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Effect of Diameter on the Aerodynamics of Sepaktakraw Balls, A Computational Study

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Abstract. In the game of sepaktakraw the players often use the head to control the ball at high speeds. Recently a new type of ball was introduced which is still made of plastic but impregnated with rubber. The reason for this is to reduce the impact of the ball on the head. However it was found that the new ball was actually causing more headaches to players. Preliminary study found that the new ball travels at higher speeds than the older plain plastic balls. From CFD studies, it was found that the new ball travels at a higher speed because of its smaller diameter. In addition the new ball generates negative lift which will cause the ball to descent at a steeper angle. The effect of the rubber is only to slightly increase the drag forces and slightly reduce the lift.

Keywords: Sepaktakraw, numerical simulation, visualization, wind tunnel

1. Introduction

The performances of balls used in various sports have recently attracted a significant amount of research. This may be due to several reasons. For example, the International Tennis Federation (ITF) is trying to slow down the speed of the ball particularly in the top ranking male player and some women players' games which has become very boring to spectators. An alternative is to reduce the speed of the ball by increasing its size. But the performance is not necessarily affected by its size. A study by Alam et al. [1] showed that a larger diameter ball has a similar drag coefficient as the normal diameter ball. However it has a larger overall drag force due to its larger cross sectional area. Other effects such as seam and fuzz are believed to be dominant. These effects have been studied using Computational Fluid Dynamics methods or CFD in short.

Kim, H [2] investigated the effects of dimple geometry on the flow field around a golf ball using CFD. The results are used to design balls with less drag and longer flight distances. CFD has also been used to study the effect of spinning of a dimpled cylinder in order to get a better understanding of its effect on flow conditions around the ball.

CFD have also been used to study the aerodynamic properties and boundary-layer dynamics of a soccer ball. It has been observed that the boundary layer of a sports ball undergoes a transition from laminar to turbulent flow resulting in the reduction of the drag coefficient. This produces the strange swaying on non-spinning type soccer balls by lateral force fluctuations known as the 'knuckle effect' [3].

The objective of this paper is to use CFD methods to study the difference in behavior of two different types of sepaktakraw balls. Sepaktakraw is a traditional game played in Malaysia and other South East Asian countries using rattan balls. Players typically used their feet and head to control the ball in high speed exchanges between two opposing teams of three players. The game is now played at the international level. The balls have been replaced by plastic balls. Recently plastic balls impregnated with rubber were introduced. However there have been complains about the new balls being faster and are causing headaches to players on impact on their heads.

Measurements using motion analysis software have shown that the new balls are faster than the old balls. In this paper CFD methods are used to investigate the reasons for the faster speed of the new balls.

2. Numerical Method and Calculation

In this paper, the ball when moving in the air is analyzed using numerical simulation. The analysis is performed using a computational fluid dynamics (CFD) code called FLUENT[4]. The analysis involves two steps. Both the steps includes preparing the computational domain and the numerically analysis. The first step is carried out using Gambit which is an integrated pre-processor of FLUENT to create the geometry of the model, to generate the grid system, and to assign the boundary zone. While the second step is carried out using FLUENT in which the numerical model is set up and the solution is computed.

The geometry of the model is built based upon the existing geometry of the ball which is hollow with 12 holes. In order to obtain a numerically acceptable model, a simplified model of the ball was considered as shown in Figure 1. The diameters of the model are of two sizes which are 0.1341 m and 0.1313 m, respectively. Both model of have the same thickness and the same size of each hole.

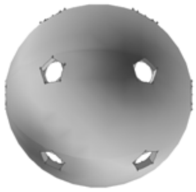

Figure 1 Model of the sepaktakraw ball.

The model of the ball is then placed in the center of a wind tunnel where air is drawn across the model. Two 3–D computational domains for the two different diameters were prepared. Tetrahedral unstructured grids were generated in both the computational domains with the total number of grids of each the domain is approximately 960,000. Actually, the grid systems of both the domains are relatively similar as shown in figure 2. Figure 2a shows the grid distribution on the symmetry plane, while Figure 2b provides a combined isometric view of the grid distribution on both the half surface of the ball and the symmetry plane. It can be seen from figure 2 that the grid density is high around the ball where the flow gradients can be large.

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Each of the computational domain file is imported into FLUENT to be numerically analyzed. FLUENT cannot begin a calculation if any error exists in the grid. Therefore, the grid of each the computational domain is checked to make sure that there is no error. Node smoothing and face swapping on the grid is performed in order to ensure the best possible grid quality for the calculation. In this study, the model of the ball with the diameter of 0.1341m was used to simulate two types of balls, plastic ball and rubber impregnated ball, while the model with a diameter of 0.1313 m was used to simulate only the rubber impregnated ball. Both the plastic ball and the rubber ball were distinguished by the different values of surface roughness.

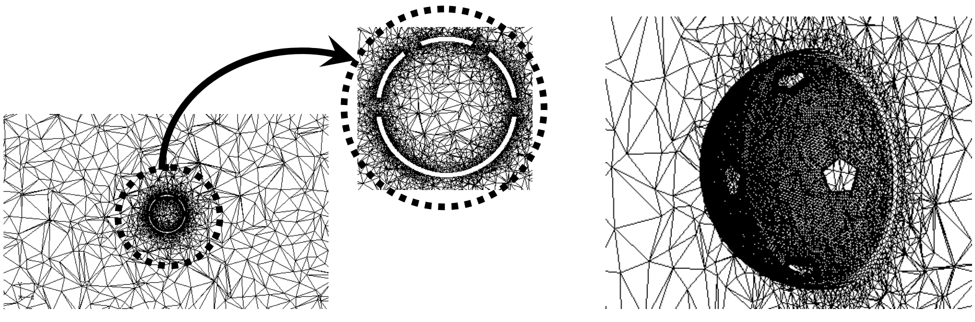

Figure 2a. Figure 2b.

Figure 2 The grid system of the computational domain. **(a)** On the symmetry plane. **(b)** On the half surface of the ball and the symmetry plane.

The numerical model is set up in which the segregated solver is used to solve the governing equations which are the 3–D Reynolds–averaged Navier–Stokes equations with turbulence model using the standard k–ε [2]. The flow is modeled as steady and incompressible. The velocity–inlet and pressure–outlet boundary conditions are used on the upstream and the downstream boundaries, respectively. The non–slip conditions are applied on the entire ball surfaces and on the wall of the wind tunnel. Moreover, the non–equilibrium wall functions are also applied by considering their ability to deal with complex flows involving separation, reattachment, other non–equilibrium effects and strong pressure gradients [5].

Numerical simulations were carried out on all the models at various inlet velocities of 10, 20, 25, 30, and 40 m/s. In order to improve the accuracy of the solution, the second–order upwind scheme was used for the convection terms in the discretized equations. Several iterations have to be performed before a converged solution is obtained. At each iteration, the computed variables was controlled by under-relaxation factors as shown in Table 1. These under-relaxation values are the default values which have been near optimal for largest possible number of cases [5].

Table 1 The under-relaxation factors

Variable	**Under-relaxation factor**
Pressure	0.3
Density	1
Body forces	1
Momentum	0.7
Turbulence kinetic energy	0.8
Turbulence dissipation rate	0.8
Turbulent viscosity	1

During the solution process, the convergence is generally monitored by checking the residuals of the numerically solved governing equations. On the other hand, the residuals are not absolute measures of model convergence. Hence, it is necessary to monitor the convergence behavior of other quantities in order to properly judge the convergence of the computations. In the simulations, the convergence behavior of the drag coefficient and the lift coefficient were also monitored. The threshold for the convergence of the residuals was reduced to five orders of magnitude in order to allow the monitored quantities to converge to consistent values.

3. Results

Table 2 shows the drag coefficients of the sepaktakraw balls. Note that the actual balls are the rubber impregnated ball with diameter 0.1313m and plastic ball of diameter 0.1341m. The rubber impregnated ball with diameter 0.1341m is the existing plastic ball impregnated with rubber but having the same diameter. It can be seen that the drag coefficients of the smaller diameter ball is higher compared to the other balls. Both balls of the same diameter have drag coefficients that are closer to each other. Thus the effect of impregnating seems to be of little significance as compared to the effect of the diameter of the ball.

Table 2 Drag coefficients of sepaktakraw balls at different speeds

Velocity *(m/s)*	**HOLLOW MODEL**		
	Rubber	**Plastic**	**Rubber**
	D = 0.1313 *m*	**D = 0.1341 *m***	**D = 0.1341 *m***
10	**0.799**	**0.783**	**0.789**
20	**0.679**	**0.661**	**0.668**
25	**0.652**	**0.634**	**0.641**
30	**0.633**	**0.615**	**0.622**
40	**0.609**	**0.590**	**0.597**

Table 3 Drag on the sepaktakraw balls at different speeds.

Velocity *(m/s)*	**HOLLOW MODEL**		
	Rubber	**Plastic**	**Rubber**
	D = 0.1313 *m*	**D = 0.1341 *m***	**D = 0.1341 *m***
10	**0.636**	**0.651**	**0.657**
20	**2.162**	**2.199**	**2.224**
25	**3.245**	**3.294**	**3.334**
30	**4.538**	**4.601**	**4.659**
40	**7.753**	**7.849**	**7.953**

Table 3 shows the drag values under various velocities. The smaller diameter ball has the lowest drags at all velocities. This indicates that although the drag coefficients of the smaller diameter ball are higher, the drag forces are smaller. The effect of the rubber only slightly increases the drag values. But the effect of diameter change is more significant.

Tables 4 and 5 shows the coefficient of lifts and lifts of the balls at various velocities. The smaller diameter ball has developed a negative coefficient of lift and lift. Both the plastic and rubber balls of the same diameter shows little difference in the values of the coefficient of lifts and lifts. Clearly the impact of the diameter has significantly altered the flight characteristics of the ball. In this case the negative lift would have contributed to a steeper angle of descent of the smaller diameter ball particularly at higher velocities(figure 3).

Table 4 Coefficient of lifts of sepaktakraw balls

Velocity *(m/s)*	**HOLLOW MODEL**		
	Rubber	**Plastic**	**Rubber**
	D = 0.1313 *m*	**D = 0.1341 *m***	**D = 0.1341 *m***
10	**- 0.003**	**0.002**	**0.002**
20	**- 0.005**	**0.006**	**0.007**
25	**- 0.006**	**0.008**	**0.009**
30	**- 0.007**	**0.009**	**0.010**
40	**- 0.008**	**0.011**	**0.011**

Table 5 Lift of sepaktakraw balls at various velocities

Velocity *(m/s)*	**MODEL HOLLOW**		
	Rubber	**Plastic**	**Rubber**
	D = 0.1313 *m*	**D = 0.1341 *m***	**D = 0.1341 *m***
10	**- 0.003**	**0.002**	**0.002**
20	**- 0.018**	**0.021**	**0.024**
25	**- 0.031**	**0.042**	**0.046**
30	**- 0.049**	**0.070**	**0.072**
40	**- 0.100**	**0.150**	**0.146**

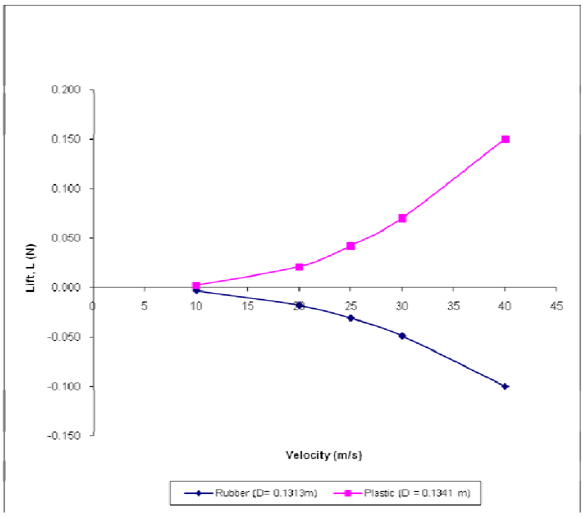

Figure 3. Lift of sepaktakraw balls at various velocities

4. Conclusions

Computer Fluid Dynamics is a powerful means of predicting the characteristics of objects moving past a fluid. In this paper, CFD was used to compare the characteristics of sepaktakraw balls having different diameters and made of two different materials. It can be concluded that the effect of embedding rubber in sepaktakraw balls of the same diameter only slightly increases the drag. The greatest impact is the diameter of the ball where a reduction in diameter decreases the drag and generated a negative lift. The negative lift is higher at higher velocities resulting in a steeper descent angle.

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