Golf Ball Boundary Layer and Flow Separation

MCEN 5151 Flow Visualization - Team First Report

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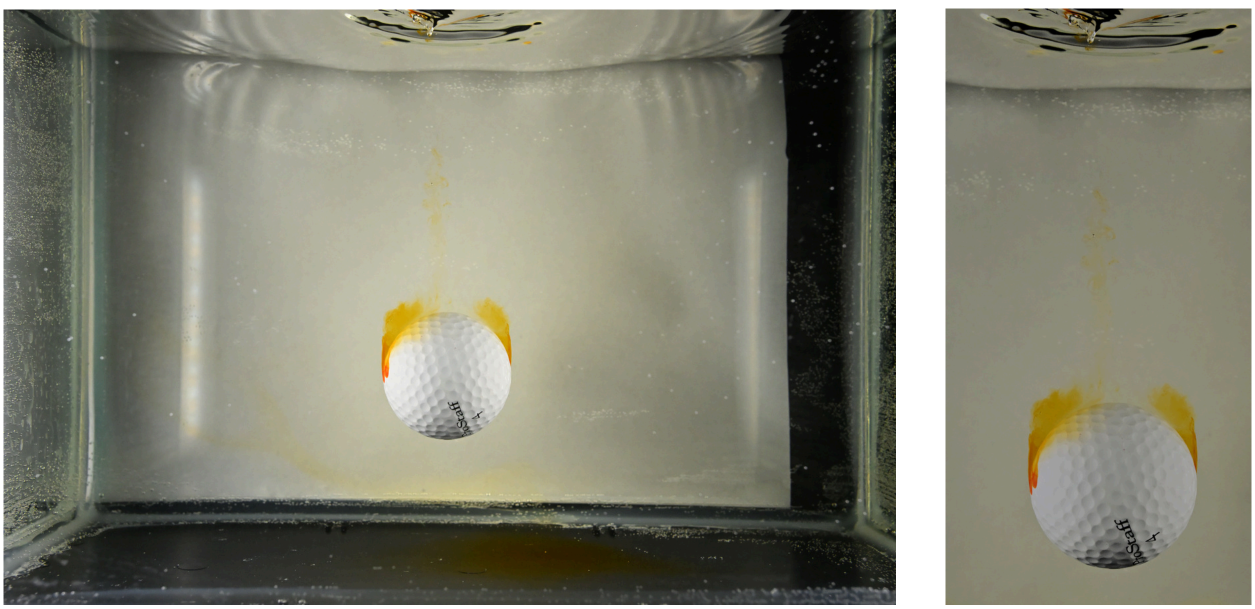
Statement of Meaning Figure 1 was created for the second flow visualization assignment and shows a golf ball seeded with dye falling through water. This setup attempted to illustrate the boundary layer and wake of the golf ball with the aid of orange food dye. Close inspection of the image shows the separation point and turbulence level of the boundary layer, in addition to the wake — all of which have been shown to be functions of the Reynolds number.



(A) Compressed Unedited Photo (B) Edited Photo

Figure 1: Golf ball with orange food dye placed on its sides falling through water.

Setup and Flow Description This flow was created inside a 2.5 gallon glass-walled fish tank 15 cm × 30.5 cm × 20.5 cm in dimension. A golf ball with dye on its sides was lowered to the surface of the water in the center of the tank and then released. The dye placed on the golf ball helped to visualize the boundary layer that formed near the ball's surface in addition to the trailing wake. While imperfect, the dye shows the general size and shape of the boundary layer and wake, though it doesn't show very detailed flow inside these regions.

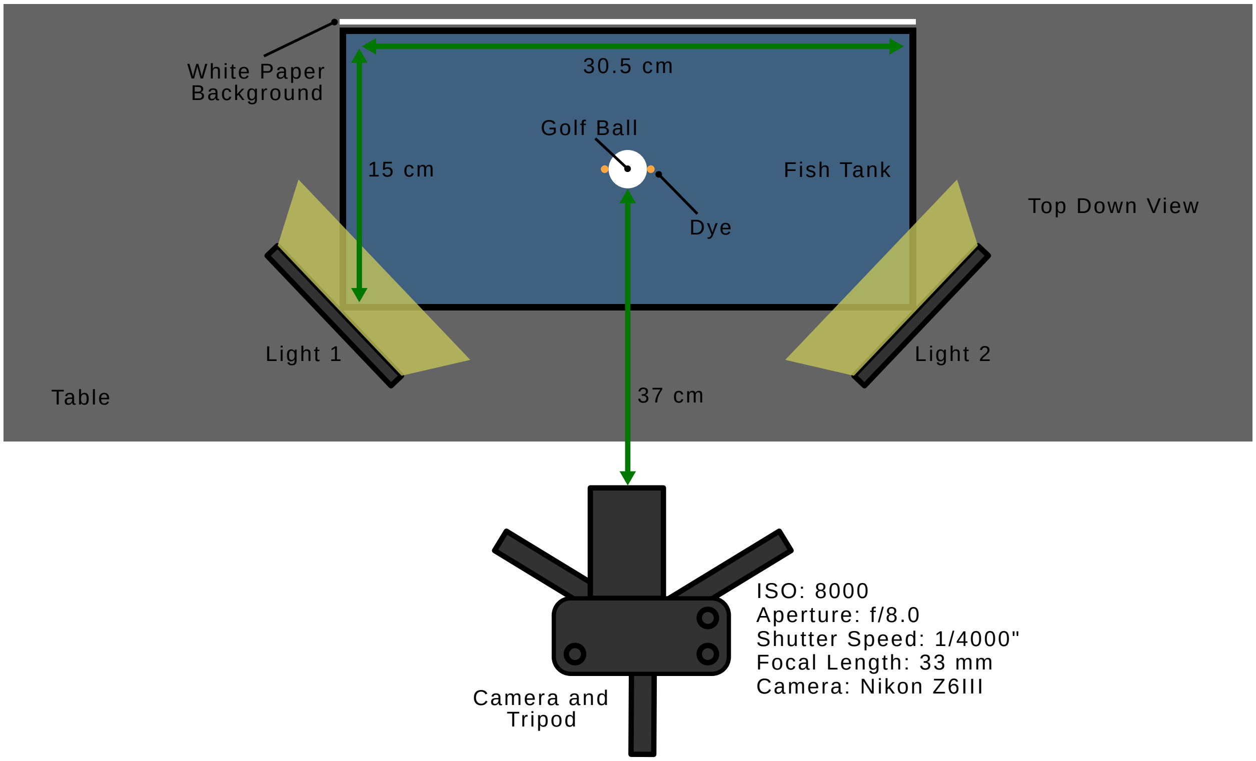


Figure 2: Top-down view visualization setup

As shown in Figure 2, lights were placed at corners of the tank closest to the camera. The two 10 W, 4500 K color temperature LED panel lamps were angled so their light bounced off the white paper background before traveling into the camera lens. Their placement angles were also chosen to illuminate the dye streams along the sides of the golf ball.

A Nikon Z6III camera with a 24 – 120 mm f/4.0 Nikkor lens was used to record photos of the falling golf ball, and was set up 37 cm away from the desired plane of focus, which was the middle of the tank where the golf ball was falling. The height of the camera was set so the middle of the camera frame aligned roughly with the middle of the tank height.

Images of the falling golf ball were taken with the continuous shooting feature on the Z6III, which allowed for seven pictures to be taken per second. Continuous shooting was started right before the golf ball was released and finished after the golf ball contacted the bottom of the tank. Videos were also recorded of the falling golf ball at 120 frames per second and were used to calculate the speed of the falling golf ball.

After the golf ball was released at the surface of the water, the viscous effects of the surrounding water pulled the dye placed along the sides of the golf ball toward the trailing edge of the ball. Some of the dye remained close to the surface of the ball, though other parts of the dye left the surface of the ball and entered the wake region of the ball. A small trail of dye was also left behind along the center axis of the ball's falling motion. When examined closely, some dye is also left near the surface of the water, indicating that some of the dye was pulled from the surface of the ball as it entered the water, and then remained at the surface.

Because the viscous forces of the water acting on the dye and the inertial forces of the flow moving around the golf ball are both important, the Reynolds number (see Equation 1) was chosen as the nondimensional parameter to compare the flow in Figure 1 to previous flow experiments and simulations around golf balls. Quantities needed to calculate the Reynolds number are listed in Table 1. Some of the quantities (such as kinematic viscosity) are estimated using tables of known values while others were measured from recorded videos of the falling golf ball.

Constant	Description	Value
D	diameter of ball	4.3×10^{-2} m
U	mean velocity of ball	$0.386\,\mathrm{m\,s^{-1}}$
ν	kinematic viscosity of water	$1.0023 \times 10^{-6}\,\mathrm{m^2/s}$ [1]
α	boundary layer separation angle	96°

Table 1: Constants and measurements. Some measurements (angles and velocities) were measured using Fiji.[2]

$$\mathrm{Re} = \frac{DU}{\nu} = \frac{(4.3^{-2})(0.386)}{1.0023^{-6}} = 1.7 \times 10^4 \tag{1}$$

Numerous studies on the aerodynamics of golf balls have been conducted to find the relationship between golf ball design and flight performance. By better understanding these relationships, golf ball manufacturers can design balls that perform well while still following the guidelines of golf associations.[3] Understanding the wake and boundary layers of a golf ball traveling through air is important, because both of these flow structures are related to the drag and lift forces the golf ball experiences and consequently affect how far the ball travels through the air.[3]

The boundary layer surrounding the golf ball as well as the wake trailing the golf ball are functions of the Reynolds number. If the Reynolds number of a golf ball flying through the air is kept similar the Reynolds number of a ball moving through water, then the flow structures around each ball can be considered to be similar. Testing and imaging a golf ball traveling through water at lower speeds might be more feasible than testing a golf ball traveling through the air at higher speeds, which is one reason why nondimensional numbers are useful.

Numerical (computer) simulations of the flow around golf balls found that the flow separation point moved from 84° to 110° when the Reynolds number moved from 2.5×10^4 to 1.1×10^5.[4] These flow separation point angles are measured from the point where the leading edge of the golf ball intersects the axis the golf ball is moving along. As shown in Table 1 and Equation 1, the flow separation angle of my golf ball was 96° and the Reynolds number was 1.7×10^4. My Reynolds number was smaller than the lower Reynolds number reported in the numerical study, though my separation angle was larger.

This discrepancy could be caused by a couple things. First, the falling golf ball that I imaged might not have reached its steady state speed — the golf ball was imaged about ten centimeters below the surface of the water and had not fallen for a long distance. Because the golf ball may have still been accelerating, the flow around the ball cannot be considered steady, which limits the comparisons that can be drawn. Another discrepancy could have been measurement errors in the angle of separation. Flow separation might have occured further up along the edge of the falling ball, but it might not have been easily visible until a little further back. This effect was exacerbated by the placement of the dye on the ball: the dye was placed near the 90° mark on the ball, which severely limits the visualization of the boundary layer before and after the separation point.

The wake region of the golf ball was also found to be larger in the smaller Reynolds number case than in the larger Reynolds number case.[4] The wake for the 2.5×10^4 Reynolds number simulation was wider than the golf ball itself, though that cannot be said for the falling ball that I imaged. Again, this could be caused by limitations such as the dye placement and the unsteady flow around the ball.

Visualization Technique A single drop of orange-yellow food dye was placed on each side of the golf ball in an effort to create a dyed boundary flow. Continuous, bright lighting was used to illuminate the front and sides of the golf ball while allowing for a short shutter speed. Two continuous 10 W, 8 inch LED panels (Ubeesize brand) were angled as shown in Figure 2, illuminating the front and sides of the golf ball while allowing for a short shutter speed. Overhead lights in the room were on to increase the amount of light in the system.

Photographic Technique The image was taken with a focal length of 33 mm, which allowed for a large field of view even though the camera was placed 37 cm away from the falling ball. 35 cm is the minimum focus distance of the Nikkor 24 – 120 mm f/4.0 lens that was used. As shown in Figure 2, a Nikon Z6III with an f/4.0 aperture, a 1/4000 second shutter speed, and an 8000 ISO setting were used to capture the image. The Z6III recorded images with dimensions of 6048×4032 pixels and a view angle of $84 \times 21.3°$.[5]

After cropping and editing, the final image had dimensions of 1594×3100 pixels. Post processing of the photo decreased the exposure of the photo using Darktable in an attempt to increase the visibility of the dye. The cropping was chosen to include the entry area along the surface of the water to highlight that some of the dye was left at the surface.

Analysis and Reflection As mentioned previously, the image shows a golf ball falling through a fish tank full of water. It highlights the flow around the boundary of the golf ball as well as the wake. These flow features could have been better imaged by lengthening the distance of the dropped ball (increasing tank depth), changing the location of the seeded dye on the golf ball, positioning the lights behind the ball, darkening the color of dye used, and zooming in more with the telephoto lens. By increasing the tank depth, the flow around the golf ball might have become more developed. Placing dye closer to the leading edge of the golf ball would have improved the imaging of the boundary layer near the separation points. Positioning the lights behind the golf ball and using a darker dye would have increased the contrast of the dye, allowing for easier visualization of the wake and boundary layer. Zooming in on the golf ball or using a macro lens would have increased the resolution and detail of the flow around the golf ball, though doing so could have made capturing the golf ball mid-frame more difficult.

$$\frac{20{,}297\,\text{pixels}}{\text{m}} \times \frac{0.386\,\text{m}}{\text{s}} \times \frac{1\,\text{s}}{4000\,\text{frames}} = 2\,\text{pixels/frame} \tag{2}$$

$$\frac{0.386\,\text{m}}{\text{s}} \times \frac{1\,\text{s}}{4000\,\text{frames}} \times \frac{1000\,\text{mm}}{1\,\text{m}} = 0.1\,\text{mm/frame} \tag{3}$$

The shutter speed used to take the photo was sufficient to "freeze" the golf ball in place. Equation 2 shows that the ball moved 2 pixels/frame in my image, minimizing motion blur. In actual distance, the ball moved 0.1 mm during the time used to take the image. Future tests could also consider shortening the shutter speed further, which could be afforded once the lights are positioned behind the golf ball.

References

[1] "Water - Dynamic and Kinematic Viscosity at Various Temperatures and Pressures." (), [Online]. Available: https://www.engineeringtoolbox.com/water-dynamic-kinematic-viscosity-d_596.html (visited on 10/03/2025).

[2] J. Schindelin, I. Arganda-Carreras, E. Frise, *et al.*, "Fiji: An open-source platform for biological-image analysis," *Nature Methods*, vol. 9, no. 7, pp. 676–682, Jul. 2012, ISSN: 1548-7105. DOI: 10.1038/nmeth.2019. [Online]. Available: https://www.nature.com/articles/nmeth.2019 (visited on 09/24/2025).

[3] A. J. Smits and S. Ogg, "Aerodynamics of the Golf Ball," in *Biomedical Engineering Principles in Sports*, G. K. Hung and J. M. Pallis, Eds., Boston, MA: Springer US, 2004, pp. 3–27, ISBN: 978-1-4419-8887-4. DOI: 10.1007/978-1-4419-8887-4_1. [Online]. Available: https://doi.org/10.1007/978-1-4419-8887-4_1 (visited on 10/02/2025).

[4] C. E. Smith, N. Beratlis, E. Balaras, K. Squires, and M. Tsunoda, "Numerical investigation of the flow over a golf ball in the subcritical and supercritical regimes," *International Journal of Heat and Fluid Flow*, Sixth International Symposium on Turbulence and Shear Flow Phenomena, vol. 31, no. 3, pp. 262–273, Jun. 1, 2010, ISSN: 0142-727X. DOI: 10.1016/j.ijheatfluidflow.2010.01.002. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0142727X10000147 (visited on 10/02/2025).

[5] "Nikon Z 24-120mm f/4 Review & Sample Images by Ken Rockwell." (), [Online]. Available: https://kenrockwell.com/nikon/z/24-120mm.htm (visited on 10/03/2025).