Turbulators and Coefficient of Drag

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Abstract

Turbulators have been shown to reduce the drag force on an object moving through a fluid. The relationship between the number of turbulators and the coefficient of drag of a sphere moving through water is investigated here. 3D-printed spheres of radius 25 mm with turbulators ranging in number from 0 to 106 were pulled through water to measure their drag coefficients. The results show a nonlinear relationship between the number of turbulators and the coefficient of drag. The drag decreased with the increase in number of turbulators up to around 70 turbulators, then increased with increasing number of turbulators, showing that there is an optimal range for reducing drag.

***Keywords*:** turbulator, drag coefficient, turbulent flow

I. INTRODUCTION

Today's golf balls are textured with hundreds of dimples, not for the looks, but because they enhance the ball's aerodynamics. These dimples reduce the resistance a ball faces as it travels through the air. Turbulators, which are bumps rather than dimples, have been shown to have the same effect, as early golfers discovered that damaged balls with bumps, cuts, or nicks traveled further.[1]
Drag in fluid dynamics is composed of two components: pressure and skin friction drag. Pressure drag, also referred to as form drag, occurs when the fluid flowing around an object separates from the rear surface of the object. This separation creates a wake – a region of turbulent flow and low pressure at the rear of the object – thus creating an imbalance in the force between the front and rear surfaces.[2] Skin friction drag, in contrast, arises from the friction of a fluid against the surface of an object that is moving through it.[3] Additionally, it is directly related to the area of the surface that is in contact with the fluid.

Friction drag occurs in the boundary layer, where fluid velocity increases from zero at the surface to the free-stream speed, due to the viscosity of the fluid and the friction between the fluid and the object's surface.[3] The fluid's molecules close to the surface move slowly, while those farther out move faster. This difference in speed creates a resistance within the fluid, resulting in retarding forces that oppose the object's motion.
The total drag on an object is represented by its drag coefficient, C_d, which is the sum of skin friction drag and pressure drag. The drag coefficient can be calculated using Equation 1:[4]

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

where C_d is the coefficient of drag, F_d represents the drag force, ρ is the density of the fluid, A is the cross-sectional area of the object, and v is the velocity of the object.

Though turbulent flow increases drag, it also delays separation of the flow from the skin of the object, reducing the wake behind the object.[5] Figure 1 illustrates the difference in size of a wake for an object experiencing laminar flow compared to turbulent flow. The smaller wake experienced in turbulent flow causes a reduction in the pressure drag, resulting in the object experiencing less resistance as it moves through the fluid.

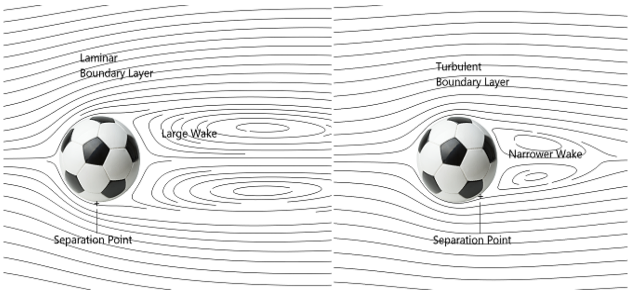

Figure 1. Effect of boundary layer type on flow separation and wake size.[6]

Turbulators are small, spherical protrusions, designed to disturb the laminar boundary layer near the surface and create an earlier shift to turbulence.[7] Turbulators increase the turbulence of the boundary layer, which causes the fluid to flow along the surface longer and reduces pressure drag. However, because they also increase the sphere's effective surface area, they raise skin friction drag. The net effect depends on whether the reduction in pressure drag outweighs the added friction or not.

This research investigates how the number of turbulators affects the drag experienced by a ball as it moves through the water. Additionally, pulling the balls over a range of speeds will determine whether the drag coefficient is dependent on speed for the range tested.

The coefficient of drag is expected to follow a nonlinear pattern in response to the number of turbulators. Initially, increasing the number of turbulators is expected to reduce drag by creating a more turbulent boundary layer. However, as more turbulators are added, at some point it is expected that the increase in skin friction will likely become greater than the decreased pressure drag. As a result, the drag coefficient is anticipated to decrease at first, then rise again, forming a U-shaped curve. The lowest point of this curve would display the optimal number of turbulators for minimizing the drag coefficient.

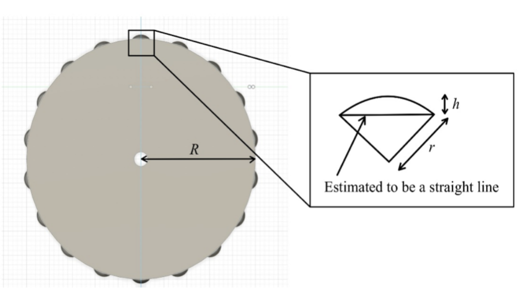

Figure 3. Cross-sectional diagram of ball with turbulators

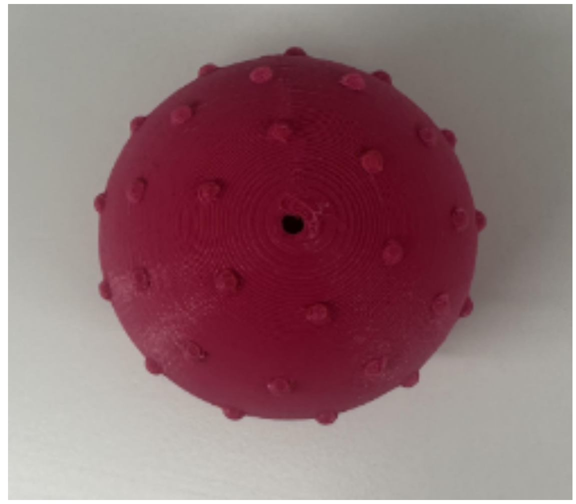

Figure 2. Sphere with turbulators used in experiment

II. METHODS

Spheres of 25 mm radius with spherically shaped turbulators of radius (r) 25 mm and height (h) 1.25 mm were 3D-printed, as shown in Figure 3. The spheres were designed with a hole through the center to allow them to be strung on a guidewire. Six spheres with numbers of turbulators, n = 0, 20, 38, 63, 82, 104, were made. The total cross-sectional area of the sphere was then calculated using Equation 2.

$$A = \pi R^2 + n[cos^{-1}(1 - \frac{h}{r})r^2 - (r - h)\sqrt{h(2r - h)} \quad (2)$$

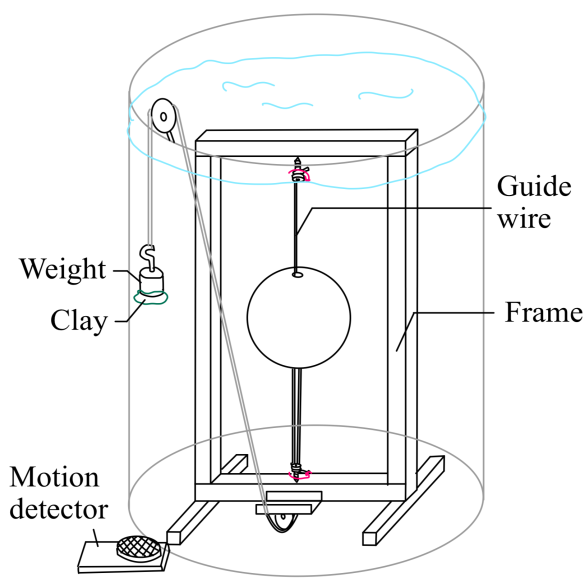

Figure 4. Diagram of experimental setup

A 70 cm tall frame was constructed with a guide wire strung in the middle, as shown in Figure 4. The ball was threaded on the guide wire. A string was attached to the bottom of the ball, passed through two pulleys, and tied to a weight on the other end, and clay added to the weight to compensate for friction in the system. The ball was released from just under the surface of the water and pulled to the bottom by the hanging weight. A motion detector, sample rate of 40 samples per second, was used to determine the terminal velocity of the weight as it fell down, as shown in Figure 5. This was done with all six spheres, each with three pulling weights of mass 50, 80, and 110 g. Three trials were conducted for each configuration.

III. RESULTS AND DISCUSSION

The spheres were pulled through water with different hanging masses, leading to terminal velocities ranging from 0.76 m/s to 1.14 m/s. It was found that the varying velocities had no effect on the drag coefficient for any of the spheres over the range of speeds tested.

Figure 6 shows a decrease in drag for all the spheres with turbulators compared to the control sphere (0 turbulators); the sphere with the lowest number of turbulators showed a significant difference, indicating that any number of turbulators will affect the drag coefficient. This further suggests that the increased skin friction caused by turbulators was relatively small compared to its effects on the decrease in pressure drag.

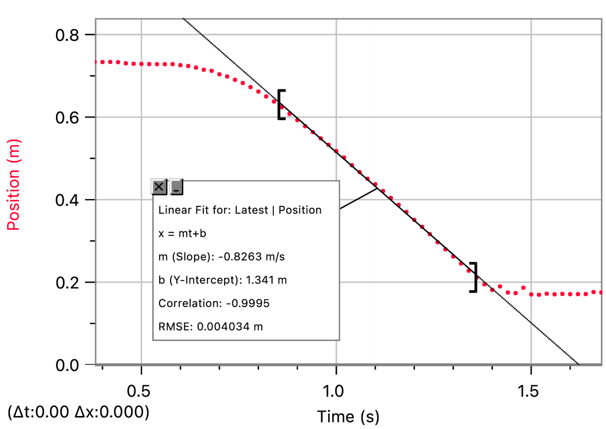

Figure 5. Position-time graph of trial 1 of the ball with 38 turbulators and a pulling mass of 50 grams with terminal velocity as the slope.

The minimum coefficient of drag occurs when there are approximately 70 turbulators. This optimal point is caused by the lowest total of skin and pressure drag, meaning that before this point, the rate at which pressure drag decreases is greater than the rate at which skin friction increases. As the coefficient of drag increases past the optimal point, the opposite would happen, where skin drag increases at a greater rate compared to the decrease in pressure drag.

As can be seen in Figure 6, the drag coefficient of the sphere with 38 turbulators was higher than expected, not fitting this trend. This could have been caused by the guide wire and the pulling wire occasionally becoming twisted, likely resulting in increased system friction which was not compensated for. Another factor might have been the fact that the apparatus had to be reassembled for each sphere, leading to variation in system friction for each set of trials. Development of an improved apparatus to reduce the effects of these issues is recommended for future research. It must be noted that the optimal number of turbulators is specific to only this setup. Further research is suggested into factors such as turbulator size and shape that could affect the minimum value for the coefficient of drag.

IV. CONCLUSION

As an increasing number of turbulators was added to the sphere, the drag coefficient reduced until it reached an optimal number. Past this threshold, drag gradually starts increasing. The speed at which the ball traveled through water had no significant effect on the turbulator's ability to reduce drag over the range of speeds tested, 0.76 m/s to 1.14 m/s.

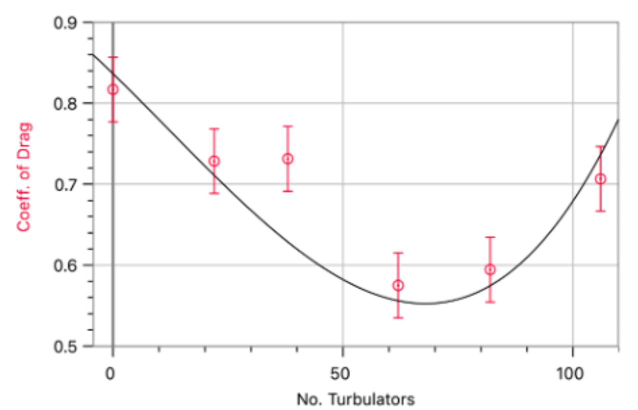

Figure 6. Model displaying the effect of the number of turbulators on the average drag coefficient.

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