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Experiment of aerodynamic force on a rotating soccer ball

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Abstract

The purpose of this study was to measure the aerodynamic force acting upon a soccer ball spun in a wind-tunnel test. In particular, we prepared two types of spinning soccer balls (air and motor types), measured the aerodynamic force on each, and examined the validity of the measurement method. In the case of the air-type spinning ball, the ball was made to spin by applying compressed air from an air compressor via an air duster. In the case of the motor-type spinning ball, a motor was placed at the middle inside the ball, and the ball was then automatically spun. First, both the air- and motor-type spinning balls demonstrated very strong spin-parameter (*Sp*) dependence with respect to drag during spinning. In addition, the side-force coefficient showed signs of linear increase as *Sp* increased in the motor-type spinning ball, whereas it increased along a slight curve in the air-type spinning ball. In particular, a negative Magnus effect was observed in the motor-type spinning ball when the Reynolds number was approximately 2.0×10^5 and *Sp* was approximately 0.14 (-0.007) and when the Reynolds number was approximately 2.2×10^5 and *Sp* was approximately 0.13 (-0.005).

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Keywords: Aerodynamics; Ball; Soccer; Trajectory

1. Introduction

A number of studies have been conducted in recent years on the aerodynamic and flight characteristics of soccer balls due to changes in the form of the ball panels [1-7]. However, these studies were mainly concerned on the aerodynamic characteristics of fixed non-spinning soccer balls and did not elucidate the aerodynamic characteristics of curving or otherwise spinning soccer balls most often used in soccer matches. The major reasons for this deficiency are the extreme difficulty in spinning balls and the fact that obtaining precise data from the influence of auxiliary tools (wires and frames) needed to provide spin is believed to be difficult. However, kicking a non-spinning ball during a soccer match [8,9], including balls demonstrating a knuckling effect [10-12], is actually an extremely difficult technique and very infrequently occurs. In other words, most soccer balls in flight spin in various directions, and we believe that the fundamental state of a ball flying during an actual match is spinning. Therefore, in this study, we prepared two types of spinning soccer balls (air and motor types) to measure the aerodynamic forces on a soccer ball in the wind tunnel and examined the aerodynamic characteristics of the spinning soccer balls from the obtained aerodynamic force data. In addition, by comparing the aerodynamic force on the two types of spinning soccer balls used in the tests, we examined the validity of each measurement model.

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2. Methods

2.1. Wind-tunnel test

In this test, we used a closed-circuit, low-speed, and low-turbulence wind tunnel in the University of Tsukuba, Japan (Fig. 1). The maximum wind speed was 55 m/s, the blow-off size was 1.5 m × 1.5 m, the wind-speed distribution was within ±0.5%, and the turbulence was 0.1% or less. The test was performed by mounting four types of soccer balls in this wind tunnel as test subjects. In addition, the force acting on the soccer balls was measured by a sting-type six-component force detector (LMC-61256, Nissho Electric Works). The data obtained from the test were recorded by a computer via an A/D conversion board.

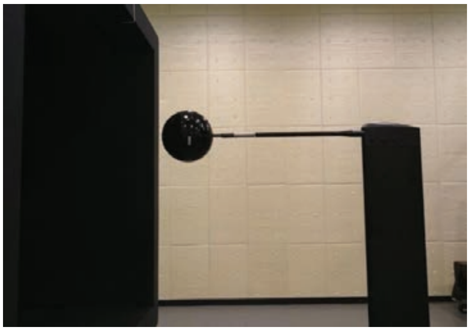

Fig. 1. Wind-tunnel test setup.

In this test, the drag coefficient (C_D) and side-force coefficient (C_S) were obtained from the measured aerodynamic force [Equations (1) and (2)]. In addition, the spin parameter (*Sp*) was used for the dimensionless relationship between the spin and speed.

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

$$Cs = \frac{2S}{\rho U^2 A} \quad (2)$$

Here, ρ is the air density (ρ = 1.2 kg/m^3). U is the flow rate (in meters per second). A is the projected area (in square meters) of the soccer ball.

$$Sp = \omega R / U \quad (3)$$

Sp indicates the ratio of the flow rate to the spin speed, ω indicates the angular speed, R indicates the ball radius, and U indicates the flow rate.

In this study, two types of balls were used in the test: air- and motor-type balls (Fig. 2).

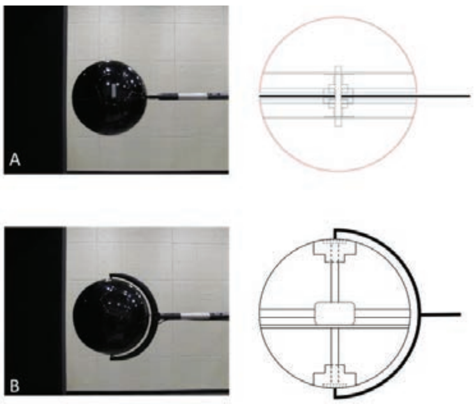

Fig. 2. Setup of the spinning soccer ball used in this test. (a) Air-model design drawing. (b) Motor-model design drawing.