Turbulator Diameter and Drag on a Sphere

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Abstract

A sphere with turbulators of varying diameter was pulled through water with constant force. The relationship between the diameter of the turbulators and the ball's total coefficient of drag was determined. The maximum drag reduction was found with turbulators of 0.002 m. The drag reduction was less for turbulators of sizes 0.004 m and 0.005 m.

Introduction

In the 17th and 18th centuries, golfers discovered that golf balls with nicks, bumps, and slices traveled farther than smooth golf balls. Dimples now cover the surface of all golf balls. The dimples decrease form drag, one of four drag types acting on a blunt body travelling through a fluid[1]. The subject of this research was to determine whether small protruding bumps, known as turbulators or vortex generators, had the same effect of decreased total coefficient of drag on a sphere moving through the water.

Turbulent flow was assumed since the Reynold's number for the sphere moving through water at the speeds used is approximately 6 x 10^4. The formula for the coefficient of drag in turbulent flow is

$$C_d = \frac{2F_d}{\rho V^2 A} \qquad \text{(Equation 1)}$$

where C_d is the total coefficient of drag, F_d is the total force of drag, A is the cross-sectional area, ρ is the fluid density, and V is the velocity of the object[2]. The coefficient of drag for this research is defined as

$$C_d = C_{d\,form} + C_{d\,friction} \qquad \text{(Equation 2)}$$

since only the form drag, $C_{d\,form}$, and friction drag, $C_{d\,friction}$, are appreciable in this situation. The wave drag was negligible since the sphere was not moving near the surface.

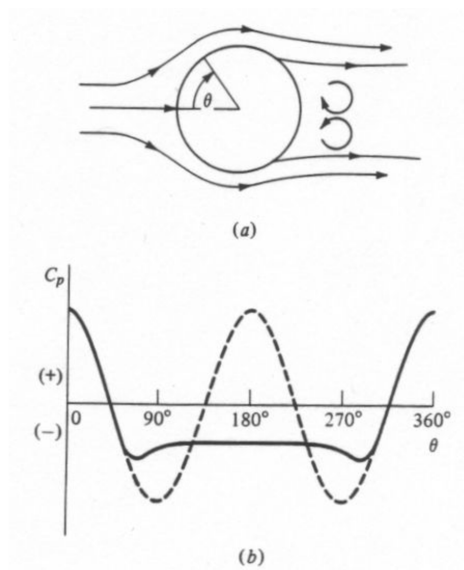

Figure 1 Flow and pressure characteristics around a sphere.[2] Note that at approximately 90° and 270° the actual coefficient of pressure (C_p) varies from the expected C_p. This is due to flow separation.

The most important drag acting on a blunt body moving through deep water is form drag. Form drag accounts for more than 90% of the total drag on a sphere[2], due to pressure differences between the front and back of the sphere. There is a high pressure area at the front of the sphere and a low pressure area at the back of the sphere. The result is a net backwards force on the sphere, known as the *form drag*.

The low pressure area at the back of the sphere is a result of flow separation. Flow separation occurs since pressure is slightly increased at 90° and 270° (figure 1) on the sphere as the boundary flow moves downstream. The lower velocity fluid at 90° and 270° separates from the sphere. This creates a low pressure wake.
In order to decrease the form drag, the boundary layer flow must be converted from laminar to turbulent flow. Turbulent flow characteristics decrease the flow separation, since the flow "spins" around the ball instead of separating from it (figure 2)[2].

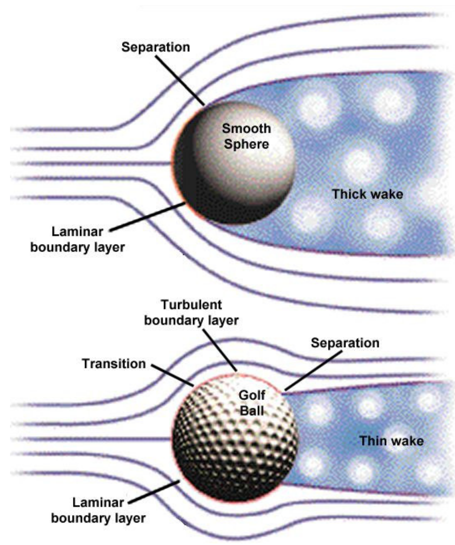

Figure 2 Laminar Versus Turbulent Flow

To change flow conditions around the ball from laminar to turbulent, the flow has to be interrupted. On golf balls, dimples are used to interrupt the flow around the ball, while on some cars turbulators (fins) are used to interrupt the flow.

As the turbulator size is increased, the turbulence of the flow is increased, and the form drag is expected to decrease. Increasing turbulator size is also expected to increase friction drag as a result of the increased cross-sectional and surface area. An optimal pin size is thus predicted for minimizing total drag. Equation 3 shows the relationship that is expected,

$$C_d = A/(P_s - C) + B(P_s - C) \qquad \text{(Equation 3)}$$

where ***A*** is a coefficient of form drag, ***B*** is a coefficient of friction drag, ***Ps*** is the pin size, and ***C*** is a constant for phase shift.

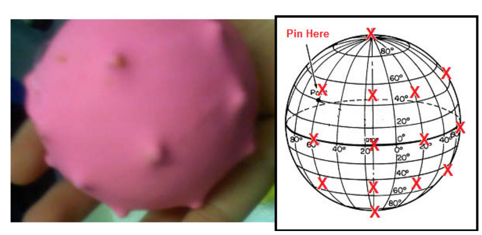

Figure 3 Tennis ball with pins and membrane.

Methods

Pins with spherical heads of known diameter were inserted into a tennis ball, which was then covered with a rubber membrane (figure 3). A string was attached to the top pin, passed over two pulleys and attached to a mass of 0.20 kg.

The tennis balls were filled with water and, since different pins added different total mass, lead was added to the tennis balls in order to make the buoyancy of each ball the same for each trial within ± .002N. The hanging mass was released and the terminal velocity of the sphere moving through the water was measured. Five different size pins were tested, with three trials conducted for each size.

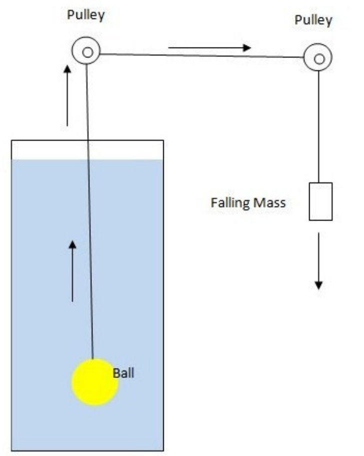

Figure 4 The experimental setup.

Results and Discussion

Figure 5 shows that the insertion of the turbulators had an immediate effect of decreasing the coefficient of drag. The 2 mm turbulators decreased the coefficient of drag significantly from the point where there were no turbulators, but as the size increased to greater than 2 mm, the coefficient of drag increased steadily. Pin diameters of 4 and 5 mm had the same coefficient of drag within uncertainties, and they were also the same as the coefficient of drag with no turbulators, within uncertainties. The data points were adequately described by the equation 3, as shown in figure 5. The initial drop in coefficient of drag was expected due to increases in turbulence in the boundary layer from the implementation of the turbulator, thus increasing form drag. The increases in coefficient of drag for pin sizes larger than 2 mm was expected due to increases in friction drag which became more substantial than the decrease in form drag.

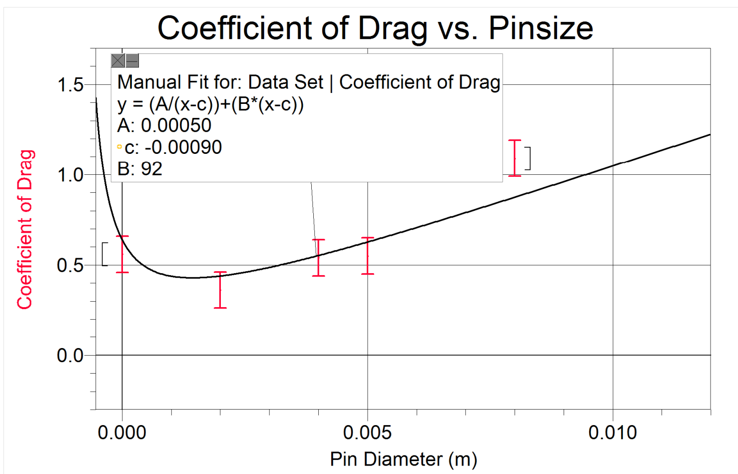

Figure 5 Coefficient of Drag as a function of Pin Diameter.

Conclusion and Evaluation

The results of this research were as predicted. Adding pins to a tennis ball moving through water did decrease the total coefficient of drag by decreasing the coefficient of form drag of the object, with the greatest coefficient of drag reduction being found at .002 m diameter turbulators – approximately 33%. The relationship shown in equation 3 was not sufficiently supported, but theory was, because while the pins decreased the form drag, they also increased the friction drag.

The greatest reduction in coefficient of drag was at the best balance between form and friction drags. Points above ***Cd*** = .6 are increases in friction which are larger than the reductions in form drag.

The reliability of the data in this research can at best be described as fair, since the uncertainty is quite large. It must be noted that equation 3 is only an assumption based on theory and was not sufficiently supported by the results of this research. Improvements to this research can be made by making a track for the tennis ball to run on so no lateral movement can affect the drag of the ball, and a better system for maintaining the same buoyancy in all the trials. Further research could be conducted on how the spacing of turbulators affects the reduction in coefficient of drag on a sphere, or how turbulators affect drag reductions on other blunt bodies such as a human moving through water, the hull of a boat, or other animals such as fish or dolphins.

References

1 *Dimples and Drag*. (n.d.). Retrieved October 13, 2008, from Aerospaceweb: http://www.aerospaceweb.org/question/aerodynamics/q0215.shtml

2 *The Drag Coefficient*. (n.d.). Retrieved October 13, 2008, from National Aeronautics and Space Administration: http://www.grc.nasa.gov/WWW/K-12/airplane/dragco.html