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AERODYNAMIC STUDY OF A MODERN *SEPAK TAKRAW* BALL USING SMOKE FLOW VISUALIZATION TECHNIQUE

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Abstract

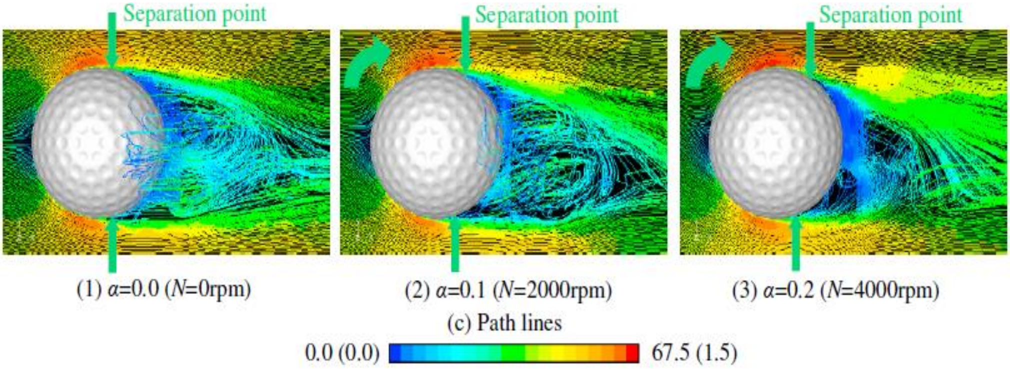
It has been shown in previous studies that the flight trajectories of sports balls are influenced by their aerodynamic characteristics. These aerodynamic characteristics are primarily dependent on the physical shape and surface texture of the balls. Even though *sepak takraw* is well established as a sport, little is known regarding the aerodynamic characteristics of the *sepak takraw* ball, which has a rather complex shape and surface texture. Hence, the main objective of this research is to investigate the aerodynamic characteristics (specifically the drag and lift coefficients) and flow features of a modern *sepak takraw* ball commercially available in the market by means of numerical simulations and wind tunnel experiments using the smoke flow visualization technique. The aerodynamic characteristics and flow features of the ball are determined for non-spinning conditions at a wind speed of 3 m/s. It is found that the drag coefficient and lift coefficient of the *sepak takraw* ball is 0.4868400 and -0.0130915, respectively. The images captured from the smoke flow visualization experiments reveal that the *sepak takraw* ball is in the subcritical flow regime at a wind speed of 3 m/s, which is the regime before the drag crisis. The laminar boundary layer separates from the upper and lower surfaces of the ball at points upstream of the equator of the ball, creating a large wake region downstream of the *sepak takraw* ball and resulting in high drag. This in turn, influences the trajectory of the *sepak takraw* ball in flight. The flow features observed from the smoke flow visualization experiments are representative of the flow during a *sepak takraw* game. Owing to the complexity of *sepak takraw* ball, it is recommended that the aerodynamic characteristics of the *sepak takraw* ball are investigated for spinning conditions in future studies.

Keywords: Aerodynamics, drag, flow visualization, *sepak takraw*

Introduction

Aerodynamics plays a crucial role in ball sports since the ball is hit, kick, struck or thrown into the air, which affects the flight trajectory of the ball. The performance of sports players during a game is partially influenced by the various shapes and sizes of sports balls. One of the unique sports balls is the *sepak takraw* ball. With a hollow spherical shape consisting of several pentagonal holes, the *sepak takraw* ball is distinctive from the balls used in other sports. A *sepak takraw* ball consists of several spherical hoops intertwined with each other and therefore, the flow produced by such a ball is complex and of interest to sports scientists and aerodynamicists. Even though there is a large a number of studies available in the literature pertaining to the aerodynamic characteristics of sports balls, little is known regarding the aerodynamic characteristics of a *sepak takraw* ball, which forms the motivation of this research. Hence, the objective of this research is to investigate the aerodynamic characteristics and flow features of a *sepak takraw* ball by means of a flow visualization technique as well as numerical simulation.

One of the techniques used to analyse the aerodynamic characteristics of sports balls is flow visualization. Flow visualization is a purely qualitative technique used to analyse the flow features surrounding an object and has been implemented in a number of studies related to sports science such as tennis (Djamovski, Pateras, Chowdhury, Alam, & Steiner, 2012), soccer (Alam, Chowdhury, Moria, & Fuss, 2010; Carré, Goodwill, & Haake, 2005) and golf (Aoki, Muto, & Okanaga, 2010). There are various types of flow visualization techniques, namely smoke flow visualization, tuft flow visualization (Alam, Smith, Chowdhury, & Moria, 2012) and oil flow visualization. The smoke flow visualization technique is chosen for this research, in which the *sepak takraw* ball is mounted in a fixed position in an open-loop, low-speed wind tunnel in order to visualize the flow features surrounding the ball.



(1) α=0.0 (N=0rpm)

(2) α=0.1 (N=2000rpm)

(3) α=0.2 (N=4000rpm)

(c) Path lines

Figure 1: Flow characteristics of a golf ball using computational fluid dynamics simulations (Aoki et al., 2010)

Another technique used to analyse the aerodynamic characteristics of sports balls is numerical simulation. Advancements in computing hardware and software have made it possible for scientists and researchers to perform complex simulations within a shorter time frame. The availability of computational fluid dynamics (CFD) tools have enabled scientists and researchers to examine the aerodynamic characteristics of sports balls in a more flexible manner since ‘experiments’ can be carried out in a ‘virtual wind tunnel’ and the parameters can be varied to study their effects on the flow characteristics. The beauty of numerical simulation lies in its capability to reveal the features of the flow surrounding an object within a fraction of the time taken using experimental techniques, and this reduces the need to build costly prototypes whenever a new design is considered. For these reasons, CFD is an excellent complementary tool for conventional experimental techniques and it has greatly benefit scientists and researchers in analysing the aerodynamic characteristics of sports balls. One such study is the work of Aoki Muto, and Okanaga (2010), whereby they investigated the aerodynamic characteristics of the flow surrounding a golf ball. They showed the variations that occur in the flow (particularly the flow separation points) as the rotational speed of the golf ball is increased which in turn, improves the lift characteristics of the ball. These variations are shown in Figure 1.

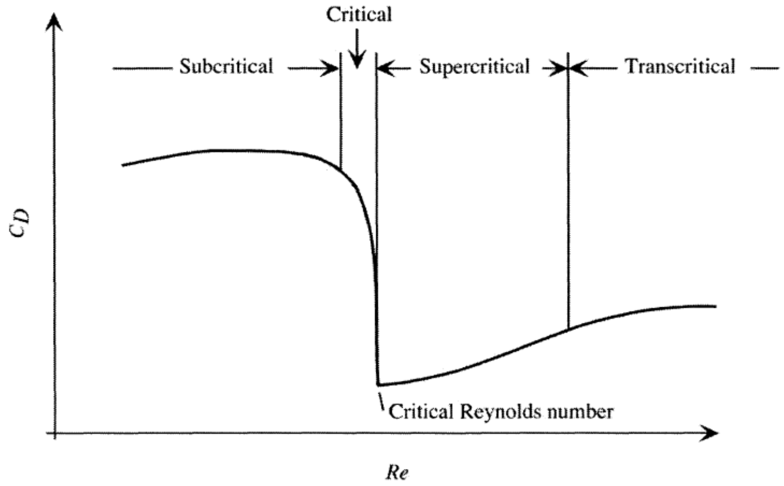


Figure 2: Flow regimes of a sphere

The variations that occur in a flow field can also be observed using the flow visualization technique. Flow visualization enables one to visualize the different stages of the flow (subcritical, critical, supercritical and transcritical), as shown in Figure 2. The features of the flow surrounding a soccer ball can be clearly seen using this technique, as shown in Figure 3 (Carré et al., 2005). The wiffle ball is a sports ball that is similar in geometry with the *sepak takraw* ball, and it has been proven in a previous study that the holes in the wiffle ball influence its aerodynamic characteristics (Rossmann & Rau, 2007).

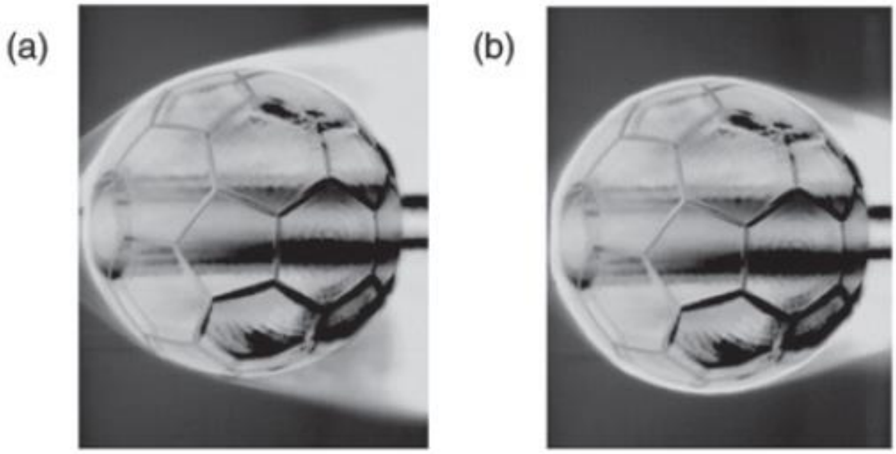


Figure 3: Smoke flow visualization which shows the differences in the flow field surrounding a soccer ball: (a) laminar flow at Re = 9×10^4 and (b) turbulent flow at Re = 1.3×10^5 (Carré et al., 2005)

Methods

Description of the ball

The ball used in the smoke flow visualization experiments is manufactured by Salim SS1, which is a modern *sepak takraw* ball commonly used in adult male *sepak takraw* games. This ball has a weight of 0.18 kg and is primarily made from plastic. The diameter of the ball is approximately 0.135 m. The specifications of the ball are approved by the International Sepak Takraw Federation (ISTAF). The *sepak takraw* ball was mounted in the test section of the wind tunnel and held in place using a cylindrical steel rod. The dimensions of the rod were determined based on preliminary measurements in order to ensure that it fits snugly into the test section of the wind tunnel.

Experimental procedure

The smoke flow visualization experiments were conducted in an open-loop, low-speed wind tunnel located within a test facility at Kuliyyah of Engineering, International Islamic University Malaysia (IIUM). The wind tunnel has a 40 cm × 40 cm opening and a turbulence intensity less than or equal to 0.1%. The wind speed was set at 3 m/s, which corresponds to a Reynolds number of 2×10^4. This wind speed setting was chosen since it was observed that wind speeds greater than 3 m/s resulted in chaotic flow, and the flow features recorded by the video camera during the experiments became indistinguishable. The wind speed was calculated once the dynamic pressure of the flow was known. The dynamic pressure (i.e. the difference between the total pressure and static pressure) was measured using a Pitot-static tube connected to a liquid column manometer. The materials and equipment used in the smoke flow visualization experiments comprise a syringe with needle, nichrome wires, a direct current power supply, SAFEX solution and ultraviolet (UV) light. The schematic diagram of the experimental set-up is shown in

Figure 3. The schematic diagram of the wind tunnel is shown in Figure 4(a) whereas the test section of the wind tunnel which houses the *sepak takraw* ball is shown in Figure 4(b). The experiments were recorded using Canon 600D DSLR video camera equipped with an 18 Megapixel CMOS sensor and Canon 50 mm f/1.8 II lens. The video camera was mounted on a tripod with a black cover placed behind it in order to minimize reflections from the test section during the experiments. The video was recorded at a resolution of 1920 × 1080 (Full High Definition (HD)) at 24 frames per seconds, which is the current standard in cinematography.

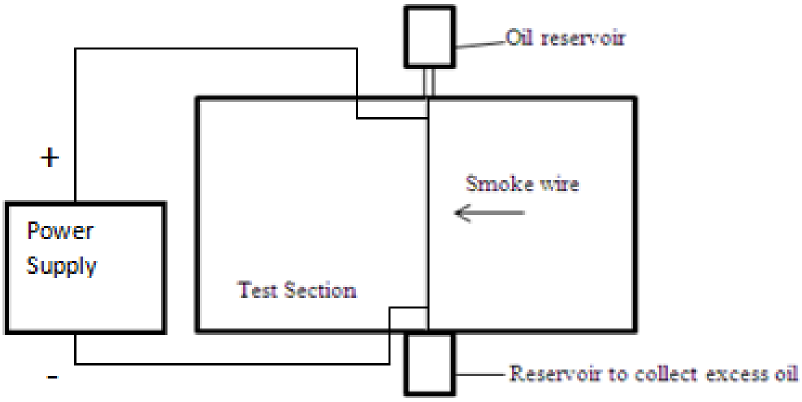
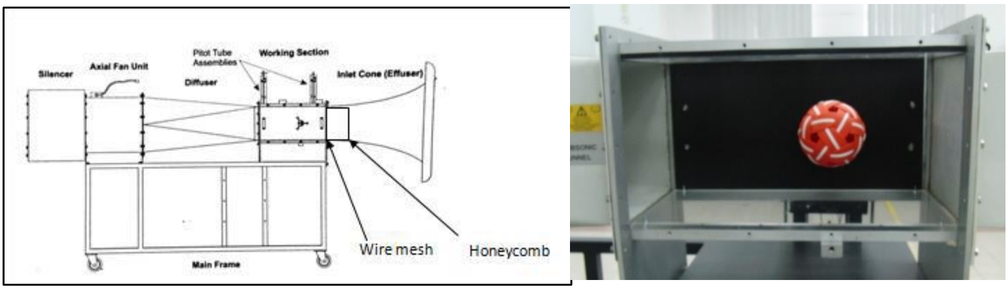


Figure 3: Schematic diagram of the smoke flow visualization experimental set-up



(a)

(b)

Figure 4: (a) Schematic diagram of the wind tunnel and (b) photograph of the test section which houses the *sepak takraw* ball

Numerical Simulation

- *Model geometry*

The first stage of a CFD analysis involves the development of a model that is representative of the actual object of interest. Hence, the model of a modern *sepak takraw* ball needs to be developed. The *sepak takraw* ball is one of the most complex sports balls and therefore, the geometry of the ball was simplified using computer aided design (CAD) software (Ahmad, Taha, Tuan Ya, & Hasanuddin, 2012). The model was exported in parasolid format (.x_t) in order to preserve its geometry when the model was exported into ANSYS-CFX software. ANSYS-CFX is a commercial software tool for CFD analysis (ANSYS, 2006). The ANSYS Workbench (provided with ANSYS-CFX) was used to create a new project and consists of five sections, namely Geometry, Meshing, Setup, Solution and Result.

- *Boundary conditions*

The flow was set as 'steady-state and incompressible'. The inlet velocity was set at 3 m/s, which is the same as the wind speed setting used in the wind tunnel. The outlet and wall conditions were configured in the Setup section. The surface of the ball was set as 'non-slip wall condition' whereas the far field wall was set as 'free-slip condition'. The 3-D Reynolds averaged Navier-Stokes equations were selected as the governing equations for the solver whereas the standard k–ε model was selected as the turbulence model (Taha & Sugiyono, 2009). The solution domain is shown in Figure 5.

Table 1: Settings used in the numerical simulation

Parameter	Details
Inlet velocity	3 m/s
Turbulence model	Standard k-ε model
Wall condition	Non-slip wall condition (surface of ball) and free-slip condition (far field wall)
Size of the computational domain	4 m × 1 m × 1 m
Mesh type	Fine mesh with a combination of tetrahedral and hexahedral elements

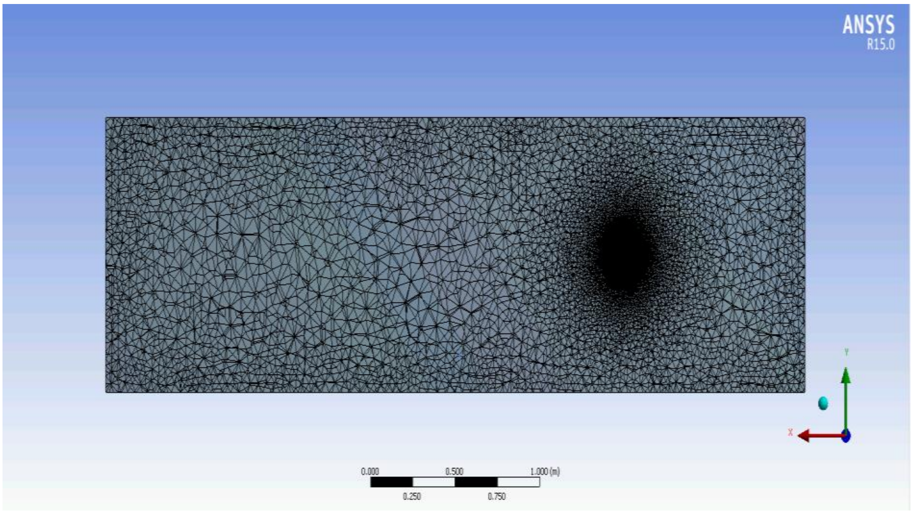


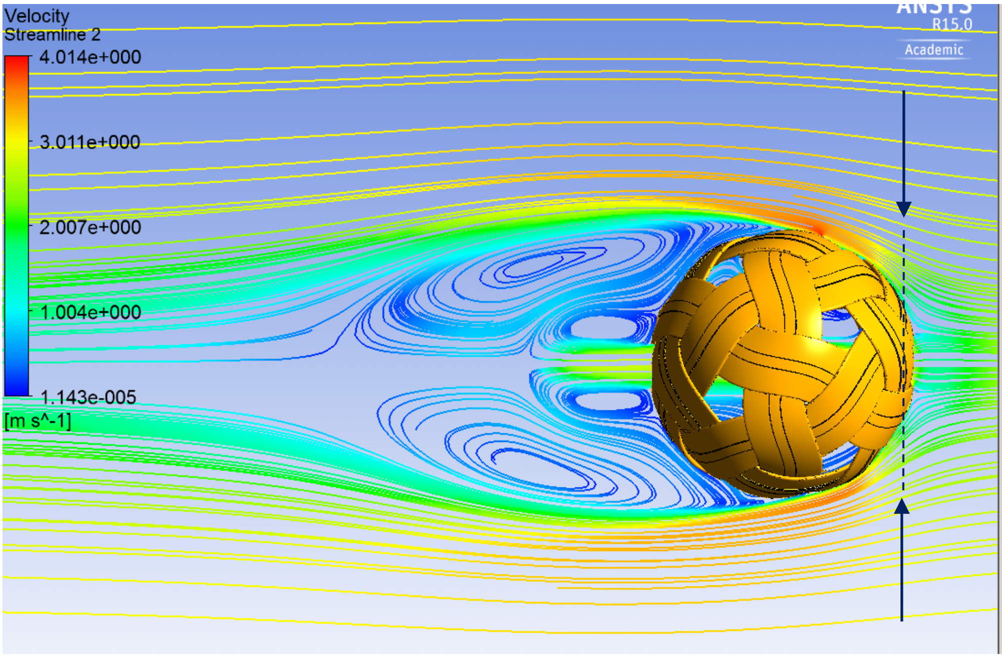
Figure 5: Solution domain of the numerical simulation

Results and Discussion

The videos recorded during the experiments were analysed using video analysis software. The image frames of the flow surrounding the *sepak takraw* ball in the test section were extracted carefully from the videos using this software. It shall be highlighted that the only images extracted from the videos are those where the flow condition appears steady and not too chaotic such that the streaklines are distinguishable. A number of image frames were taken in order to determine the images that elicit the most information on the flow characteristics of the *sepak takraw* ball at a wind speed of 3 m/s.

The image frames were compared with the velocity contours and streamlines obtained from numerical simulations. The points at which the flow separates from the *sepak takraw* ball (i.e. separation points) are evident from Figure 6. It can be seen that the separation points at the upper and lower surfaces lie nearby the equator of the ball, as indicated by the blue arrows and dotted lines. In general, the flow characteristics of the *sepak takraw* ball are similar between the smoke flow visualization experiments and numerical simulations. The flow upstream of the ball is laminar, as indicated by the smooth streaklines and streamlines in Figure 6(a) and Figure 6(b), respectively. However, it can be seen that the laminar boundary layer begins to separate at the separation points, creating a large wake region downstream of the ball. The large wake region observed here is undesirable since it indicates higher drag and lower lift. The drag and lift coefficient values are presented in Table 2. The generation of eddies within the wake region is most evident in Figure 6(b).

(a)



(b)

Figure 6: Flow characteristics of the *sepak takraw* ball obtained from: (a) smoke flow visualization experiment and (b) numerical simulation. Note that the laminar boundary layer separates at points nearby the equator of the ball, as indicated by the blue arrows and dotted lines.

Table 2: Drag and lift coefficients of the *sepak takraw* ball

Parameter	Value
Drag coefficient	0.4868400
Lift coefficient	-0.0130915

The *sepak takraw* ball is observed to be in the subcritical flow regime (i.e. the flow regime before drag crisis) at a wind speed of 3 m/s, as shown in Figure 7. Drag crisis is the flow regime in which there is a significant decrease in the drag coefficient and it occurs at the critical Reynolds number. In general, drag crisis is desirable for sports balls since it delays flow separation, which leads to a decrease in drag – however, such is not the case for the *sepak takraw* ball investigated in this research. Unlike the flow features in Figure 6, it can be seen here that the laminar boundary layer separates at points before the equator of the ball in this flow regime, creating a larger wake region downstream of the ball. More importantly, the flow within the wake region becomes more chaotic due to the holes of the *sepak takraw* ball, which is evident from the generation of eddies aft of the ball. The airflow velocity within proximity of the hole at the centre of the ball is also higher (~ 3.011 m/s), as indicated by the yellow-coloured region in Figure 7(b). In general, the results indicate that there is an increase in drag because of the laminar boundary layer separation as well as the pressure difference between the inner and outer surfaces of the ball created by the air that flows freely through the holes of the ball.

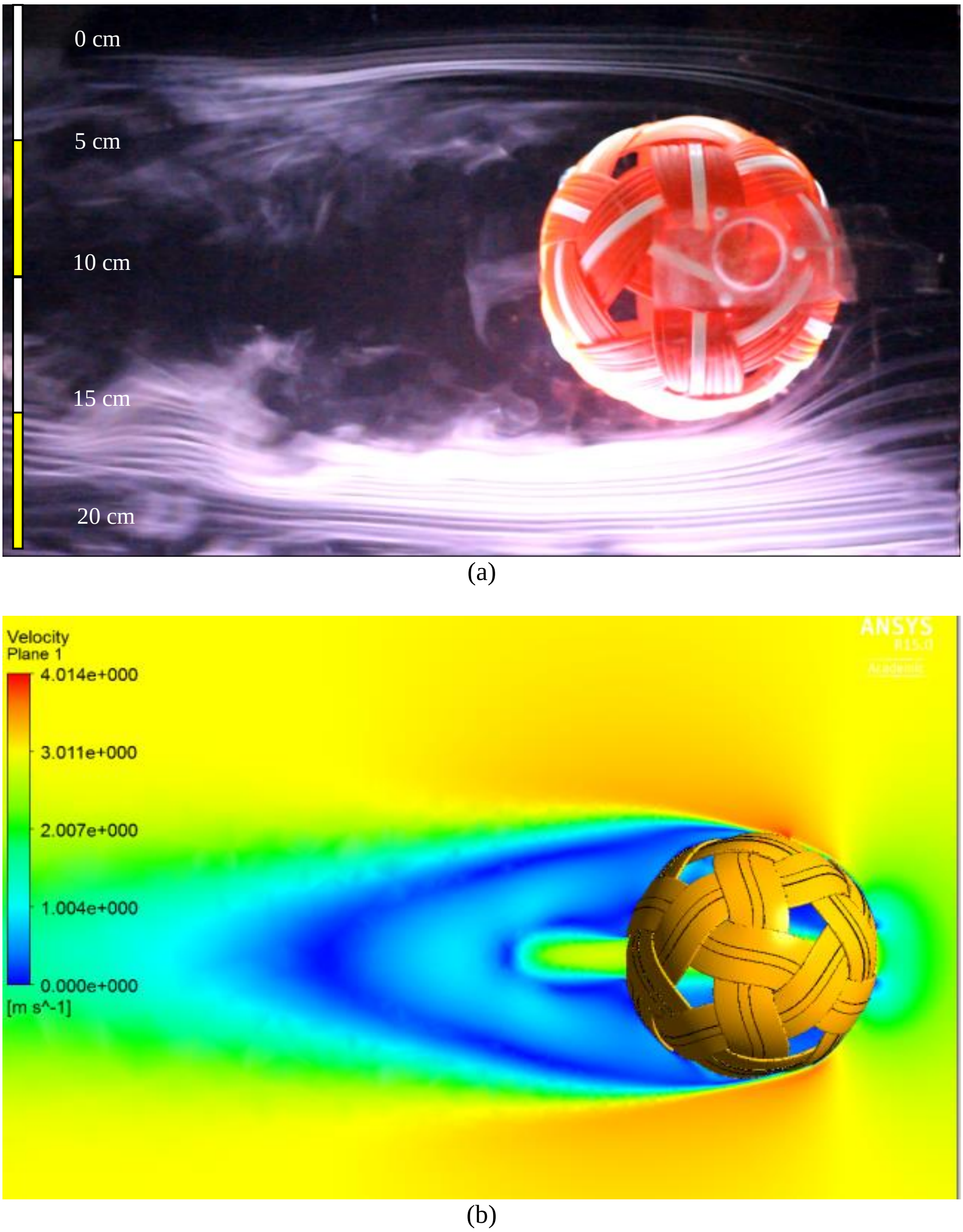
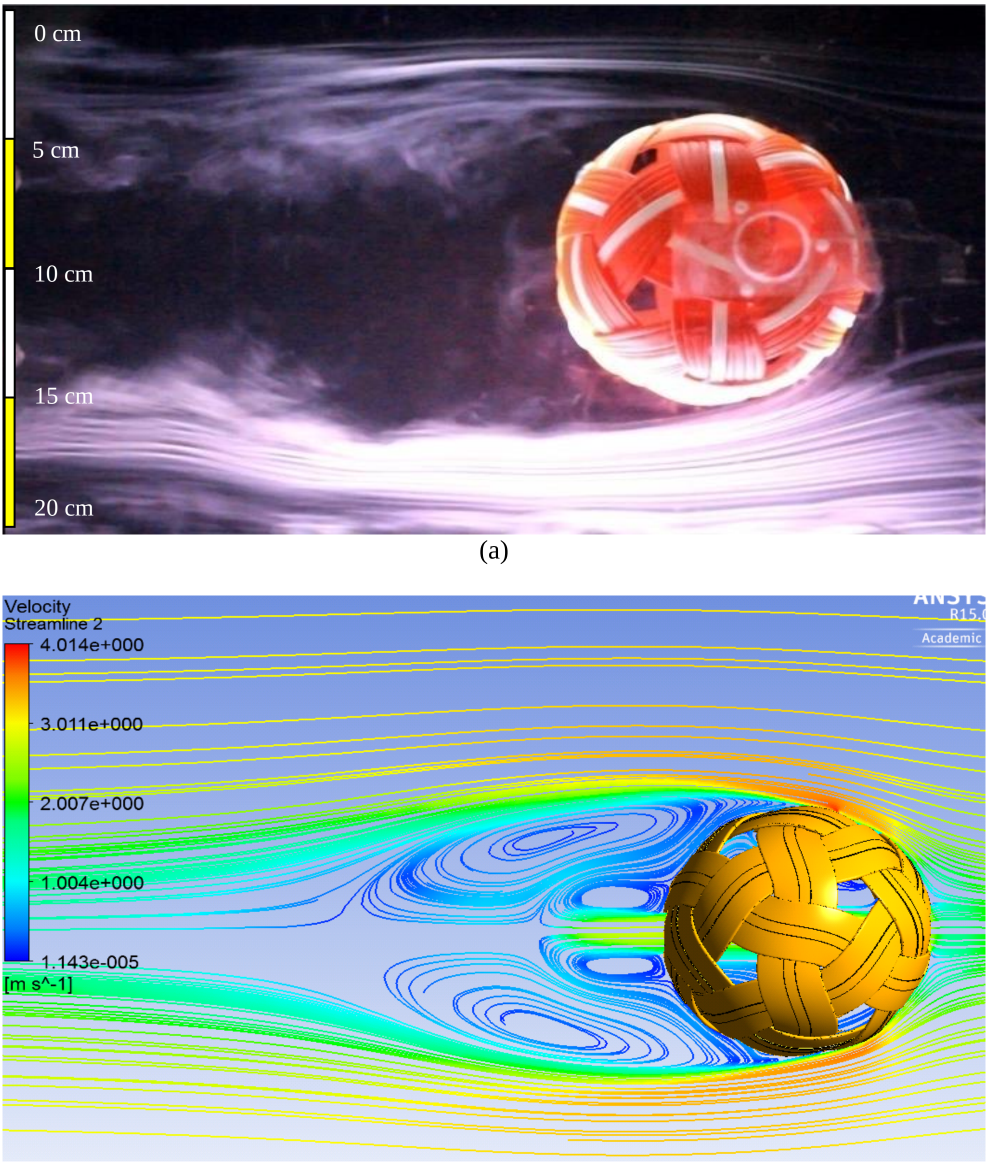


Figure 7: Flow characteristics of the *sepak takraw* ball in the subcritical region obtained from: (a) smoke flow visualization experiment and (b) numerical simulation. Note that the laminar boundary separation occurs at points before the equator of the ball, producing a larger wake region and hence, higher drag. The generation of eddies within proximity of the hole at the centre of the ball (a) corresponds to the higher airflow velocity in this region (b).



(b)

Figure 8: Flow characteristics of the *sepak takraw* ball which show similarities in the generation of eddies behind the ball: (a) smoke flow visualization experiment and (b) numerical simulation

The characteristics of the flow surrounding the *sepak takraw* ball obtained from smoke visualization experiment and its corresponding velocity streamlines are shown in Figure 8. The flow characteristics are similar to those shown in Figure 7, in which the generation of eddies is evident within the vicinity of the hole in the mid-section of the *sepak takraw* ball. Based on the results, it is perceived that the holes of the ball will delay transition from laminar to turbulent boundary layer. This is an undesirable consequence since the flow will separate at a point in front of the equator of the *sepak takraw* ball, resulting in higher drag, which in turn, decreases the speed of the *sepak takraw* ball in flight and reduces the maximum distance travelled by the ball. Hence, there is a need to overcome this drag. This can be done by either increasing the ball speed such that its Reynolds number reaches the critical Reynolds number in which drag crisis occurs or tripping the laminar boundary layer since this will result in a drastic decrease in the drag coefficient.

Conclusion

To date, studies on the aerodynamic characteristics of a *sepak takraw* ball are rather scarce. For this reason, the aerodynamic characteristics of a modern *sepak takraw* ball are investigated in this study by means of smoke flow visualization technique and numerical simulation using CFD. The results of the smoke flow visualization experiments reveal that the *sepak takraw* ball is in the subcritical flow regime (i.e. the regime before drag crisis) at a wind speed of 3 m/s. The results of the numerical simulations show good agreement with those obtained from smoke flow visualization experiments with regards to the location of the flow separation points as well as flow features surrounding the *sepak takraw* ball. It is found that the unique geometry of the *sepak takraw* ball (specifically the weave patterns and holes of the ball) has a significant effect on the aerodynamic characteristics of the *sepak takraw* ball. The flow features observed from the smoke flow visualization experiments are representative of the flow during an actual *sepak takraw* game. However, since the aerodynamic characteristics of the *sepak takraw* ball are investigated only for non-spinning conditions, it is recommended that this study is extended to include the effects of ball spin on both the aerodynamic characteristics and flow features of a *sepak takraw* ball.

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