# AERODYNAMIC INVESTIGATION OF SELECTED VOLLEYBALL BALLS

Piotr **STRZELCZYK**, Zygmunt **SZCZERBA**

*Department of Fluid Mechanics and Aerodynamics, Faculty of Mechanical Engineering and Aeronautics, Rzeszów University of Technology*

**Key words:**
- Volleyball,
- Balls,
- Wind tunel.

**Abstract:**
The paper presents results of measurements of aerodynamic drag of three selected balls designed for volleyball. Tests has been conducted in the aerodynamic tunnel TA-1000 at Department of Thermodynamics and Fluid Mechanics of Rzeszów University of Technology. The subject of tests were original balls with different structure of surface (e.g. roughness). Balls were placed in the open test section of the wind tunnel, and attached to the one component aerodynamic balance with *1000 mm* in diameter. The velocity during tests was changed in the range *5…40 m/s* which covers practical range of velocities of volleyball. The results has been presented in the form of plots of drag coefficient versus Reynolds number. The results show significant discrepancy between real balls and smooth sphere. The critical Reynolds number for balls is much smaller than in the case of smooth sphere. Besides it, balls differ each other in the critical range of Reynolds number. The fact may result in different shape of descending part of trajectory of ball. A special attention was paid on unsteadiness of drag force due to vortex shedding.

## 1. INTRODUCTION

Aerodynamic drag strongly influences trajectory of the sport balls. Therefore aerodynamic properties of the balls are interesting both from the sport and engineering point of view [6]. The main effort was concentrated on golf [3] and tennis [2] or football balls [5],[6] aerodynamics. First known work concerning of characteristics of sport ball has been published by Davies [3]. In Poland, investigations of volleyball aerodynamics and ballistics, known to the authors of the paper, has been found in the archive of CWKS "Resovia" volleyball coach Jan Strzelczyk [9] Some sample calculations for ball with an without drag has been presented at Fig. 1 and 2. The aim of his work was optimisation serve technique.

He has also observed a significant differences between aeroballistic performance of new and used ball. A new ball, made form lacquered leather, had weaker ballistic performance in comparison with used one with rough structure of surface. The explanation was influence of surface roughness on earlier tubulisation of boundary layer in case of used (rough) ball. This resulted in later separation of boundary layer, an in consequence, in lower pressure drag, in comparison with new one. This led to greater range of rough ball in comparison with smooth one at the same initial conditions: velocity, height of serve and elevation angle.

The similar effect of aerodynamic drag reduction may be caused by dimples in case of golf ball [6], or hairs on the surface of tennis ball [2]. This observations inspired authors of the present paper to compare aerodynamic characteristics of several contemporary volleyballs.

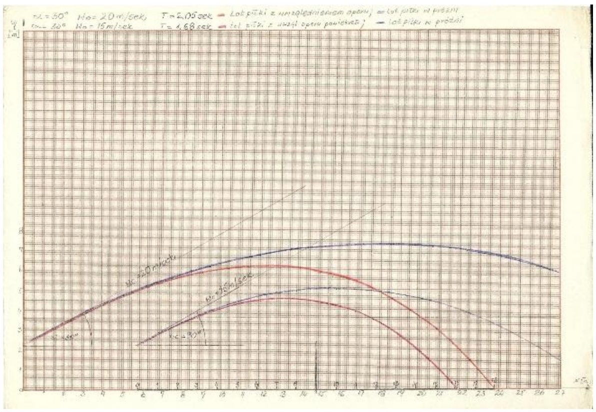

**Fig. 1.** Ball trajectories in vacuum and in the air, blue: in vacuum, red: in the air Plot by J. Strzelczyk

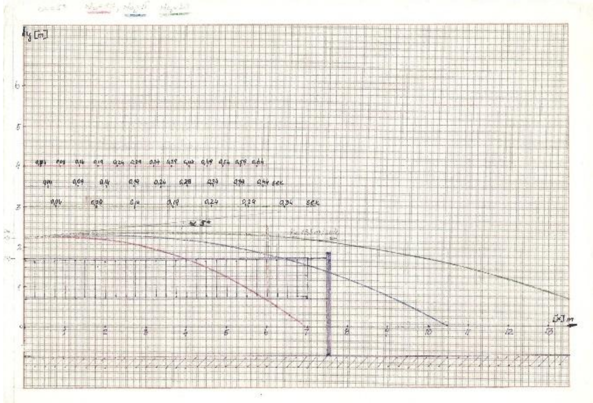

**Fig. 2.** An approach to optimisation of volleyball serve by J. Strzelczyk [9]

## 2. EXPERIMENTAL SETUP

The tests were conducted in a low-speed wind tunnel of Department of Fluid Mechanics and Aerodynamics of Rzeszów University of Technology. The tunnel has open test section with *1000 mm* in diameter and *1700 mm* long. The test section is enclosed in the so-called Eiffel chamber with volume *27 m*$^3$. The contraction ratio of nozzle is *1:9*. Maximum flow velocity in the test section is *50 m/s*. Tunnel is powered by one-stage axial fan with *90 kW* direct current electric motor. The tunnel has been schematically depicted at Fig. 3. Detailed description of the tunnel may be found in [10, 11].

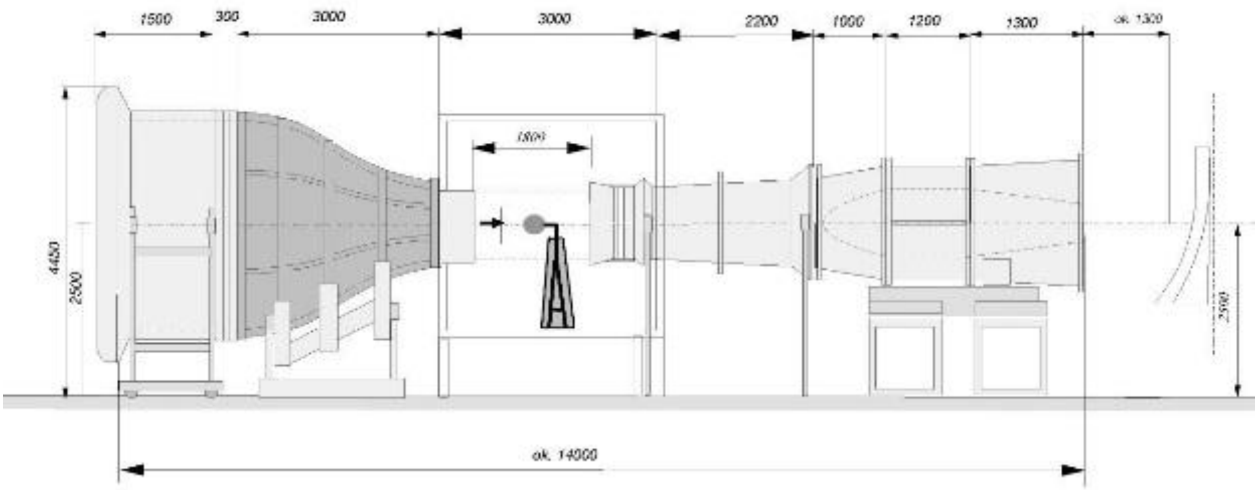


**Fig. 3.** General view of TA-1000 wind tunnel


**Fig. 4.** Tested balls

The subjects of tests were three volleyballs denoted as A, B, C which differed significantly in roughness of surface. The smoothest is ball A (glued) and the most rough is ball C (stitched). Balls were attached by silicone glue to plate with rod connected to a one-component strain gauge aerodynamic balance. Balance was connected to the strain-gauge measurement card DaqBook DBK-16. Inflow velocity, and static pressure in a test chamber was measured by Prandtl-type probe connected to two channel electronic manometer. Experimental data like: drag force, dynamic pressure, static pressure, humidity, temperature were collected employing DaqLab 2004 interface controlled by DasyLab software. During the experiment an on-line Fourier analysis was conducted to investigate unsteady component of drag.

## 3. RESULTS

Measurements of the drag force has been conducted for the velocities ranging from *7…40 m/s (25…144 km/h)* which covers values expected during competitions. The blockage of test section by tested ball was as small as *4,4%* of the cross-section area. Results of experiments are presented at Figs. 5…9.

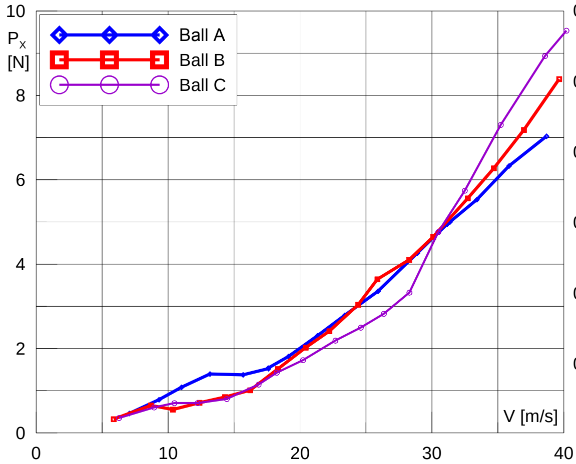


**Fig. 5.** Relationship between velocity and aerodynamic drag for three balls

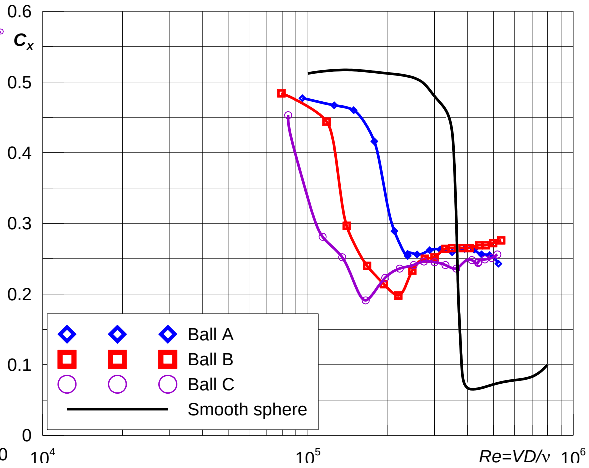


**Fig. 6.** Relationship between drag coefficient and Reynolds number for three balls compared with smooth sphere

At Fig. 5. one may observe plateau of drag curve for smooth ball A, between *12…17 m/s.* Increasing of roughness leads to the reduction of drag for velocities under *30 m/s (108km/h)* For velocities over *30 m/s* rough balls show higher values of drag. The drag characteristics in non-dimensional form have been shown Fig. 6., showing the dependence between drag coefficient $C_X$:

$$C_x = \frac{2P_x}{\rho V^2 S} \qquad (1)$$

and the Reynolds number:

$$Re = \frac{VD}{\nu} \qquad (2)$$

where: $\rho$ is density of air $V$ –is velocity, is a reference surface, ν –is a kinematic viscosity of air and $S=\pi D^2/4$ In our case: $D=0{,}204\ m$ is a diameter of ball. The critical Reynolds number in all cases is much smaller in comparison with a smooth sphere. This is typical for another types of sport balls [5, 7]. Note that in supercritical range of Re ball have much higher values then sphere.

Another interesting behaviour of ball is its dependence of drag on time. Measurements has been conducted with temporal resolution of $2\cdot10^{-4}$ *s* with $N_p=4092$ points per sample. The example of time series from measurements for ball A are presented at Fig. 7. One may see unsteadiness of drag force in time.

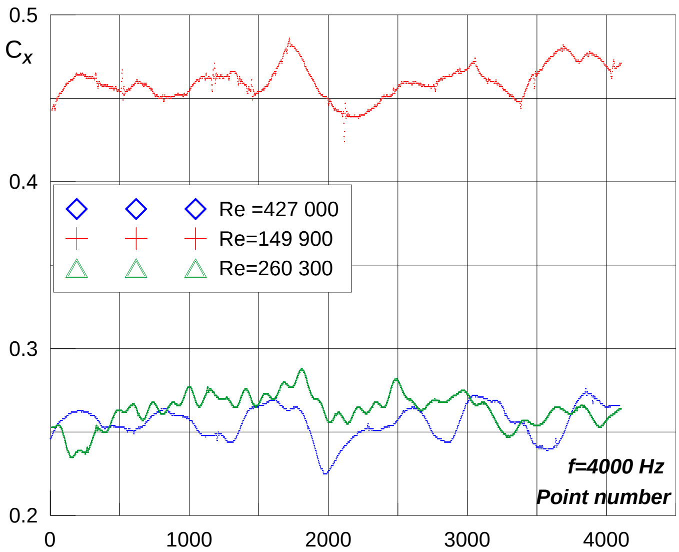


**Fig. 7.** Unsteadiness of a ball drag coefficient

The phenomenon is associated with random vortex shedding form the downwind part of ball, an is similar to that of reported in [7]. The process is stochastic with short periods of poliharmonic oscillations. Especially high amplitude if oscillations appeared for lower range of velocities up to *15 m/s* which corresponds with drag crisis (see: Figs. 5 and 6).

For the periods of poliharmonic oscillations a frequencies corresponding to the maximum amplitude has been determined. The results are shown at Figs. 8 and 9. Unlike in case of smooth spheres [1, 8] one may observe a severe scatter of the data. This is mainly due to complex form of ball surface (seams between of gores) in comparison with sphere with no surface disturbances.

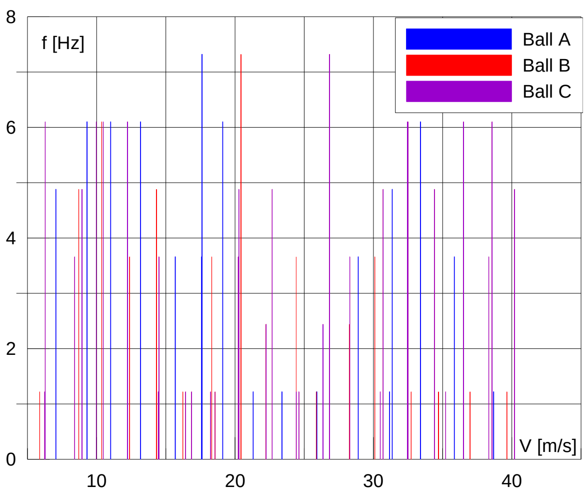


**Fig. 8.** Frequencies corresponding to the maximum amplitudes as a function of velocity

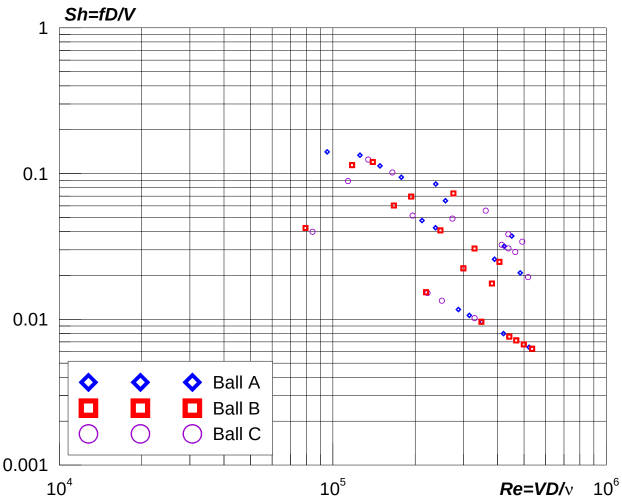


**Fig. 9.** Non-dimensional frequency (Strouhal number) as a function of Reynolds number

## 4. CONCLUSIONS AND FINAL REMARKS

In the paper a results of aerodynamic drag of three different balls has been presented. The balls have different surface facture (roughness). All balls showed a lower critical Reynolds number in comparison with smooth sphere. This behaviour is typical for sport balls [2, 5, 6, 7]. Increase of roughness of ball surface leads to decrease of aerodynamic drag of ball for subcritical range of Reynolds number (velocities) and decreases value of critical *Re* number. For supercritical range of *Re* $(Re>385\,000)$ drag is always greater than in case of smooth sphere. In this range an increase of roughness results in the increase of drag. This may have a significant influence on the trajectory of ball. At high speed range (serve) high roughness will affect on rapid deceleration of ball, whereas at lower speed range (at descending part of trajectory) it will result in lower deceleration ratio then in case of a smooth ball. Time characteristics of drag showed its unsteady, stochastic behaviour, which is a result of vortex shedding in the leeward side of ball. The effect is stronger for the range of small velocities, and may result in "chaotic" behaviour of ball [7] in the descending part of trajectory. To obtain a complete picture of behaviour, a time dependent measurements of side and lift force for non-rotating ball would be desired.

## REFERENCES


1. Bakić V., Perić M., *Visualization Of Flow Around Sphere For Reynolds Numbers Between 22 000 And 400 000 Thermophysics and Aeromechanics, 2005, Vol. 12, No. 3 pp. 307-315*
2. Cooke, A.J. *"An Overview of Tennis Ball Aerodynamics," Sports Engineering, 3 (2) 2000* pp. 123 - 129.
3. Davies J. M., *The Aerodynamics of Golf Balls, J. Appl. Phys.* 20, 821 (1949)
4. Karamanev D. G., Nikolov L. N., *Free Rising Spheres Do Not Obey Newton's Law for Free Settling, AIChE Journal,* Nov. 1992, Vol. 38 No. 11, pp. 1843-1848
5. Kensrud J. R., Determining *Aerodynamic Properties Of Sports Balls In Situ*, MSc Thesis, Washington State University, Pullman 2010
6. Mehta R.D., *"Aerodynamics of Sports Balls," Annual Review of Fluid Mechanics, 17 (1985),* pp. 151-189.
7. Mizota T. et al, *The strange flight behaviour of slowly spinning soccer balls*, *Scientific Reports* 3, 1871; (2013) DOI:10.1038/srep01871 pp. 1-7;
8. Sakamoto H. , Haniu H., *A Study of Vortex Shedding From Spheres In A Uniform Flow, Transactions of the ASME,* Vol. 112 Dec. 1990 pp. 386-392
9. Strzelczyk J., Unpublished materials from private archive, 1984.
10. Strzelczyk P., *Tunel aerodynamiczny do badania śmigieł,* Journal of Aeronautica *Integra 1/2006 (1) str. 69-73; (in Polish)*
11. Węsierski Ł., P. Strzelczyk P., Szczerba Z., *Tunel aerodynamiczny do badania śmigieł i turbin wiatrowych, Pneumatyka, nr1 (62) 2007 str. 52-55 (in Polish)*