Free Flight Aerodynamics of Sports Balls

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Acousto-Scan
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Introduction

Many sports make use of balls whose flight characteristics are often important to the playing of the sport. In particular, golf, tennis and soccer use spherical balls of various surface roughness. Their free flight aerodynamics will be dependent on the speeds they achieve during play and the interaction of the ball with the air through which they move.
Most studies of the subject have examined the aerodynamic properties of fixed balls in wind tunnels, rather than of balls in free flight. In free fight aerodynamic perturbations such as those produced by vortex shedding are fairly unpredictable and have much greater effect due to the balls' interaction with them.

Measurements

In this study I have measured the kinematics of several sports balls dropped without spin through an air column – a 27 m stairwell of cross section 3 by 3 m. A radar speed gun downloading at 33 Hz to a notebook computer was used to track the fall velocities from above. The computer software collected the data and processed it – low order Butterworth filtering to smooth the data and determination of instantaneous accelerations. The raw data before filtering was also available.
Examples of the speed versus time relationships of four sports balls – those of golf, soccer, tennis and squash – are shown in Fig 1.

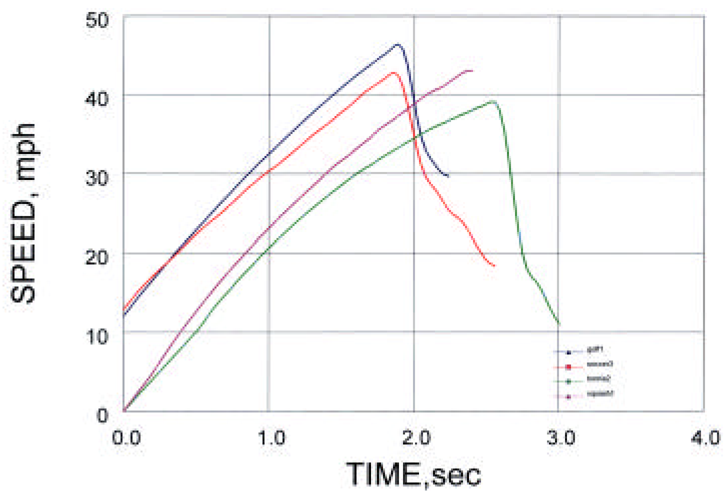

Fig 1 Speed of drops of golf, soccer, tennis and squash balls

The graphs show the increase of speed due to gravity – the curvatures from linearity being due to aerodynamic drag. There is a bounce at the bottom of the drop – not shown as instantaneous due to the filtering of the data.

Analysis

The theory of a rigid sphere moving with respect to a viscous fluid (air) has been exhaustively treated by Auchenbach (1974). The phenomenon may be described generally by a relationship between C_D, the drag coefficient, and Re, the Reynolds Number, describing the speed of the sphere.

Here the following definitions apply -

$$C_D = D / 0.5 \rho u^2 A$$

Where D is the drag force, ρ is the density of air, 1.21 kg/m^2, u is the velocity of the ball relative to the fluid, and A the cross-sectional area,
And

$$Re = \rho \, d \, u / \eta$$

Where d is the ball diameter and η the viscosity of the fluid, 1.81E-5 Poise for air.

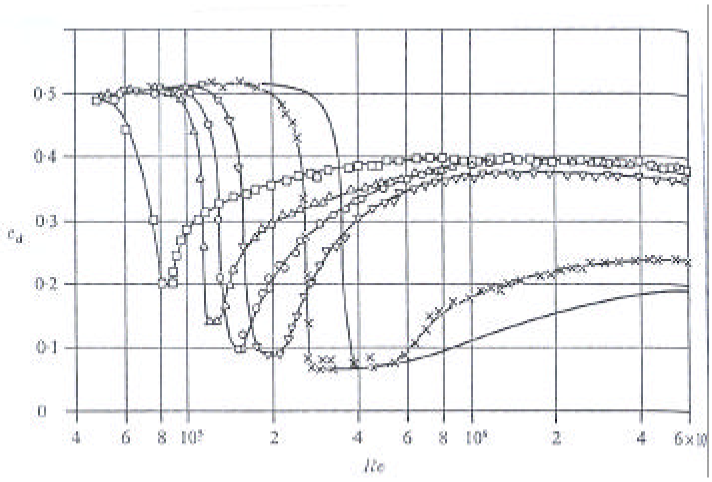

Fig 2 Auchenbach's (1974) aerodynamic drag curves for spheres of different roughness; k/d = 0, 25, 150, 250, 500, 1250 E-5, increasing to the left

Fig 2 shows the relationships between C_D and Re for spheres of various roughness. Roughness is defined by the parameter k/d, k being the diameter of a roughness sphere attached to the surface of the ball.
The graph shows that there is a speed transition zone (Reynolds Number range) where the drag coefficient falls as the air flow past the ball changes from laminar to turbulent. The speeds at which this zone exists fall with increasing roughness.

Results

The data obtained from the measurements of the falling sports balls may be graphed in a manner similar to Achenbach as shown in Fig 3 – 6.

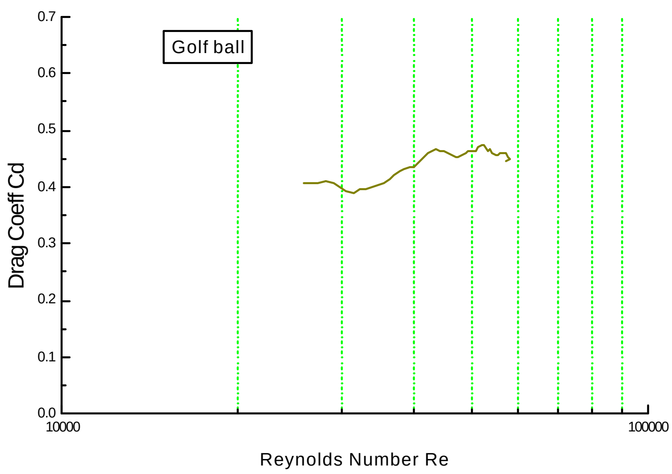

Fig 3 Determined Drag Coefficient of the falling golf ball

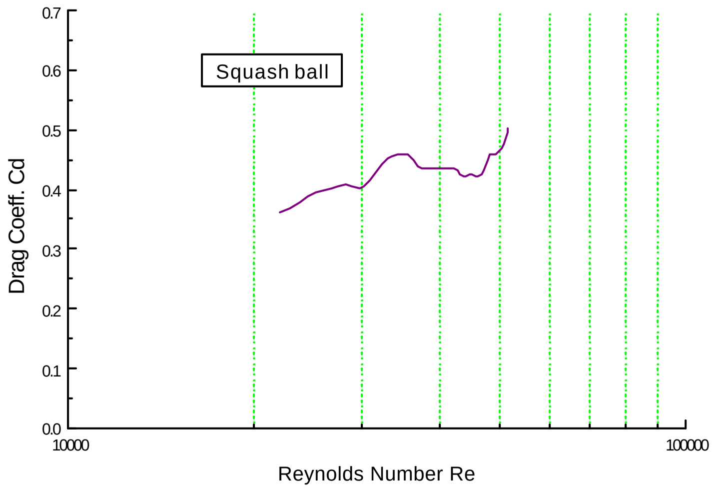

Fig 4 Determined Drag Coefficient of the falling squash ball

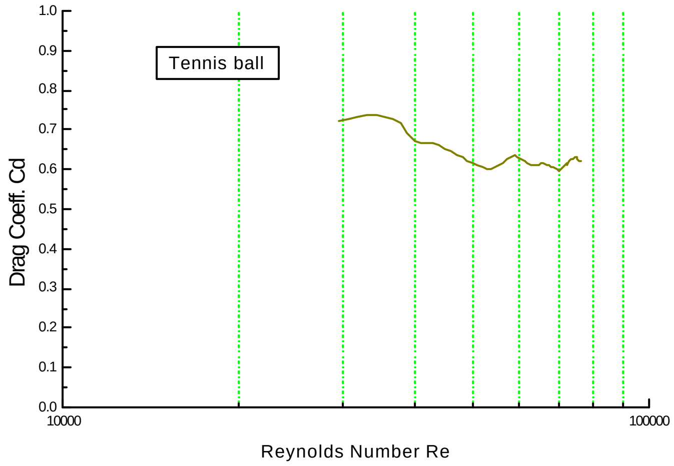

Fig 5 Determined Drag Coefficient of the falling tennis ball

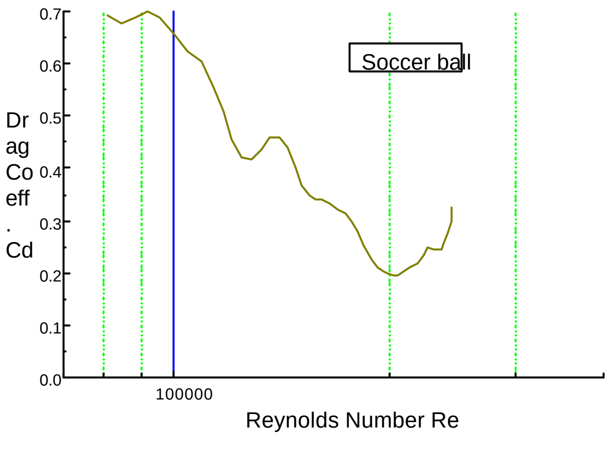

Fig 6 Determined Drag Coefficient of the falling soccer ball

The data showed considerable scatter of points which ahas bee smoothed out by filtering to produce the graphs.
The graphs indicate that the achieved speeds were generally below the critical speed zone for a rough spherical ball. The values obtained for the drag coefficients C_D of these balls corresponded to those for speeds below the critical zone – about 0.4 for golf and squash balls but 0.6 for the tennis ball, an unexpectedly high value but which has been observed before (Pallis and Mehta, 2000).

The exception to this was the speed of the soccer ball, which lay well within this zone. The drag coefficient C_D of the soccer ball was observed to range from above 0.5 at lower speeds to 0.2 at a speeds near Reynolds Number 200k. This agrees well with Achinbach's data for a roughened sphere.

Discussion

The free flight of the spherical sports balls investigated was affected by the aerodynamic drag forces generated. Their motions were generally retarded but not smoothly as indicated by the Drag Coefficient graphs. Drag coefficients derived fell within acceptable limits. The non-smooth characteristics of their flights were most probably the result of vortex shedding around the periphery of the ball. This phenomenon appeared most prevalent for the soccer ball over the range of speeds achieved in the tests as these speeds lay in the aerodynamic transition zone, and also perhaps because the density of the ball is comparatively low.

References

Achinbach E. (1974*), The effects of surface roughness and tunnel blockage on the flow past spheres*, Journal of Fluid Mechanics, **65**, 113 - 115
Pallis J. M. and Mehta, R. D. (2000), *Tennis science between NASA and Cislunar Aerospace*, in Tennis Science & Technology, Ed. Haake & Coe, Blackwell Science Ltd, UK.

Acknowledgements

Thanks are due to DSTO, MRL, Sydney for permission to use the stairwell of its building.

Appendix

Ball properties

	Mass	Diameter	Observed C_D	Surface
Golf ball	45 g	42 mm	~ 0.4	recess dimples
Squash ball	24	39.5	~ 0.4	smooth
Tennis ball	57	65	~ 0.6	hairy
Soccer ball	427	219	~ 0.5 –> 0.2	recess pattern