AERODYNAMIC CHARACTERISTICS ON A RUGBY FOOTBALL

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. INTRODUCTION

Rugby players have understood spinning the ball around its longitudinal axis gives it more flight distances in a touch- kick and a long pass. Moreover, the spinning pass is easier to catch because of the stability resulting from the gyro effect during the flight. Though aerodynamic loads on an American football were measured by Rae (Rae 2002), there is no aerodynamic data for a rugby football.

We have measured aerodynamic forces on a spinning rugby football as well as those of a non-spinning ball by the wind tunnel tests for the purpose of a more efficient flight.

METHOD

A full size model of a rugby football was employed to mount in a low-speed wind tunnel that had a rectangular nozzle of 1.5 m × 1.0 m at Department of Aeronautics and Astronautics, Tokai University, Japan. The model was the real rugby football (Gilbert Triple Crown, Size:5) with a spinning axis of stainless steel inserted along the longitudinal axis, and urethane foam surrounded spinning axis. The spinning mechanism was composed of a motor (AXUD90A, Oriental Motor), a couple of pulleys, a rope, ball bearings and the spinning axis as shown in Figure 1. The feature of the motor was to have the flat torque for all spin rates. The spinning direction was counterclockwise around the longitudinal axis from the front view. The airfoil cover (NACA0020) is also shown below the ball. The motor, struts, the pulley and the rope were surrounded with the airfoil cover in order to prevent the flow disturbance produced by them.

Figure 1: Rugby football with the spinning mechanism. The airfoil cover (NACA0020) is also shown below the ball.

The definition of characteristic parameters is shown in Figure 2. The upper schematic is the side view, and the lower one is the front view. The wind direction is shown by U. The drag, the lift and the side force are denoted by D, L and S, respectively. The angle of attack, which is the angle between the longitudinal axis of the ball and the direction of the flight path, is done by α, and the seam angle is done by β. Though α was varied in a horizontal plane by changing the yaw angle of the platform in practice, the angle of attack α was defined by converting the axis.

Experimental conditions were as follows. The wind speed was set at 15 and 30 m·s⁻¹ for the non-spinning case, and 15, 20, 25 and 30 m·s⁻¹ for the spinning case. The spin rate of a ball was varied from 0 to 4.7 revolutions per second (r.p.s). The angle of attack α was varied from 0 to 90° for the non-spinning case, and 0 to 40° for the spinning case. In the non-spinning case, the seam angle β was also varied from 0 to 360°. Six aerodynamic forces, which were the drag, the lift, the side force, the rolling moment, the pitching moment and the yawing moment, were measured by six-component platform balances. They were acquired with a personal computer with the aid of a 12 bit A/D converter board (PCI-3120, Interface). Since the board had A/D converters for every channel, simultaneous conversion for all channels was possible.

Figure 3 is the back view of our experimental set-up at α=0°.
RESULTS AND DISCUSSION

Time Variation Data
Time variations of volt data of the side force S are shown in Figure 4 as an example. The broken line denotes the raw data, and the solid line does the moving average data of the raw data. This is the spinning cases at 1.6 r.p.s, the wind is 30 m·s⁻¹, and the angle of attack $\alpha$ is 30°. The raw data were measured for 20 seconds. It is clearly seen that the raw data is oscillating at a certain frequency. The frequency for this case is 1.6 Hz, which coincides with the spin rate. This oscillation seems likely to be caused by the lack uniformity of mass distribution of the ball. This can be seen from the video analysis. When the seam goes up against the gravity, the spin rate is smaller, and vice versa. Since the weight of the seam is heavier than other parts, the spike appears in the raw data once per a revolution. In what follows, therefore, the moving average data will be considered as a time variation data to remove the oscillation from the raw data.

Figure 4: Time variations of volt of the side force, S $\alpha=30^\circ$, $\beta=180^\circ$, 1.6 r.p.s and U=30 m·s⁻¹.

Figure 5 shows time variations of volt of the side force, S. The spin rate is taken as a parameter, r.p.s=0.6, 1.6, 2.4, 3.5 and 4.7, respectively. $\alpha=30^\circ$, $\beta=180^\circ$ and U=30 m·s⁻¹. It is seen that the mean value depends on the spin rate. Moreover, the amplitude of the time variation for smaller spin rates is bigger than that of higher spin rates. In other words, the time variation of S for higher spin rates is more stable. It might be easier for players to catch the spinning ball because there is less chance of changing the trajectory of the ball during the flight (time variation of S is stable).

Figure 5: Time variations of voltage of the side force, S. The spin rate is taken as a parameter, r.p.s=0.6, 1.6, 2.4, 3.5 and 4.7, respectively at $\alpha=30^\circ$, $\beta=180^\circ$ and U=30 m·s⁻¹.

Time variations of voltage of the side force S for the non-spinning case is shown in Figure 6. The angle of attack $\alpha$ is taken as a parameter, $\alpha=0$, 30, 60, 62 and 90°, respectively. $\beta=180^\circ$ and the wind speed U is 30 m·s⁻¹.

Figure 6: Time variations of volt of the side force, S. The angle of attack $\alpha$ is taken as a parameter, $\alpha=0$, 30, 60, 62 and 90°, respectively. $\beta=180^\circ$ and U=30 m·s⁻¹.

In the case of $\beta=180^\circ$, it is impossible to see the seam from the front view for all the angle of attacks except for $\alpha=0^\circ$. It is also seen that the mean value depends on the angle of attack $\alpha$. The mean value decreases with the increase of $\alpha$. 

Figure 3: A back view of the experimental set-up.
until $\alpha = 30^\circ$, and then increases up to $\alpha = 90^\circ$. The side force $S$ is greatly affected by the angle of attack as well as the spin rate. It, however, should be noted that the absolute values are one order larger than those in Figure 5 except for $\alpha = 0^\circ$. The time variation becomes more unstable with the increase of $\alpha$ until $\alpha = 62^\circ$. The amplitude is tremendously big at $\alpha = 62^\circ$. Though the amplitude becomes small over $\alpha = 62^\circ$, the time variation is still unstable at $\alpha = 90^\circ$. It seems that there are some intermittent periodic phenomena in the side force. Accordingly, the wavelet transform is applied for the time variation of volt of $S$ at $\alpha = 90^\circ$, $\beta = 180^\circ$ and $U = 30 \text{ m} \cdot \text{s}^{-1}$ as shown in Figure 7.

**Figure 7:** Wavelet transform for volt data of the side force at $\alpha = 90^\circ$, $\beta = 180^\circ$ and $U = 30 \text{ m} \cdot \text{s}^{-1}$.

The abscissa is time, the ordinate is $1/\text{scale}$, and the height is shown by contours. The ordinate, $1/\text{scale}$, corresponds to the frequency. The French hat is applied as a mother function of the wavelet transform. There are a couple of peaks at lower values of $1/\text{scale}$ (lower frequency) around 5.0, 11.3 and 14.7 seconds, which are corresponding to troughs at $\alpha = 90^\circ$ in Figure 6. It, moreover, is found that there are some peaks at 30 of $1/\text{scale}$ from 4 to 8 seconds, and at 25 of $1/\text{scale}$ from 8.5 to 10.5 seconds, respectively, though peaks are not so clear because of the lower height. The result of the wavelet transform implies that the high frequency phenomena also appear intermittently as well as the low frequency phenomena. The flow pattern around the ball should be changing with the time. In order to make clear the higher frequencies, the short term Fourier transform is applied for the time variation of volt of $S$ as shown in Figure 8. The solid line denotes the result from 4 to 8 seconds, and the broken line does the result from 8.5 to 10.5 seconds.

The drag coefficient $C_D$ in Figure 9 is the time averaged data for 20 seconds. The aerodynamic forces acting on the airfoil cover is subtracted from the total forces acting on the ball and the cover. The spin rate is taken as a parameter. The seam angle $\beta$ is $90^\circ$ at 0 r.p.s. It is seen that $C_D$ increases with the increase of $\alpha$ for all spin rates. There is a little difference between the data of the spinning ball (0.6 & 4.7 r.p.s.) and those of the non-spinning ball (0 r.p.s.). The drag coefficient of the non-spinning ball is smaller than that of the spinning ball.

**Average Aerodynamic Forces**

The drag coefficient $C_D$ with respect to the angle of attack $\alpha$ is shown in Figure 9. The definition of $C_D$ is the drag divided by the dynamic pressure and the cross-sectional area of the axial midplane as expressed by (1).

$$C_D = \frac{D}{\frac{1}{2} \rho U^2 A} \quad (1)$$

Here, $\rho$ denotes the density of air, and $A$ does the cross-sectional area of the axial midplane. Since the radius of the axial midplane is 0.0955m, $A$ is equal to 0.0287m$^2$.

**Figure 8:** The result of Short Term Fourier Transform for volt data of the side force at $\alpha = 90^\circ$, $\beta = 180^\circ$ and $U = 30 \text{ m} \cdot \text{s}^{-1}$. The solid line denotes the result from 4 to 8 seconds, and the broken line does the result from 8.5 to 10.5 seconds.

The drag coefficient $C_D$ in Figure 9 is the time averaged data for 20 seconds. The aerodynamic forces acting on the airfoil cover is subtracted from the total forces acting on the ball and the cover. The spin rate is taken as a parameter. The spin rate is taken as a parameter, 0, 0.6 and 4.7 r.p.s.) and those of the non-spinning ball (0 r.p.s.). The drag coefficient of the non-spinning ball is smaller than that of the spinning ball.

**Figure 9:** Drag coefficient $C_D$ as a function of the angle of attack $\alpha$. The spin rate is taken as a parameter, 0, 0.6 and 4.7 r.p.s.

The side force coefficient $C_S$ at $\alpha = 0$ and $30^\circ$ with respect to the spin rate is shown in Figure 10. The side force
coefficient $C_S$ is defined as a same manner with $C_D$. Though the side force coefficient $C_S$ is affected by the seam angle $\beta$ in the case of 0 r.p.s, Figure 10 shows the result at $\beta=180^\circ$ as an typical example. Error bars are also shown. It is seen that $C_S$ at $\alpha=0^\circ$ is almost independent of the spin rate, and its value becomes 0. This is because there is no chance that the Magnus force acts on the ball at $\alpha=0^\circ$. On the other hand, $C_S$ at $\alpha=30^\circ$ decreases steeply from 0 to 2.4 r.p.s, and then it slightly decreases with the increase of the spin rate. This decrease could be explained by the Magnus effect. The range of the error bar increases with the decrease of the spin rate, because $C_S$ depends on the wind speed $U$ especially for the smaller spin rates.

Figure 10: Side force coefficient $C_S$ with error bars as a function of the spin rate at $\alpha=0$ and $30^\circ$.

**SUMMARY**

Aerodynamic forces acting on a spinning rugby football as well as those of a non-spinning ball rugby football were measured by the wind tunnel tests. The key findings can be summarized as follows.

1. The side force fluctuates with the time. The amplitude of the time variation of the side force decreases with the increase of the spin rate. The time variation of the side force is more stable in the case of the higher spin rates.
2. In the case of a non-spinning ball, the amplitude of the time variation of the side force increases with the increase of the angle of attack until a certain angle of attack. There are some intermittent periodic phenomena in the side force. It seems that the flow pattern varies with the time.
3. There is a little drag difference between the data of the spinning ball and those of the non-spinning ball.
4. The side force coefficient is independent of the spin rate at the angle of attack $=0^\circ$, and its value becomes 0.
5. The side force coefficient decreases with the increase of the spin rate at the angle of attack $=30^\circ$. This decrease could be explained the Magnus effect produced by the spin.

**REFERENCES**


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