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Aerodynamics of modern soccer balls

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Abstract

The scope of this article is to find out what are the differences between four modern soccer balls and find out how these differences influences the flight path of the ball in a free kick. Experiments have been carried out in static and spinning conditions and drag and side forces have been acquired. The results from the wind tunnel experiments have been implemented in a Matlab routine and a free kick simulation using the different balls has been made. The effect of the different balls on the flight path has been calculated. Major differences between the different soccer balls have been found.

Keywords: football; aerodynamics; drag;

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1. Introduction

Spheres have been extensively studied from the aero dynamical point of view. Studies regarding balls have been mostly focused on baseball and golf balls, where the flight characteristics of the ball have been interpreted using the lift and drag data acquired ([5], [6], [11], [12], [18], [12], [21])

A closer look on tennis balls aerodynamics has been given by Stepanek [20] while some other authors focused their research on the ball surface roughness [10], [12], [19].

However, despite soccer being the most common sport in the world [13] soccer balls have been only recently studied from the aerodynamic point of view. ([7], [8], [9], [4], [3]).

Considering that in the 1998 FIFA World Cup 21% of the 171 goals scored were from free kicks [15], the free kick shot is one of the most interesting game situations to study.

In the past, some bizarre ball trajectories have been seen in free kick and it has been proved that the aerodynamic characteristics of the ball can sensibly influence its trajectory [3]. One of the most known examples is the free kick shot by Roberto Carlos in the confederations cup in France 1997 [2] which Asai [3] suggested to interpretate as a consequence of the reverse Magnus effect [18].

In the past years, the major sport brands such Nike, Puma and Adidas have put a remarkable effort in order to improve soccer ball qualities such as roundness, improved friction when kicking, low water absorption. A big effort has been put also in improving the aerodynamic properties of the balls by adding roughness to the ball surface. The

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results presented by Asai [3] show a remarkable difference in aerodynamic properties between 3 Adidas soccer balls: Adidas Fevernova, Adidas Roteiro and Adidas Teamgeist.

The present article compares four different soccer balls (Adidas Terrapass, Adidas Terrapass replica, Puma v1.08, Nike T90 omni epl showing the differences in terms of drag and side force parameters and thus the effect of each ball on a simulated free kick

2. Methods

2.1. Experimental setup

Wind tunnel: the experiments have been carried out in the NTNU (Norwegian University of Science and Technology) wind tunnel in Trondheim. The test section of the wind tunnel is 12.5m long, 1.8m high and 2.7m wide. The maximum reachable speed is ca. 30 m/s.

Force balance. The balance (Carl Schenck AG) used is a six component balance capable to measure the three forces and the three momentums around the three axes. Variations of forces and moments are measured using strain gauges glued to the balance body. The voltage outputs are acquired with a USB acquiring card produced by National Instruments.

Two channels have been used, one for the drag and one for the speed. The acquiring rate was set to 300Hz and 5 samples of 5seconds each were taken per each sample and each speed.

Static model: The static model has been used to estimate the drag of the ball without rotation (fig 1.a). The model is shown in figure 1a. The ball glued to the support and the support was mounted on the back of the ball, in the recirculation area, to avoid any interference with the flow. The support has been shielded.

Rotational model: The spinning model (fig 1.b) was used to acquire the drag and side force while the ball was spinning. The ball was connected to a support connected to a electrical motor. The rotation speed could be adjusted.

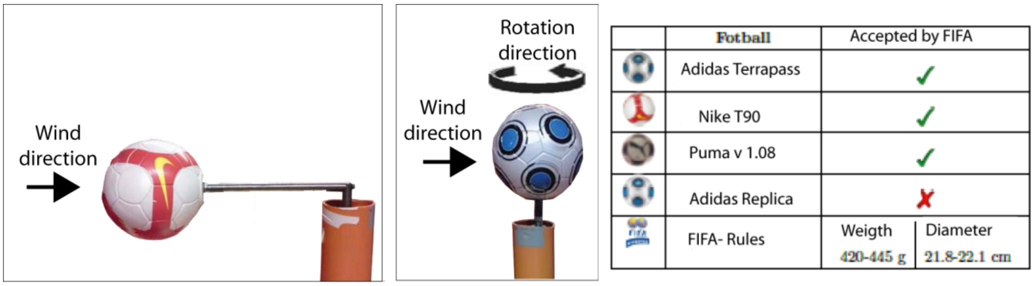
2.2. Balls

Adidas Terrapass matchball: this matchball uses the so called “power balance” technology for an optimal roundness shape. The Terrapass ball features the PSC-Texture, a fine structure on the ball's outer skin which has been created to allow a better ball control to the players. The cover is thermally-bonded seamless surface made with 16panels

Nike T90 Omni EPL matchball: The Nike Omni Ball features a micro-grooved PU casing which has been designed to reduce drag, resulting in more consistent flight. The design of the panel geometry incorporates hexagons and pentagons designed in order to obtain a more spherical shape and evenly distribute pressure all around the ball

Puma v.1.08 matchball: this matchball is made with 24-panel design in order to reduce the internal radii variance and improve the roundness. A dimple outer casing is made to reduce drag.

Adidas Terrapass replica: this ball is the replica version of the Terrapass ball



	Fotball	Accepted by FIFA	
	Adidas Terrapass	✓	
	Nike T90	✓	
	Puma v 1.08	✓	
	Adidas Replica	✗	
	FIFA- Rules	Weigth 420-445 g	Diameter 21.8-22.1 cm

Fig. 1. (a) Static model (b) Spinning model (c) List of the fottballs tested

3. Tests

In order to be able to simulate the flight path of a football, the aerodynamic forces are needed. These have been acquired by placing the balls in the wind tunnel and connecting them to a force balance with a support.

In the static test the drag has been acquired. Per each speed five measurements were taken and averaged.

Defining the drag coefficient c_d as

$$c_d = \frac{2F_D}{\rho v^2 A} \tag{1}$$

Where F_s [N] is the side force, ρ [Kg/m^3] is the density of the air, A [m^2] is the frontal area and v [m/s] is the wind speed.

The air density used was the reference density for standard atmosphere at 15ºC : 1.225kg/m^3.

And the Reynolds number as:

$$\mathrm{Re} = \frac{2\rho v r}{\mu} \tag{2}$$

Where ρ [kg/m^3] is the density of the air, v [m/s] is the wind speed, r [m] is the ball radius and μ [kg/m $\cdot$ s] is the dynamic viscosity of the air.

Drag has been acquired at eight different Re and c_d-Re curve were plot (fig. 2)

In general, soccer balls are kicked with spin. This lead to the fact that the ball, during its flight, will experience either side or lift forces, depending on the spinning direction. A deeper look at the forces caused by the spin and thus a wind tunnel test with a spinning ball was needed,

In the test with spinning ball drag and side force were acquired at 4 different Reynolds number (corresponding to four different speed:12m/, 17m/s, 22m/s, 26m/s) and at four different spinning speeds for a total number of sixteen measurements.

Defining the side force coefficient as:

$$c_s = \frac{2F_s}{\rho v^2 A} \tag{3}$$

Where F_s [N] is the side force, ρ [Kg/m^3] is the density of the air, A [m^2] and v is the wind speed [m/S],

Defining the spinning parameter as:

$$S_p = \frac{\omega r}{v} \tag{4}$$

Where ω [rad/s] is the rotational speed of the ball, r[m] is the radius of the ball and v[m/s] is the wind speed.

Four different curves c_s-S_p, each of them at four Re were plot (fig. 3). In each plot the data relative to the 4 balls were plotted in order to be able to compare the performances of the different balls.

4. Results

4.1. Static test

The drag for all the footballs tested was in a range between 0.5N and 3.8N for a wind speed range from 6m/s to 26m/s. The balls showed to have different behaviors in terms of drag.

Previous studies ([1], [2]) showed that the drag is related to the surface roughness present on the balls.

A consistent difference between the soccer balls has been found and the results are shown in fig. 2. The Re_{crit} for the different balls was $\sim 2.0 \cdot 10^5$ for the Adidas Terrapass, $\sim 1.5 \cdot 10^5$ for Nike T90 and Adidas Replica and $\sim 1.2 \cdot 10^5$ for the Puma V1.08. A comparison between the balls shows that the Puma v.1.08 has much lower drag at low speed but, for higher Reynolds number, it becomes the ball with the highest c_d , on the other hand, the Adidas Terrapass showed the highest Re_{crit}. This mean that for Re>2*10^6, the Terrapass is the ball with the highest drag.

Surprisingly, and higher speeds, the ball with lower drag is resulted to be the Adidas Terrapass Replica which is the cheap mass produced version of the Adidas Terrapass. This ball does not have the “pimpled” surface like the Terrapass and it has not been approved by FIFA.

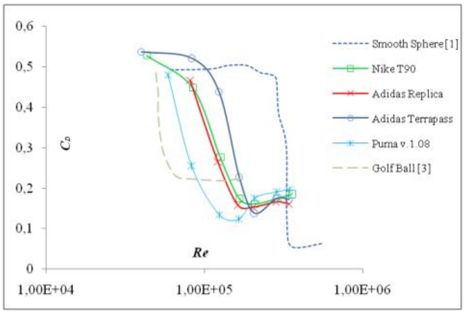


Fig. 2 - c_d-Re curve for the stationary ball

4.2. Spinning test

The test with the spinning ball showed some interesting results. A correlation between the drag acquired and the c_s is noticeable. The puma ball is the ball with the highest side force coefficient (c_s) at any speed and any rotation parameter S_p. This lead to the fact that, if kicked with spin, the Puma ball will curve its trajectory more than the other balls tested. The ball with lowest c_s is the Terrapass.

For a Re=154333 and Sp<0,25, a reverse Magnus effect is noticeable for the Terrapass and the Nike T90 ball while the sign of the side force coefficient is always positive for the replica ball and the Puma.

The reverse Magnus effect could then occur towards the end of the flight which would give an unpredictable trajectory to the ball.

The reverse Magnus effect occurs when, in the region of the critical Re, the two sides of the ball are in different flow regimes: the advancing side in supercritical regime with turbulent separation, and the retreating side in subcritical regime with laminar separation. [18]

This would result in a negative Magnus force, since the turbulent boundary layer on the advancing side will now separate later compared to the laminar boundary layer on the retreating side.

Comparing figure 2 and figure 3 it can be seen that, the ball with the lowest Re_{crit}, has the highest side force coefficient while the ball with the highest Re_{crit}, has the lowest side force coefficient.

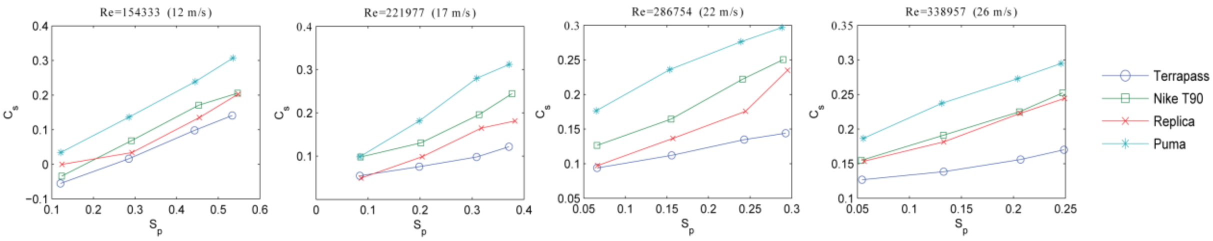


Fig. 3 - c_s-S_p curves for different *Re*.

Figure 4 shows how the spinning parameter influences the side force coefficient for the Puma v.1.08 ball. The same trend has been found for all the other balls.

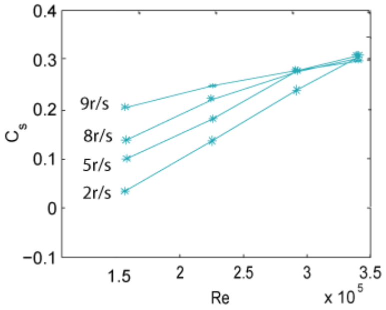


Fig. 4 - cs-Re for the Puma v.1.08 ball. When increasing the spinning speed, cs increases.

As expected and as predicted from the Magnus theory [16], increasing the spinning coefficient, the side force coefficient increases too.

4.3. Simulation

A numerical simulation has been done in order to estimate the trajectory of the different balls if kicked in a free kick with the same initial conditions.

Defining kd=ρAcd/2m and ks=ρAcs/2m [9] the equations of the motion can be written and solved numerically using a Runge-Kutta iteration routine.

In order to solve the equations, the initial conditions were given: vx0, vy0, vz0, x0, y0, z0 , and the constants m, A, g and R.

Where m [kg] is the ball mass, A [m²] is the frontal area of the ball, g is the gravity force and r [m] is the radius of the ball.

For the parameters cd and cs, the measurements from the wind tunnel test have been used.

The initial conditions (fig. 5) were set to be v0=25m/s ψ=19º, θ=19º, γ=60º and a spinning speed of 5r/s

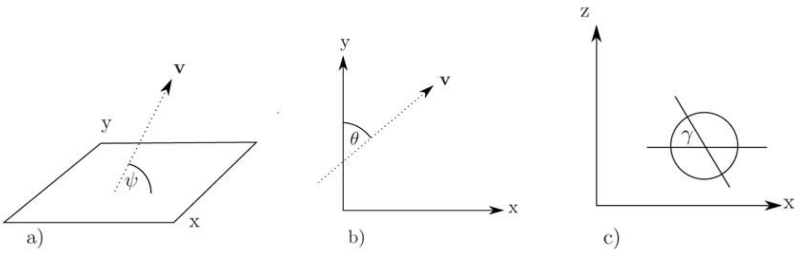


Fig. 5 - Angles used of the simulation (a) Definition of the ψ angle (b) Definition of θ angle (c) Definition of γ angle.

The plot in figure 6 shows that the Puma v.108 ball (dotted cyan line) resulted to be the ball with the most curved flight path while the Adidas Terrapass is the ball that has a flight trajectory closer to a straight flight path.

However, due to the higher side force coefficient, the puma ball resulted to be the ball which is able to cover the lowest distance.

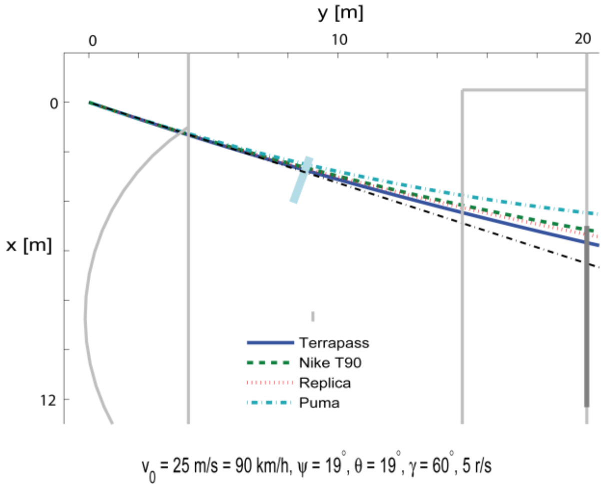


Fig. 6 – simulated trajectory for the 4 different balls tested. The dotted black line represents a straight line

5. Conclusions

All the balls tested resulted to have different aerodynamics characteristics due to their difference surface structure.

Surface structure (dimples, different panels shape, different number of panels, different seaming) resulted to affect the performances of the balls.

The dimples present of the Puma ball resulted to be efficient in order to shift the Re_{crit} at low Re and increase the side force coefficient. On the other hand, the excrescences present on the Adidas Terrapass surface resulted to have a different effect in the ball trajectory, keeping the ball trajectory almost in a straight line even if kicked with high spin.

A reverse Magnus effect for low spin parameters has been found from the tests on the Terrapass ball. This could influence the ball trajectory.

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