

Get Wet: Flow Visualization of a Milk Drop Ring in Water

Anton Ignatenko

MCEN 5043-001: Flow Visualization

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Introduction

This image was created for the introductory Get Wet assignment in MCEN 5043. My primary goal for this assignment was to capture the fluid dynamics of a single drop of whole milk when it hits still water, and to visualize how this falling drop transitions from a spherical droplet into a donut-shaped vortex ring as it travels downward. During early test shots, I encountered two major challenges. The first was to get the camera to focus on the traveling fluid within the glass rather than the walls of the glass themselves. The second was managing glare during daytime. Switching to manual focus and minimizing outside light by waiting until the evening solved these issues. I completed this work independently, with some minor assistance from a family member to hold the dropper.

Discussion of Flow

The experimental setup consisted of a clear wine glass filled with tap water at room temperature ($\sim 20^\circ\text{C}$, density $\rho_{\text{water}} = 998 \text{ kg/m}^3$, viscosity $\mu_{\text{water}} = 1.002 \times 10^{-3} \text{ Pa} \cdot \text{s}$) at a depth of $\sim 10 \text{ cm}$. Waiting until the water surface was still (a few seconds), I used a small plastic pipette to release a single drop of cold whole milk ($\sim 5^\circ\text{C}$, $\rho_{\text{milk}} = 1032 \text{ kg/m}^3$) from about 3 cm ($h = 0.03 \text{ m}$) above the water surface. Estimating the impact velocity of the drop right before surface contact gives:

$$U_0 = \sqrt{2gh} = \sqrt{2(9.81 \text{ m/s}^2)(0.03 \text{ m})} \approx 0.77 \text{ m/s}. \quad (1)$$

As the milk enters the water, kinetic energy overcomes surface tension and pushes fluid into the medium. Shear forces between the downward moving milk and the stationary water cause the boundary layer to roll backward, shaping the fluid into a toroidal vortex ring [1]. Shariff and Leonard [2] explain that this shear boundary layer creates a localized sheet of vorticity that rolls up into a stable core. With an estimated ring core width of $d = 0.015 \text{ m}$, the Reynolds number is:

$$Re = \frac{\rho_{\text{water}} U_0 d}{\mu_{\text{water}}} = \frac{(998 \frac{\text{kg}}{\text{m}^3})(\frac{0.77 \text{ m}}{\text{s}})(0.015 \text{ m})}{1.002 \times 10^{-3} \text{ Pa} \cdot \text{s}} \approx 1200. \quad (2)$$

A Reynolds number of $Re = 1200$ indicates a transitional flow. As the core sinks, shear forces between the spinning ring and surrounding water cause instabilities to grow over time, forming tendrils along the core [2]. Calculating the Atwood number

$$A = \frac{\rho_{\text{milk}} - \rho_{\text{water}}}{\rho_{\text{milk}} + \rho_{\text{water}}} \approx 0.017 \quad (3)$$

shows that the density difference is small, so any initial movement is mostly driven by the drop's downward momentum [1]. As the primary ring continues to sink, tiny disturbances in the water cause the milk to accumulate unevenly along the edge of the ring. Because the cold milk is denser than the surrounding water, these heavier areas descend faster than the rest of the ring, pulling down vertical tendrils. Thomson and Newall [1] explain that as these heavy areas sink, shear drag forces the bottom of each tendril to roll up into its own miniature secondary vortex ring. Because the fluids lack surface tension, these secondary rings do not

pinch off, leaving thin threads of milk connecting the lower additional structures back to the main ring and giving the flow its unusual tentacled jellyfish appearance, seen in Figure 2.

Visualization Techniques

I used store-bought whole milk because its drops are white and stand out against a dark background. To light the scene, I placed a Pixel 8a phone flashlight operating at about 85% capacity directly underneath the center of the wine glass base. I set up a black backdrop behind the wine glass using a black T-shirt, as seen in Figure 1. I chose a time in the evening so that daylight would not interfere and turned off all the lights in the room.



Figure 1: The experimental setup showcasing the wine glass standing on the phone flashlight, the dark backdrop, and the camera position.

The photo was taken with a Canon PowerShot S110 digital camera placed 13.5 cm away from the glass and elevated to a height of 11.75 cm . The camera metadata lists an aperture of $f/2$, a shutter speed of $1/250\text{ s}$ to freeze the fluid motion, ISO 400, and a focal length of 5 mm , chosen by holding a pencil at the center of the wine glass and focusing on it before the milk drop experiment.



Figure 2: The unedited photograph taken of the disturbances in the vortex. The glare from the flashlight is highly visible.

Post-processing on the raw camera file (Figure 2, originally 4048×3047 px) was done in Darktable. I cropped the frame vertically around the ring to dimensions of 2590×3046 px, adjusted the contrast curve to deepen the black background, applied a local exposure mask near the stem to tone down glare, and used the retouch heal tool to remove dust specks and other minor glares, and the result of these tweaks is seen in Figure 3.

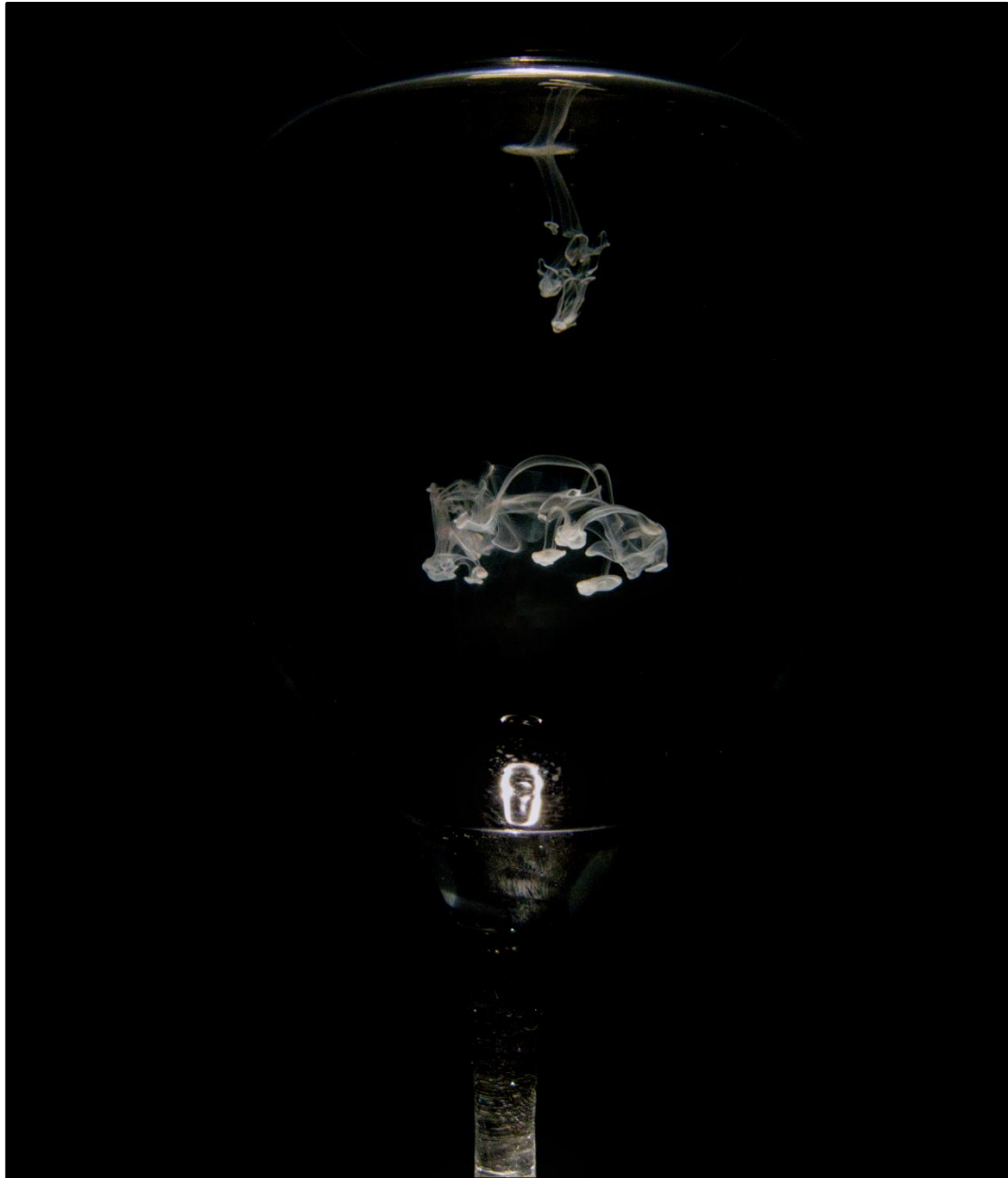


Figure 3: The final processed image. The actual milk drop is more visible, while the glare has been slightly decreased.

Conclusion

The final image clearly reveals the primary vortex ring and the trailing shear-layer tendrils extending above it. I am satisfied with the visual contrast and how clearly the ring structure appears, which meets my original intent. However, shooting at $f/2$ created a shallow depth of field which left the far edges of the ring soft. Additionally, glare close to the bottom of the water is still prevalent, and the vortices are not fully in focus. In future tests, I would like to experiment with drop height to see how impact velocity changes the vortices, as well as attempt to use a white paper as a diffuser to soften glare.

References

- [1] Thomson, J. J., & Newall, H. F. (1885). On the Formation of Vortex Rings by Drops Falling Into Liquids, and Some Related Phenomena. *Proceedings of the Royal Society of London*, 39(239-242), 417–436.
- [2] Shariff, K., & Leonard, A. (1992). Vortex Rings. *Annual Review of Fluid Mechanics*, 24(1), 235–279.