outer domain was 200 mm. The domain was cut into half as to reduce the number of elements. Depending on the model, about 450000 to 512000 of unstructured, tetrahedral elements were used for the simulation. Number of elements as well as skewness (indicates the quality of the meshing cells) were carefully controlled.

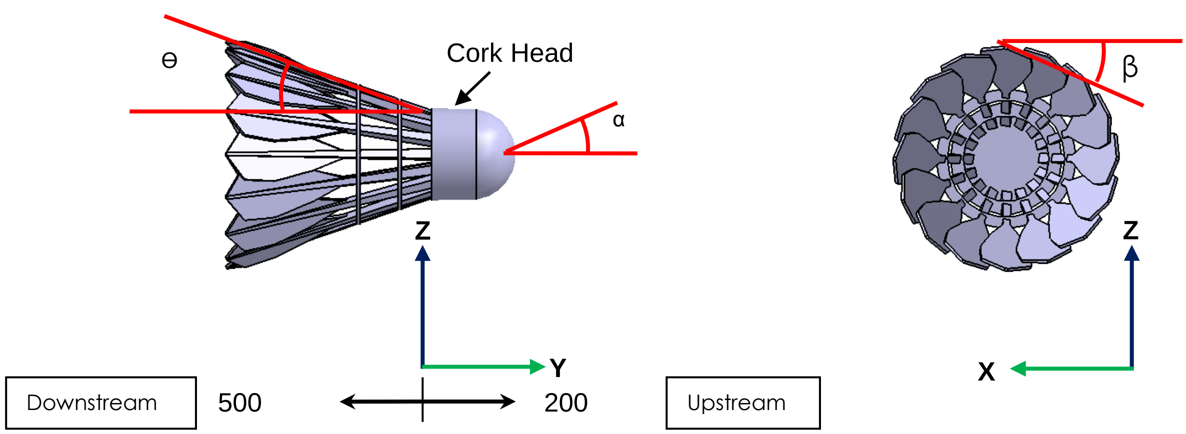


Figure 1 Angle of attack, α; angle of skirt, ϴ; and angle of feather, β; of a standard shuttlecock

For this study, the fluid inside the domain was assigned to be air with ideal temperature of badminton game, which is at 16°C (ρ = 1.222 kg/m3 and μ = 1.817e-5 kg/(m.s)). The air velocity was fixed at 92 m/s which represented the highest speed of jump-smash ever recorded in badminton game or Mach number, Ma = 0.27 [11]. The air flow was assumed to be incompressible because the Ma value was below 0.3 [12]. The simulation was set up to the pressure based settings. For every shuttlecock model, it was assumed to be wholly rigid body (does not deform under the action of air forces) and the feathers skirt was modelled as solid with no porosity. The shuttlecock was modelled at steady state flight and without spin rotation. 'No-slip' condition was assigned on the walls (surfaces) of the shuttlecock of which the air velocity will be zero. Going further from the walls, 'free-stream' condition was assigned for the air velocity. The gauge pressure was set up to be zero at the pressure-outlet (downstream). Also, the air flow was modelled to be calmer at the velocity-inlet (upstream) than at the pressure-outlet. For the surfaces of the outer domain, 'symmetry' condition was applied, where the components of velocity normal to the surfaces as well as the shear stress vectors in the tangential direction are zero. At velocity 92 m/s, Reynolds Number or Re calculated is approximately 400000. The Reynolds Number is defined as Re = ρVD / μ, where ρ is the air density, V is the air velocity, D is the diameter of shuttlecock skirt and μ is the air dynamic viscosity. The drag coefficient is defined as Cd = 2Fd / ρAV2, where Fd is the drag force and A is the reference area of shuttlecock. For external flow, this is considered to be fully turbulence. Hence, the simulation was carried out with the realizable k-epsilon model where it utilises two transport equations in order to bring out the sensitivity of the simulation. According to some studies, k-epsilon model performs well for external flow around bluff body with complex geometries [13-16]. Furthermore, this model is also very popular for industrial applications due to its good convergence rate and relatively low memory requirements. For the solution methods, 'coupled' scheme was used for the pressure-velocity coupling. Besides that, the simulation in this study utilised 'first order upwind' as well as 'second order upwind' for the spatial discretisation.

3.0 RESULTS AND DISCUSSION

3.1 Effect of Angle of Attack, α; Angle of Skirt, Θ; and Angle of Feathers, β; on the Performance of Standard Shuttlecock

Figure 2 shows the effect of angle of skirt, Θ; on the drag coefficient, Cd. The horizontal line indicates the performance of the standard shuttlecock (Θ = 20°, α = 0°, β = 10°) with Cd about 0.425 and at α = 0°, it has the highest Cd. Interestingly, due to physical nature of the shuttlecock, it will always fly the cork ahead at steady-state flight. Shuttlecock has distinguished centre of gravity and aerodynamic centre. The aerodynamic centre of shuttlecock is always behind the centre of gravity, i.e. shuttlecock is stable at all times [5]. Shuttlecock cork is denser than the skirt so the centre of gravity is near to the cork. Meanwhile the aerodynamic centre is near to the centre of the skirt [6]. It also confirm that the standard shuttlecock has the right possible skirt diameter within the requirements specified in BWF Statutes [17] in which allows it to have the highest Cd which depends on frontal area of the shuttlecock skirt. The area is influenced by the diameter, which can be controlled through Θ. It can be seen that the Cd decreases with decreasing Θ. This reduction in the Cd is due to the reduction of frontal area of the shuttlecock skirt, which leads to a more streamline shape of the shuttlecock. This frontal area is defined as Af = πD2 / 4, where D is the skirt diameter. The equation shows that the area is a function of the skirt diameter, and the diameter is influenced by Θ. Hence, the decrease in Θ will cause the decrease in the skirt diameter, and eventually reducing the frontal area.

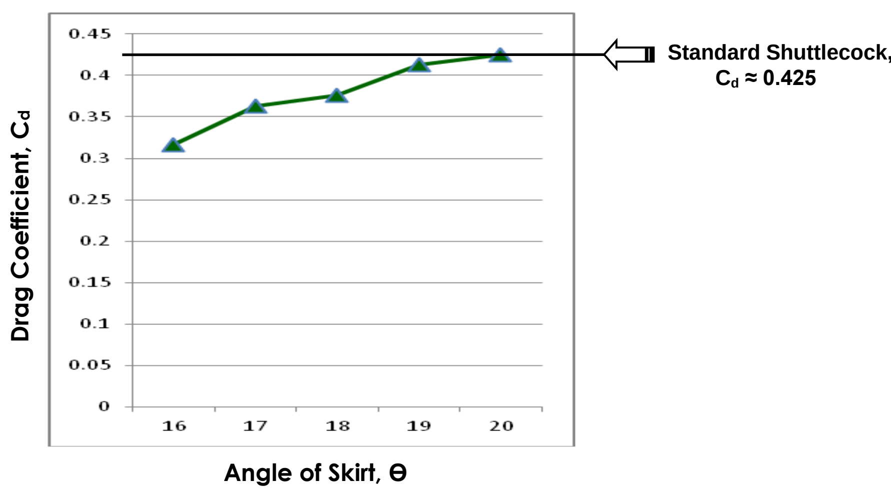


Figure 2 Drag coefficient, Cd versus angle of skirt, Θ

This effect of decreasing angle of skirt, Θ is also observed to have a similar effect as the deformation of shuttlecock skirt (the skirt deforms under the action of air forces). The deformation of shuttlecock skirt (based on the relationship between the Cd and Reynolds Number) was reported by Cooke [5] and Hasegawa *et al*. [3]. However, during badminton game, this skirt deformation is less possible to occur due to the rotation of shuttlecock which will cause the skirt to be more rigid. Figure 3 also shows that Cd gradually decreases with increasing of angle of attack, α. The finding is in an agreement made by study of Hasegawa *et al*. [3]. Also, due to the nature of feathers shuttlecock (the skirt is considerably stiff), the deformation is less likely to be promoted. Thus, Θ may be considered as one of the design parameters in order to obtain the desired aerodynamics performance.

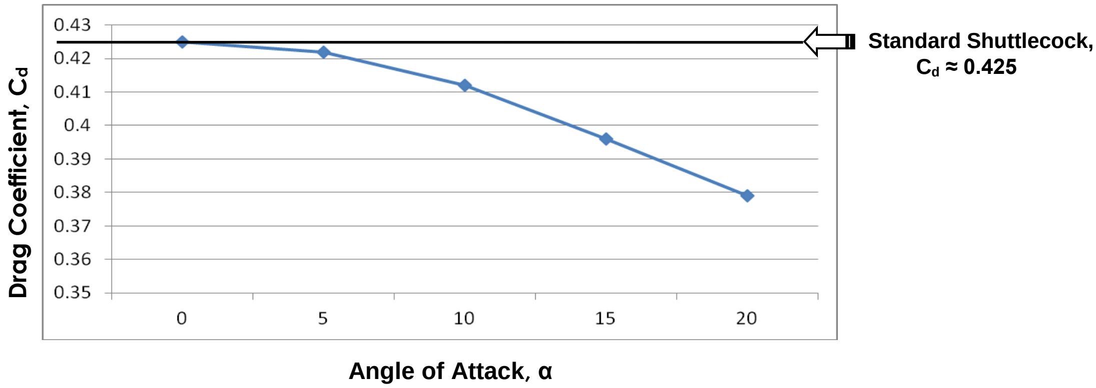


Figure 3 Drag coefficient, C_d; versus angle of attack, α

In terms of angle of feathers, β, it can be seen that the Cd for the standard shuttlecock is fairly small (apart from the Cd at β = 0°) (Figure 4). To describe in detail, β represents the twist of individual feather which overall forms the overlapping feathers of the shuttlecock skirt. The increase in β increases the gap between the feathers. It is observed that the Cd is the lowest at β = 0° and fairly high at β = 5°. Practically, each individual feather can be only twisted starting from minimal angle β = 8°. Hence, it is more appropriate to look at the graph above this value. In that case, it can be seen that the Cd increases from β = 10° and then decreases to β = 20°. At β = 15°, the Cd is the highest. This highest Cd is associated with the strongest air flow through the gaps as was reported by Verma *et al*. [4]. It should be pointed out that unlike Θ, it is impossible for the feathers to have twist effect (variable β) during badminton game. In Figure 4, it is clearly shown that there is an optimal value of β for maximum drag. As a recommendation, the feathers of the standard shuttlecock may be further twisted to this value as to increase its drag. Hence, similar to Θ, β may also be considered as a design parameter in order to obtain the desired aerodynamics performance.

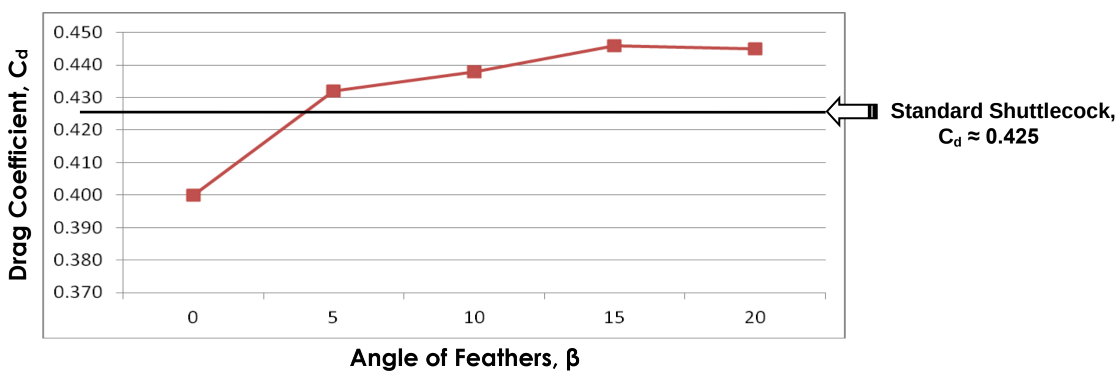


Figure 4 Drag coefficient, C_d; versus angle of feathers, β

4.0 CONCLUSION

In this study, a computational fluid dynamics (CFD) analysis was carried out to investigate the aerodynamics of a standard feathers shuttlecock. It was found that the standard shuttlecock (Θ = 20°, α = 0°, β = 10°) has a Cd at about 0.425. The Cd decreases with decreasing Θ because of the reduction of frontal area of the shuttlecock skirt. At α = 0°, the standard shuttlecock has the highest Cd. due to skirt diameter which falls within requirements specified in BWF. In terms of β, the standard shuttlecock has fairly small Cd (apart from the Cd at β = 0°). The feathers of the standard shuttlecock may be further twisted to the optimal value of β in order to increase its drag. Θ and β may be considered as design parameters in order to obtain the desired aerodynamics performance.

Acknowledgement

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