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CFD Study of Drag and Lift of Sepak Takraw Ball at Different Face Orientations

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There have been a significant number of researches on computational fluid dynamic (CFD) analysis of balls used in sports such as golf balls, tennis balls, and soccer balls. Sepak takraw is a high speed court game predominantly played in Southeast Asia using mainly the legs and head. The sepak takraw ball is unique because it is not enclosed and made of woven plastic. Hence a study of its aerodynamics would give insight into its behaviour under different conditions of play. In this study the dynamics of the fluid around a static sepak takraw ball was investigated at different wind speeds for three different orientations using CFD. It was found that although the drag did not differ very much, increasing the wind velocity causes an increase in drag. The lift coefficient varies as the velocity increases and does not show a regular pattern. The drag and lift coefficients are influenced by the orientation of the sepak takraw ball.

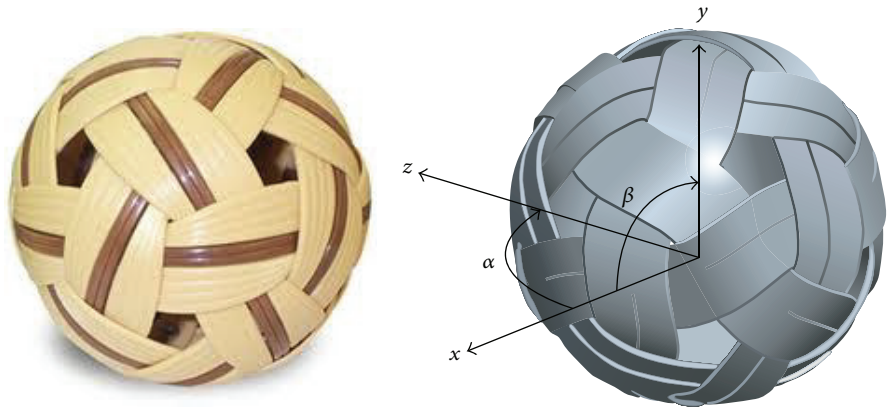
1. Introduction

Most sports balls have spherical shapes and are subjected to throwing, hitting, or kicking. As a result they are dynamically affected by the surrounding fluid either air or water. One of the earliest researches on the aerodynamics of sports balls was by Mehta [1]. Subsequent studies have focused on sports ball drag coefficient (C_D) values. Bearman and Harvey [2] studied the drag and lift parameter for different types of golf ball in a wind tunnel test. For baseballs, the relationship between rotation and lateral forces was evaluated [3], as well as the effects of seams on their aerodynamic properties [4]. Several similar studies have investigated tennis balls [5], soccer balls [6–8], and cricket ball [9].

The sepak takraw ball is unique since it is not enclosed like any other balls, as such air can pass through the ball and there are many seams on its surface. These features are expected to produce great efficacy on its aerodynamic performance. In this paper a numerical study of a nonspinning sepak takraw ball was carried out to investigate the dependence of its aerodynamic characteristics on the orientation of the ball face. The simulation was conducted for a nonrotating ball model for all three different orientations at different wind speeds using Ansys CFX as the CFD modelling tool.

2. Related Research

The flight of a sports ball can be influenced by two crucial aerodynamic properties, lift and drag. Lift can be defined as the force acting on the ball whose direction is perpendicular to the ball's flight path, while drag can be described as force acting on the opposite direction of the ball's trajectory. Lift on a ball is dedicated by several factors of the ball such velocity of the ball, orientation, geometry characteristic of the ball, and rotational speed [10]. Haake et al. [11] investigated the performance of various sports balls as performance of sports



(a) (b)

Figure 1: (a) Actual sepak takraw ball; (b) CAD model of sepak takraw ball.

balls is directly influenced by the position of the separation points of the boundary layer. The most important part is that these points are dedicated by the surface roughness of the ball. The drag force is influenced by velocity of the ball, orientation, surface geometry of the ball, and rotational speed; the same applies for lift force. For example, the drag force for smooth spheres did not remain constant as velocity or surface roughness changed and, therefore, many scientists began studying different spheres to prove this point. Lower seam lengths and adding more surface smoothness decrease the drag coefficient at high Reynolds number as shown by Alam at al. [12] with different types of soccer balls. The aerodynamic parameters of a soccer by Barber at al. [13] also concluded that the seam width was found to have a more profound effect on C_D than seam depth because the separation points were affected directly by the width.

Seo and Shibata [14] conducted experiments in a wind tunnel on different orientations of sepak takraw ball aerodynamic characteristics. They found that the drag coefficient C_D ranges between 0.42 and 0.52, while the lift coefficient (C_L) ranges between −0.1 and 0.1. Seo and Shibata [14] concluded that the orientation affects the drag and lift component. Taha and Sugiyono [15] studied different diameters of two different types of sepak takraw balls and their effect on the ball aerodynamics. They used a smooth sphere with 12 pentagonal holes which is a simple model of a sepak takraw ball. They showed that the rubber padded on the surface of plastic balls produce slightly higher drag compared to the ordinary plastic balls. In addition the rubber padded balls which had a larger diameter produced negative lift. The researchers distinguished ball types by defining a different surface roughness for each type of ball.

3. Ball Description

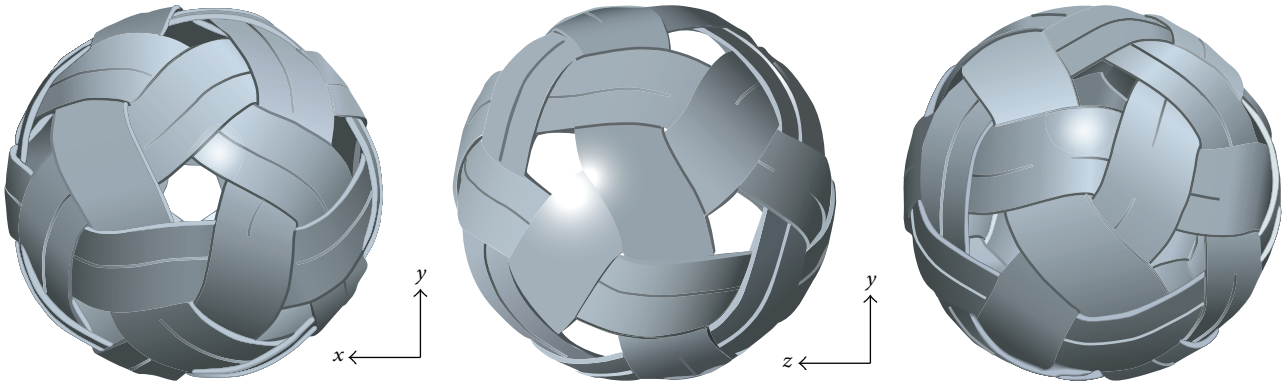
The sepak takraw ball is constructed by weaving plastic strips. It has 12 holes and the surface consists of twenty intersections (see Figure 1). The regulation requires the ball diameter to be approximately 0.135 m. However the diameter can vary slightly depending on the manufacturer of the ball and also different categories of sepak takraw game. The ball shape presents itself as a complex geometry; thus it is a challenge of understanding its aerodynamic behaviour. The traditional ball is made of rattan. In this study there are 3 different faces of the orientation which are investigated as shown in Figure 2.

4. Resources and Limitation

Considering the complex geometry of the ball limits the capability to run simulation of rotating condition which requires a significant computational overhead; therefore non-rotating condition was chosen as almost all aerodynamic sports research started with nonrotating condition [2, 7, 12, 16]. All different positions are defined as shown in Figure 2. The different kind of position distinguishes the different holes position that affect the drag and lift performance of the sepak takraw ball. The Reynolds number for each orientation are around 4×10^4 to 2.8×10^5. Any effect from vortices shedding is not considered in this study since there is no past research considering effect of vortex shedding in aerodynamics of sepak takraw. Due to computational limitations, the CFD analysis will focus on the use of the steady state Reynolds averaged Navier-Stokes (RANS) [15] and shear stress transport (SST) approach. These limitations required the assumption of a fully turbulent boundary layer. It was thought that the drag crisis did not happen over the range of Re experienced by the flow around a sepak takraw ball [14], and the aerodynamic properties would be largely unaffected by this and a steady-state flow analysis would give useful information at a much lower computational cost.

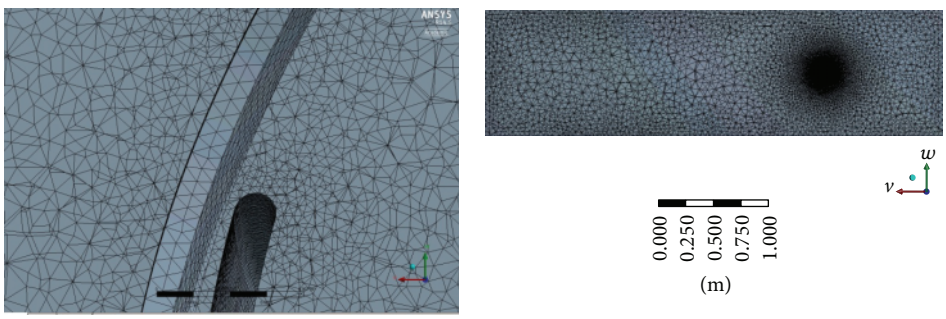
5. Comparison

The results acquired from CFD analysis are compared using drag coefficient data experiment from the Seo and Shibata [14] where the drag coefficient was recorded as a function of Reynolds number. Since the drag coefficient recorded through experiment does not drop dramatically, the assumption is that boundary layer in range of Re is expected to be in subcritical region. This further is confirmed later after the



(a) $\alpha = 90^\circ, \beta = 0^\circ$ (b) $\alpha = 0^\circ, \beta = 0^\circ$ (c) $\alpha = 0^\circ, \beta = 103^\circ$

Figure 2: Definition of front view position used for CFD simulation where the flow is through to the front view (a) position 1(P1), (b) position 2(P2), and (c) position 3(P3), respectively.



(a) (b)

Figure 3: (a) Boundary layer meshing of sepak takraw ball model; (b) half cut view of volume mesh M2 of fluid domain surrounding sepak takraw model.

data from CFD analysis is in good agreement with Seo and Shibata [14].

6. Computational Simulation Modelling

6.1. Geometry Model. In any computational modelling the initial stage is to develop the model corresponding to the actual part. A sepak takraw ball consists of complex shapes of spheres. The ball is simplified in terms of shape and is built in a CAD (computer aided design) environment as done by Ahmad et al. [17]. The CAD model is exported in parasolid format (.x_t) to the CFD software Ansys CFX [18]. Ansys Workbench in the Ansys CFX can create a new project consisting of 4 sections which are geometry, meshing, setup, and solution and result.

6.2. Mesh Sensitivity Study. The CAD model is enclosed within a rectangular box of size 4 m × 1 m × 1 m representing the fluid domain surrounding the sepak takraw ball model. The initial mesh set for medium mesh size consists of approximately 1.5 million nodes and 8.3 million elements at position P3. Let this be mesh M1. The drag coefficient acquired from mesh M1 at 2.1×10^5 Reynolds number is 0.455. The second mesh generated is of more finer size around 3.1 million nodes and 17 million elements and this mesh is represented as M2 (Figure 3). At 2.1×10^5 Reynolds number, drag coefficient for M2 is 0.465. The final mesh was set up with combination of both medium mesh and fine mesh surrounding the sepak takraw ball model. Let this combined mesh be called M3. The fine mesh was enclosed in rectangular shape mesh surrounding sepak takraw ball model and the rest of the mesh was in medium size. Drag coefficient found for M3 was 0.52936. Comparison of error of all type of mesh for drag with data from Seo and Shibata [14] specifically for the same Reynolds number 2.1×10^5 is 3.79% for M1, 1.73% for M2, and 10.51% for M3. Since the M2 mesh is in much accurate comparison with actual data, M2 type mesh is continued throughout the analysis.

6.3. Boundary Conditions. The boundary conditions such as inlet, outlet, and wall conditions are configured in the setup section. The inlet velocity is varied from 5 to 30 m/s with 5 m/s increments. Therefore there are 6 simulations for each orientation. The wall condition for the surface of the ball is set to a nonslip wall condition while the far field wall is set to free-slip condition. The governing equations used for the solver are the 3D Reynolds averaged Navier Stokes equations with turbulence model as the standard k-ε model [15] and shear

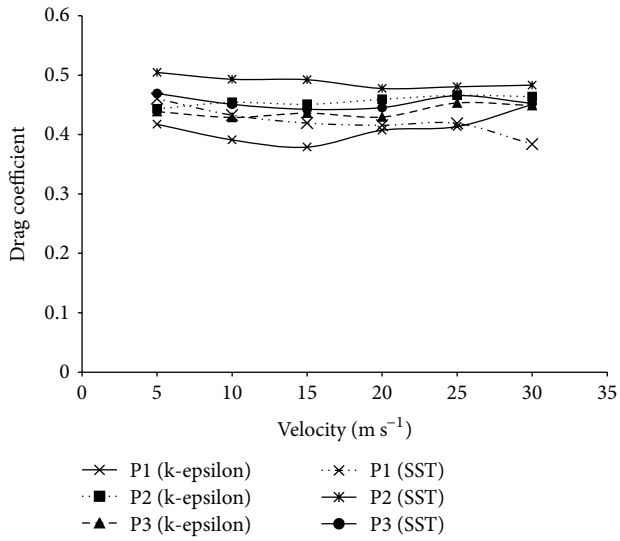


FIGURE 4: Drag coefficient as a function of wind velocity for all three positions.

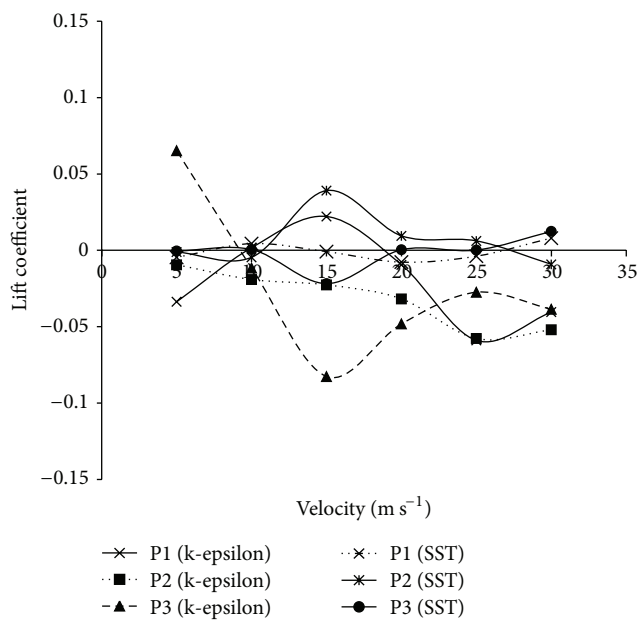


FIGURE 5: Lift coefficient as a function of wind velocity for all three positions.

stress transport model (SST). The flow is set as steady and incompressible. Expressions for drag and lift force are created in the expression tab option. The drag and lift coefficients are also input as expressions. Both C_L and C_D, respectively, are denoted by

$$C_L = \frac{2F_L}{\rho A_L v^2}, \qquad C_D = \frac{2F_D}{\rho A_D v^2}, \tag{1}$$

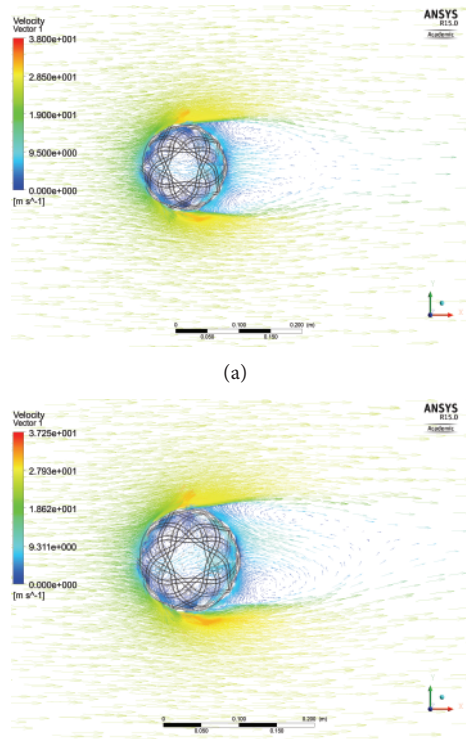


FIGURE 6: Distribution of the vector component of the velocity (a) SST model and (b) k-epsilon model at Re 2.1×10^5 at centre plane of the sepak takraw ball.

where F_L is the force due to lift, F_D is force due to drag, ρ is the fluid density, A_D and A_L are the projectile area of the ball for different position subjected for each drag and lift, and v is the velocity of the ball through the fluid. Note that each position has different projectile area of reference especially for drag coefficient. Each of projectile area for different positions have been calculated inside the CAD software earlier.

7. Results

7.1. Drag Coefficient. The drag coefficient (as shown in Figure 4) gives consistent values at varying velocities. For all three positions, the drag coefficient is in the range of 0.378 to 0.466. Similar for both turbulence model, position 2 shows higher drag coefficient compared with the other two positions for velocity values from 5 to 30 m/s. However positions 2 and 3 show almost similar results of higher drag coefficient when applied at higher speeds.

7.2. Lift Coefficient. Results for lift coefficient are quite irregular compared to drag coefficient especially for all position of k-epsilon turbulence model. All the lift results of each position using k-epsilon model range lift coefficient between −0.059 to 0.0652 meanwhile −0.022 to 0.0391 for SST turbulence model for all positions as shown in Figure 5. It is expected that the result for lift coefficient varies for each position that is not entirely asymmetry. The most

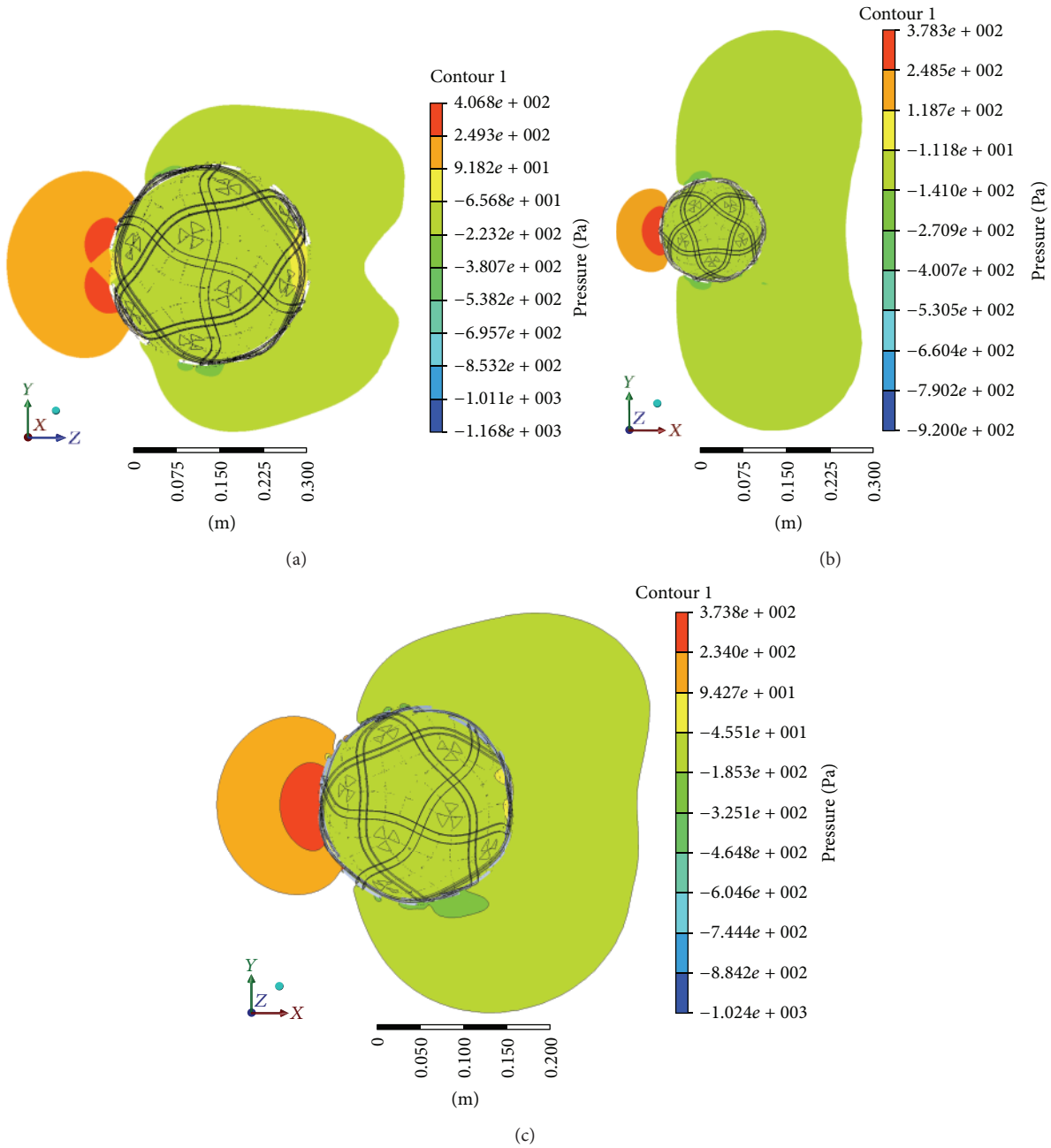


Figure 7: Pressure distribution on centre cut plane of sepak takraw at (a) position 1, (b) position 2, and (c) position 3.

symmetrical position out of all positions in the y-plane is position 2. SST model predicts well for position 2 since the lift is the minimum range and closest to zero compared to k-epsilon model as shown in Figure 6.

8. Discussion

8.1. Drag Coefficient

8.1.1. Pressure. Drag is produced mainly due to the pressure distribution surrounding blunt bodies [5], in this case the sepak takraw ball. The highest pressure point on the surface area of the sepak takraw ball is at the stagnation point which is located at the centre of the ball facing the wind direction [14]. Since at position 1 there are holes in the centre of the sepak takraw ball facing the direction of the wind, therefore there is no stagnation point as shown in Figure 8(a). This results in low drag since the drag depends on the pressure difference between the front and back surface of the takraw ball that faces the direction of the wind. Furthermore in position 1, there is a lack of crucial surface area for maximum pressure distribution. As shown in Figure 7 in position 1 although the pressure is the maximum compared to positions 2 and 3, the maximum pressure is not distributed well on the

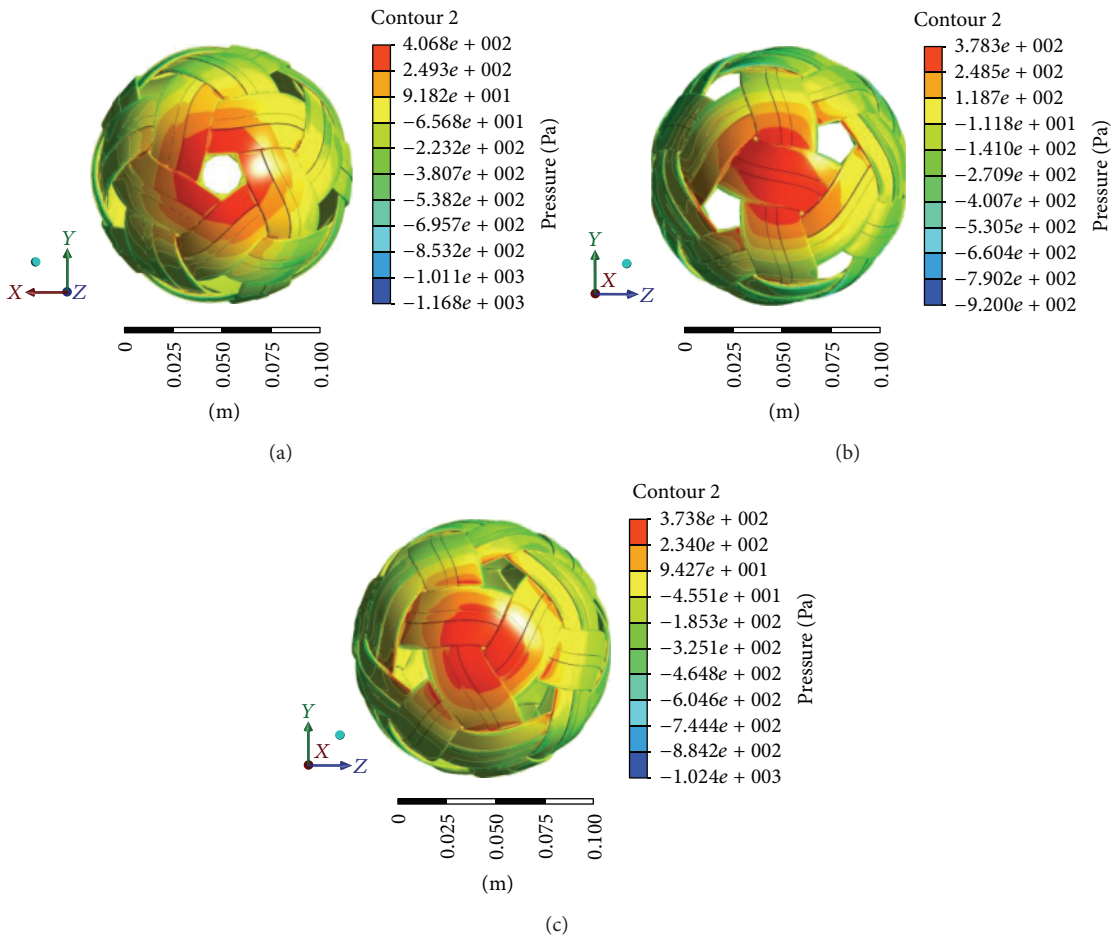
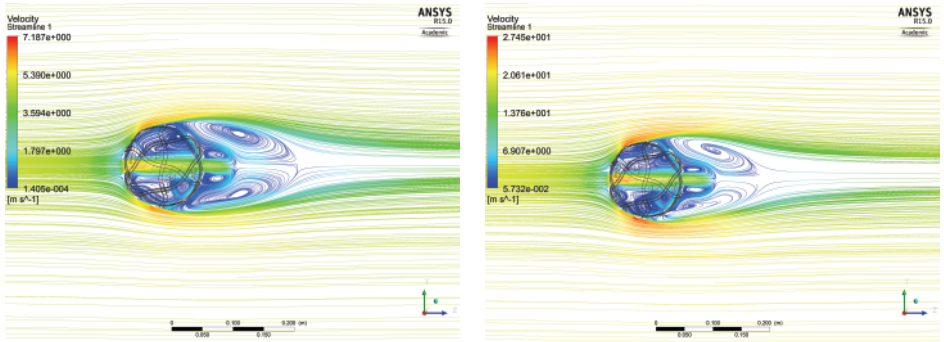


Figure 8: Pressure contour of the sepak takraw ball for different position takraw: (a) position 1, (b) position 2, and (c) position 3.

surface of position 1 resulting in lower pressure difference. At position 2, there is a stagnation point located at the centre face of sepak takraw ball; thus resulting pressure difference allows more drag to be produced compared to position 1. Figure 7(b) also indicates the surface area of pressure distribution along the sepak takraw surface is well covered, almost symmetrical compared to other positions which indicate more drag. Meanwhile the drag is produced in position 3 where the pressure distribution is not evenly through the surface of sepak takraw ball compared to the other positions (as shown in Figure 7(c)). Furthermore in position 2, the maximum pressure occurs in this position as shown in Figure 8(b). Obviously pressure difference produces more drag and this can be achieved by resulting the pressure covering more area of the sepak takraw, therefore producing higher drag coefficient.

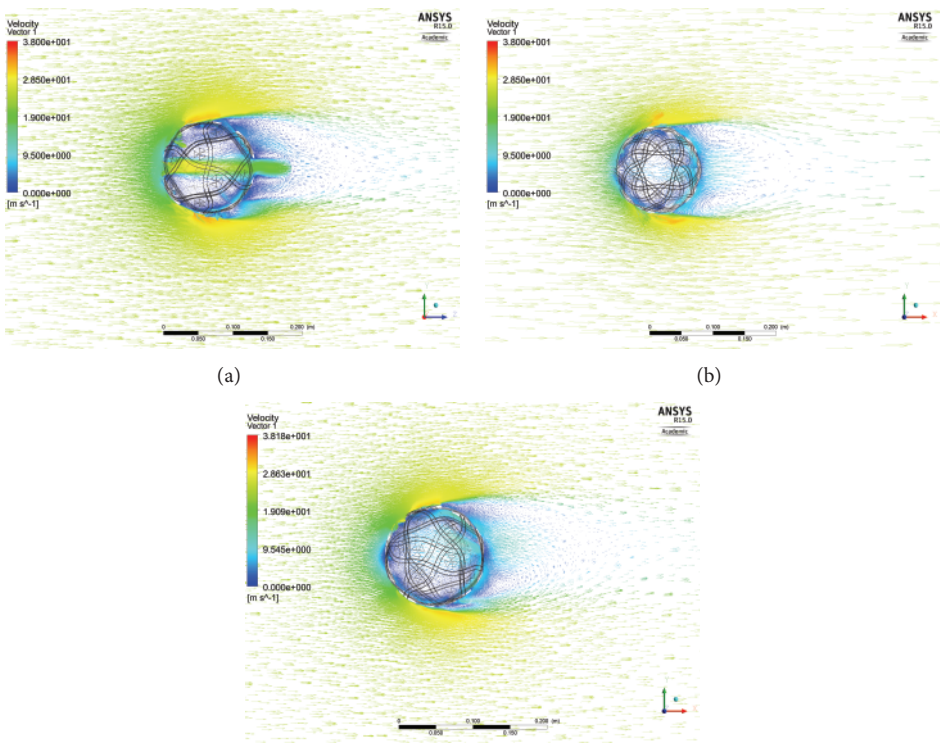
8.1.2. Velocity. The velocity contour as shown in Figure 10 indicates the intensity of velocity inside the sepak takraw ball for each position. In general the average velocity inside the ball at position 1 is highest compared to positions 2 and 3 due to opening directly normal to wind. The more high velocity indicates low pressure distribution on the surface area inside the sepak takraw ball. Therefore drag coefficient for position 1 is slightly low compared to other positions. The flow inside the ball is associated with large region of circulation. The more the circulation inside the ball, the more the drag produced towards the ball. As shown in Figure 10, the circulation flow is high inside position 2, less in position 3, and least in position 1. This is consistent with drag coefficient being largest in position 2, second by position 3, and lowest in position 1.

8.1.3. Data Comparison. The results are in agreement with Seo and Shibata [14] with almost similar pattern of the drag in the Reynolds number range of 4×10^4 to 2.8×10^5 as shown in Figure 11. The position of experiment data from Seo and Shibata is the same as position 3. CFD analysis shows that the drag is underpredicted since position 3 data is slightly over compared to Seo and Shibata [14] data. The sepak takraw ball is rough, has many holes and full of weave pattern features. All of these geometry factors may cause the boundary layer surrounding the sepak takraw ball will readily trip to turbulent early. Therefore results from CFD analysis using turbulence model yield results similar in trend to drag coefficient as shown in Figure 11. The data comparison only consists of position 3 for drag coefficient and it indicates that SST model has much better turbulence model for sepak



(a) (b)

Figure 9: Flow visualization represents velocity of the wind flow surrounding the sepak takraw ball in position 1 at (a) Re $= 4 \times 10^4$; (b) Re $= 1.7 \times 10^5$.



(a) (b)

(c)

Figure 10: Distribution of the vector component of the velocity: (a) position 1, (b) position 2, and (c) position 3 at Re 2.1×10^5 at centre plane of the sepak takraw ball.

takraw since the error of difference is much lower for SST turbulence model compared to k-epsilon.

8.1.4. Lift Coefficient. Meanwhile the lift produced for all position is both negative and positive. Lift coefficient produced for each position is relatively small less than 0.1. The significant difference between turbulence model of both k-epsilon and SST is that SST model predicts less lift compared to k-epsilon. The lift coefficient of sepak takraw should be less because of the holes of the sepak takraw ball, thus further suggesting that SST model has much better turbulence model for sepak takraw. In position 2, the lift coefficient should be near zero since the symmetrical aspect of the ball faces the wind but there still appears that the ball experiences some lift. Thus it is safe to assume that the seam affects lift coefficient of sepak takraw ball rather than the holes on the ball.

Another look at flow stream visualization for position 1 of sepak takraw ball in different Reynolds number reveals that as speed of the ball increases it also influences the lift coefficient of the ball. The vortices behind ball as well inside

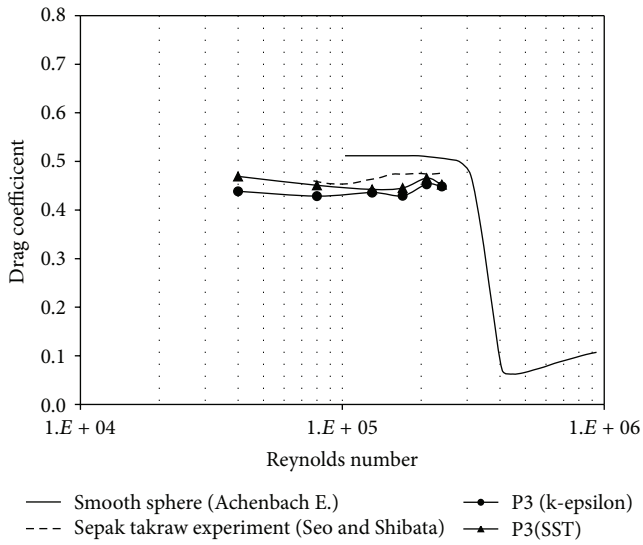


Figure 11: Drag coefficient as a function of Reynolds number for position 3, experimental data Seo et al. [14] and smooth sphere [19].

the ball became more chaotic as the speed increases as shown in Figure 9. For example in Re at 4×10^4, the vortices behind the ball seem stable thus induce to positive lift. As Re increases the vortices became more imbalanced, therefore inducing negative lift. Although this irregular behaviour of flow contributes to varying lift either positive or negative, it gives just a little impact in the aerodynamic of sepak takraw since the lift has only really small range from −0.022 to 0.0391 for SST turbulence model.

9. Conclusion

CFD is a powerful tool for determining the drag and lift of a sepak takraw ball mode given within certain limitation such as computational resource and software capabilities. The drag coefficient for the sepak takraw ball modelled in Ansys CFX for several positions was found to be in the range of 0.424 to 0.523 for velocities varying from 5 to 35 m/s. The drag force shows consistency as the velocity increases for all positions. The turbulence model suitable for predicting the drag coefficient for the sepak takraw was SST model. However lift force shows a varying behaviour value especially for positions 1 and 3 due to the asymmetrical shapes of each position. Furthermore as velocity increases significant flow visualization effect can be observed where the vortices behind the sepak takraw ball became more irregular consistent with the change in lift coefficient. The lift coefficient values vary from −0.105 to 0.116 for the same velocity range. It is clear that the different position of the ball orientations influences the aerodynamic performance of this complex structure of sepak takraw ball as Reynolds number increases. The highest drag coefficient is recorded at position 2 and position 3 where both have the same stagnation point in the front area of the model compared to position 1. Furthermore the positions of holes at all positions and the seam roughness contributed significantly to the drag and lift parameters.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

Acknowledgments

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