Coffee Creamer Vortex Ring

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March 8, 2006

A cold droplet of coffee creamer was dropped into a cup of hot black tea. The goal of the project was to capture the flow characteristics of the cold thick creamer as it traveled through a warm dark liquid medium. The project was inspired by looking down at the vortex ring and subsequent flow patterns made as creamer was dropped into coffee. Through experimentation, it was determined that coffee was too dark to produce a good image of the flow of the creamer. A trial with black tea produced better results.

The flow situation was produced by filling a clear container, in this case a shot glass, with hot black tea. Cold Half and Half coffee creamer was sucked into a plastic straw and dripped into the tea from a height of about 3cm to 5cm above the surface of the tea.

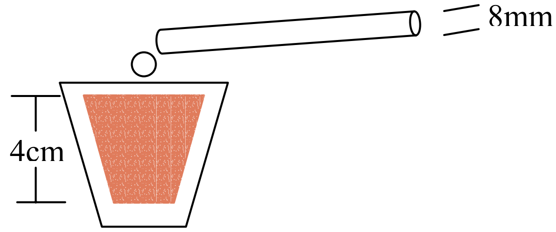

Figure 1: Experimental set-up

Each drop of creamer is estimated to have roughly the same diameter as the straw from which it was dropped, which is around 8mm. The viscosity of the creamer is approximated to be the same as that of milk, which is 0.02 Pa*s [1]. The density of half and half at 4.4C was reported to be 1.027 kg/m^3 [2]. The time it took for the creamer to pass through 4cm of tea was measured at 1.55s, which yields a flow velocity of 0.027m/s. The Reynolds number of the flow can be approximated by using the diameter of the drop as the length scale. Using these values, the Reynolds number is calculated to be 0.011. The situation is compared to a jet flow, which has a critical Reynolds number of 10. Our calculation predicts that the flow of the droplet through the tea is laminar. This agrees with the observations from the visualization. The single vortex created as the creamer falls to the bottom of the glass is in agreement with observations made by Mohsemi in Zero Mass Pulsatile Jets for Unmanned Underwater Maneuvering [3]. The paper states that a pulsatile jet generated by a cylinder with a stroke to diameter ratio, $L/D<4$ will generate a jet with only a primary vortex at the front. Since the droplet is near spherical, the L/D ratio is approximated to be around 1.

The flow was visualized using the boundary marking technique. The black tea was transparent enough to easily see the flow of the coffee creamer but also had enough color to provide information about the depth of the flow features. The flash was used to achieve an appropriate amount of light. Since the photo was shot through glass, the light had to be handled in such a way that the flash and ambient light did not produce glare. Using the shiny side of tin foil, the flash was reflected away from the glass onto a white piece of construction paper. The reflections produced from ambient light were made to blend with the reflection of the camera lens using a black piece of cardboard.

Figure 2: Camera and lighting

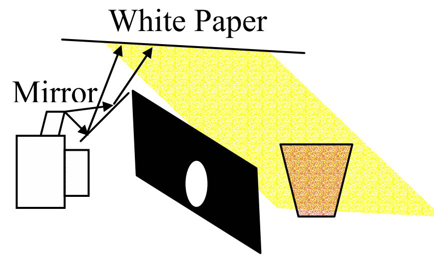

Figure 3: Camera and lighting schematic

The field of view of the final cropped photograph was 1.65 cm (0.65 in) wide and 3.81 cm (1.50 in) tall. This corresponds to an area 852 pixels wide by 1936 pixels wide. The camera was focused on a spot in the center of the glass 1 cm away. The super macro mode was used to focus on such a close object. The camera used was a 5.0 mega pixel Canon PowerShot S2 IS. The lens on the camera had focal lengths of 6.0-72.0 mm with aperture settings from f/2.7-3.5. The shutter speed used while taking the picture was 1/500 s and the aperture was set to f/2.7. The only manipulation done to the photograph was a crop to make the subject fill the frame and to mask off reflections on the sides of the glass. The shutter speed only allowed the drop to move 54 um during the photograph. The vortex moved across 3 pixels in the time the shot was taken. This caused the vortex to appear out of focus.

The image of the drop of creamer falling through warm black tea reveals many beautiful and interesting phenomena of the physics of fluid flow. Beginning from the top of the photograph, insight is given to the dynamics of a liquid drop falling through a gas-liquid interface. I could not find a journal article explaining this feature, but it appears that the creamer drop broke into many drops after impacting the surface of the tea. This is shown by the smaller vortex rings forming just under the surface to the right of the impact. A large amount of the mass of the droplet stayed together as it fell through the tea and created the large vortex ring at the bottom of the picture. A weak trail of creamer was left by the vortex ring as it propagated down through the tea. My intent to photograph the vortex ring was fulfilled. However, I was pleasantly surprised by the appearance of the remnants of the droplet impact and its reflection as well as the sliver of cream left behind the ring. I am also very happy with the way that the tea appeared darker towards the bottom, which was due to the light coming from above. One aspect of the image that I would improve was that the vortex ring appears is blurred due to the long shutter speed. In the future I would calculate the required shutter speed before taking the picture. I would also like to investigate the situation where the stroke to diameter ratio was greater than four, $L/D>4$. It is stated by Mohsemi that this produces a lead vortex that is followed by a trailing jet with some interesting flow features in the jet.

References

1. http://www.yet2.com/app/insight/needofweek/5462?sid=350
   Accessed 2/2/06
2. The Physics Factbook, Glenn Elert
   http://hypertextbook.com/facts/2002/AliciaNoelleJones.shtml
   Accessed 2/2/06
3. K. Mohsemi. Zero Mass Pulsatile Jets for Unmanned Underwater Maneuvering.
   AIAA Paper 2004-6386