The influence of golf ball dimples on aerodynamic characteristics

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Abstract

Aerodynamic forces act on a golf ball during flight. For that purpose in order to develop a golf ball with high performance, it is important to analyze aerodynamic characteristics of the golf ball. On the other hand, dimple pattern of a golf ball is complicate and the influence of dimples hasn’t been investigated in detail. Therefore the influence of golf ball dimples on aerodynamic characteristics was investigated using a wind tunnel and rotating device. Some golf balls whose dimples have different depths were measured. As a result, it was found that the shallower the dimple was, the larger the lift coefficient was. However, when the depth of the dimples was much shallower, the lift coefficient was extremely little on the slow velocity, i.e. under 30m/s. When the golf ball trajectory which was launched with a driver was calculated under various initial conditions, the ball velocity became under 30 m/s over the vertex of the trajectory in many cases, including professional male golfers and female golfers. Therefore, if the lift coefficient of the velocity of 30m/s becomes smaller, distances will become shorter. Dimple patterns that had a high lift coefficient at all velocities was researched. As a result, it was found that a golf ball with a dimple pattern that has extremely small dimples between large shallow dimples has a high lift coefficient at all velocities, including under 30m/s. In order to investigate the cause of the results, a flow visualization experiment was conducted. Visualization of flow around a golf ball was conducted by generating smoke. Moreover pictures of flow were taken by high-speed video and analyzed by PIV (Particle Image Velocimetry). As a result, there was the difference in the streamline distribution between golf balls.

Keywords: aerodynamics; wind tunnel; golf ball; PIV

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1. Introduction

The largest flight-distance of a golf ball reached 300m by a driver, and the golf ball flew for 6 seconds. During flight, aerodynamic forces act on the golf ball. Mizota and Naruo (2002) developed a wind tunnel and a ball-rotating device that provides flow velocity and spin to the golf balls that match actual flight conditions. The golf ball velocity and spin rate were changed variously and the aerodynamic force coefficients $C_D$, $C_L$, and $C_M$ were measured under many conditions. As a result, aerodynamic force coefficients were dependent on Reynolds Number $Re$ changes, and could be put in order only by spin rate parameters $S_P$.

On the other hand, a golf ball has many hollows in the surface, called dimples. The arrangement of the dimples, structure, size, depth and form are various. Although it is said that influence for the aerodynamic forces characteristic is large, there is no research and not many reports. Sajima etc. (2006) considered the influence of the depth using CFD. In the study, the influence of dimples was systematized and investigated using the wind tunnel and the ball-rotation device. Consequently, it was found that the influence of the depth of the dimples was large, and the shallower it was made, the more the lift coefficient went up and it gained a high trajectory.

Furthermore, when it was made shallow exceeding a certain threshold, it became clear that the lift coefficient declined greatly in the low-speed region of 30 m/s or less. As a result of the trajectory analysis, on the condition of a male pro golfer, a female pro golfer or an ordinary male amateur with a driver, the golf ball velocity becomes 30m/s or less when the golf ball flies in the second half of the trajectory which passes the vertex. Thereby, if a lift coefficient declines greatly in the low-speed region of 30 or less m/s, flight-distance will become shorter. A dimple design which realizes an antithesis that does not have the fall of a lift coefficient in a low-speed range but has high lift coefficient in a high-speed range of 30m/s or more is desired.

2. Wind tunnel test methods

With the ball-rotation device installed into the wind tunnel wind, high-speed rotation of the golf ball was carried out, and aerodynamic forces were measured by the three-dimensional load cell arranged under the ball-rotation device. In order to rotate a golf ball, a miniature bearing is placed in the golf ball.

In order for the tension of piano wires to prevent miniature bearing damage, it lets the thin inner tube pass inside the shaft. The piano wires which let the golf ball pass are attached to a frame so that a golf ball may be arranged in the center of the frame, as shown in Fig.1. High-speed rotation is carried out by blowing against a golf ball with jet air. By measuring the number of revolutions within a wind tunnel flow, the aerodynamic force coefficients corresponding to the spin rate parameter (circumference against flow peripheral velocity) which changes one after another was measured.

As shown in Fig.2, in order to maintain a dynamic balance, a set bolt was put into surface of golf ball from three directions, and respective positions were adjusted. By this adjustment, even if it rotated at the high speed of 200
rps, it became measurable without vibration. There were six kinds of flow velocities of the wind tunnel, 44 m/s, 40 m/s, 35 m/s, 30 m/s, 28 m/s, and 25 m/s. In a constant flow velocity, aerodynamic forces were measured continuously when the number of revolutions was set at 200 rps and decreased after that.

3. Influence of dimple on aerodynamic forces

3.1. Influence of dimple depth

The golf balls for the study are shown in Table 1. Dimple shape and the arrangement of Golf Ball A and Golf Ball B are the same, and only the depth is different. The lift coefficient obtained from the wind tunnel test is shown in Fig.3.

| Number of dimples | Diameter of large dimples (mm) | Depth of large dimples (mm) |
|-------------------|-------------------------------|-----------------------------|
| Golf Ball A       | 366                           | 4.27                        | 0.158                        |
| Golf Ball B       | 366                           | 4.27                        | 0.123                        |

Fig. 3. Results of wind tunnel experiment

Fig. 4. Results of trajectory analysis (a) Trajectory (upper); (b) Velocity (lower)
In a flow velocity of 35 m/s or more, there is almost no difference between some flow velocities, i.e. the Reynolds number. Also, Golf Ball B with a shallow dimple has a larger lift coefficient throughout the spin parameter compared to Golf Ball A. However, when it becomes less than 30 m/s, although flow velocity dependences have not appeared in Golf Ball A, they have appeared in Golf Ball B significantly.

Trajectories of Golf Ball A and Golf Ball B were analyzed based on Mizota and Naruo (2002 and 2004). The typical data of the driver shot of male professional golfer was used for the initial condition immediately after impact of the golf ball. The trajectory analysis result is shown in Fig.4. It was also found that in cases of even male pro golfers, ball velocity becomes less than 30 m/s soon after the golf ball passes over the vertex. Therefore, it turns out that aerodynamic characteristics of the velocity of less than 30 m/s, is important. Comparing Golf Ball A and Golf Ball B, Golf Ball B with a higher lift coefficient at 30 m/s or more has a higher trajectory after impact, but after passing the vertex, ball velocity becomes less than 30 m/s and the golf ball falls rapidly. In order to lengthen flight-distance, it was discovered that the lift coefficient of less than 30 m/s is important.

3.2. Effect of tiny dimples

In our other study, it turned out that lift coefficients raise when the depth of dimples is shallow, the number of dimples is lessened, dimples are enlarged, or the share of dimples on all surface is lessened. Also, velocity dependency appears in the low-speed region of 30 m/s or less, and a lift coefficient falls.

In order to lose the fall of a lift coefficient in a low-velocity range, realizing high lift coefficients on high-speed conditions, tiny dimples are arranged between large dimples. The dimple arrangement is shown in Fig. 5(a). In order to compare the aerodynamic characteristics, the golf ball which lost only tiny dimples was also created. (Fig. 5 (b)) The specifications of the dimple are shown in Table 2. The lift coefficient obtained from the wind tunnel test of two golf balls is shown in Fig.6. Although, the fall of a lift coefficient clearly appears on the low condition of 30 m/s; as for Golf Ball D, the fall in the case of Golf Ball C almost does not appear.

Flight trajectory analyses for both golf balls were conducted under the same conditions as Capture 3-1. The result is shown in Fig.7. The difference in height after passing the vertex mentioned above appeared significantly, and flight-distance of Golf Ball C became larger compared to Golf Ball D.

\[ \text{(a) Golf Ball C} \quad \text{(b) Golf Ball D} \]

\text{Fig. 5. Golf balls for study}

| Table 2. Golf balls for study |
|-------------------------------|
|                              | Number of dimples | Diameter of large dimples (mm) | Depth of large dimples (mm) | Diameter of tiny dimples (mm) | Depth of tiny dimples (mm) |
| Golf Ball C                  | 278 & 252         | 4.81                           | 0.148                        | 1.24                           | 0.191                       |
| Golf Ball D                  | 278               | 4.81                           | 0.148                        | —                              | —                           |
4. Visualization Experiment

4.1. Fuming device

In order to investigate how differences of dimples affect a flow, a visualization experiment was conducted, and peeling point and status of wake flows were observed. For gas visualization methods, although there were smoke wire methods, spark tracing methods, suspension methods, etc., where a ball is rotated, smoke wire methods were adopted because of easy experiment.

However conventional smoke wire methods could be used at a wind velocity of 0.02~10 [m/s]. (Kim, 2012) Then, the device to allow enough smoke to flow at a fast velocity was developed by stretching a wire in the upstream of the flow. Piano wire was stretched on the frame of a cuboid, and some stainless wires were stretched between the piano wires. As liquid paraffin sank into a knit lump of stainless wires, it was able to be made to a full fume, so that a visualization experiment was able to be performed while also in the airflow of the wind velocity of 40 m/s. The frame, i.e. the fuming device, was installed in the wind tunnel.

4.2. Visualization Experiment Method and Result

The visualization experiment was conducted on Golf Ball E and Golf Ball C by flow velocities of 25 m/s, 28 m/s, 30 m/s, and 40 m/s. Golf Ball E is a ball with which the lift coefficient declines greatly by less than 30 m/s, like Golf Ball B. A similar ball-rotating device as Capture 2 was used. A high velocity revolution was carried out with the air jet, and the number of revolutions to decrease was measured with a tachometer. Smoke was generated at the number of revolutions set to $S_P = 0.1$ and $S_P = 0.2$, respectively, and took a photograph of 20,000 frames per second using high-speed video (Fastcam SA5 made by PHOTORON). The example of the photoed image is
shown in Fig.8. In the case of 40 m/s, it was confirmed that the flow was greatly bent downward in the downstream. In the case of 25 m/s, there was a low level of downstream turn that can be understood as a difference in lift. In ball comparison, a change in the direction of flow in the downstream of Golf Ball E appeared from moment to moment at the low velocity. A change almost did not appear in the case of Golf Ball C.

Particle Imaging Velocimetry (PIV) was conducted using Image Tracker (made by DEJIMO). For a certain period of time (3ms), 60 frames were taken out, and streamline distribution was analyzed. Directions of the flow mentioned above can be conformed clearly. Moreover, in order to examine a change, some 60-frame sets were taken out and analyzed in the same experiment. Although Golf Ball C is carrying out almost the same streamline distribution as the case of the 60 frames, it turns out that the streamline distribution changes in the case of Golf Ball E. This change makes the flow unstable and it is thought that it makes the lift lower.

(a) 25m/s, $S_p = 0.1$  
(b) 40m/s, $S_p = 0.2$

![Streamline distribution](image)

**Fig. 8. Streamline distribution**

5. Consideration

As a result of the wind tunnel experiment results, in a high flow velocity of 35 m/s or more, a golf ball with shallower dimples has a higher lift coefficient. However, when exceeding a threshold, if it becomes too shallow, a lift coefficient will decline greatly at the low speed of less than 30 m/s, and the Reynolds number dependents will appear. The same effect as when making a shallow dimple is seen by enlarging the dimple and lessening the number. By arranging tiny dimples in the crevices between large dimples, it is able to keep a high lift coefficient. In particular, also in the low speeds of less than 30 m/s, it hardly changes, and a lift coefficient of the Reynolds number dependence is almost not shown.

By the smoke wire method using the steel wires arranged in the upper stream of the flow, it succeeded in flow visualizations to 40 m/s. PIV was carried out analyzing the visualized high-speed video. As a result, the difference in flow velocity and the difference between golf balls showed differences in the streamline distribution. In the golf ball to which a lift coefficient declines greatly in a low-speed range, there is momentarily a change of the streamline distribution and it was found that it is unstable.

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