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Flow Visualization

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Get Wet

One of my favorite parts of painting with ink is the clean-up process—it's a pleasure to watch a brush jet-black with India ink being dipped into a glass of water and gently swirled around. The languid and delicate forms of the ink as it leaves the brush and enters the medium of the water have always seemed very beautiful and fascinating to me. I decided to observe this interaction with more purpose and intent for this first project. Besides the beauty of capturing this process with photography, I thought it would be interesting to document the phenomena occurring, because I had never known exactly what was going on. Sometimes it looked like the behavior of the ink in the water was very turbulent, sometimes it seemed very smooth, and at other times the ink would branch off in odd directions in a way that I had never recognized in any other fluid behavior. With these ideas in mind, I created a very simple set-up to study this work of nature more closely.

The materials I used for my experiment were: one small jar of black India ink, one transparent smooth-sided drinking glass filled with water, a 30cm x 20cm x 15cm open cardboard box, one sheet of white computer paper, and a desk lamp. I stood the cardboard box on its side so that the open end was perpendicular to the floor, and I then placed the paper sheet inside as a background. The water glass was then placed in front of the backdrop on the box, and the drawing lamp was set off to the side with its light pointed into the box to illuminate the situation more clearly (see figure 1 in appendix). The process for observing the fluid behavior was to take the ink dropper within the bottle, and to simply drop varying amounts of ink into the glass of water. Each trial produced vastly different imagery; if I filled up the glass with water and dropped ink in immediately there would be highly chaotic flow, but if I let the glass of water sit for several minutes before dropping in the ink there was very smooth flow. The image that I ended up selecting represents laminar flow caused by a Rayleigh-Taylor instability. In my experiment, the higher density ink rests on the surface of the lower density water until it is perturbed, and it is then pulled downward into plumes through the water by gravity resulting in a Rayleigh-Taylor instability[1]. Using estimations for the physical criterion resulted in the following calculations:

$$\mathrm{Re} = \frac{\rho \upsilon L}{\mu}$$

$$\rho = density = 997 kg / m^3$$

$$\mu = dynamic\_fluid\_vis\cos ity = 9.772E-4 kg / m^2$$

$$\upsilon = fluid\_velocity = 0.03 m^2 / s$$

$$L = .characteristic\_length = 05m$$

This results in a Reynolds number of 1530, which clearly places the flow in the laminar regime. Although the dynamic fluid viscosity I used was the tabulated value for water at room temperature (20 degrees C) instead of ink, it's clear from the calculations that a marginally higher viscosity value would only decrease the Reynolds number, so this approximation is inconsequential for my purpose.

To visualize the Rayleigh-Taylor instability, I used the simple visualization technique of dye (black India ink) being introduced to fluid flow (tap water in a glass). The lighting was a sole source—a 60 W soft white bulb in a desk lamp in a larger unlit room. This setup provided enough contrast to clearly view the phenomenon without creating a harsh glare off of the water glass or lens flare, both problems that would create significant disruption to such a small-scale image.

The field of view was very small, about 4cm by 5cm. This required the use of a Zuiko Digital F3.5 Macro lens, with a focal length of 35 mm. The distance from the object to the lens was also only about 5 cm. The distance from the light source to the image was about 30 cm, and the source was pointed from above the glass down at about a 30 degree angle towards the glass. The camera used was an Olympus E-500 Digital SLR, which has a sensor size of 3264 pixels on the x-axis by 2448 pixels on the y-axis. The ISO setting was 250, the shutter speed was 1/125th of a second, and the aperture was 4.5. The flow moved 2.4E-4 meters during the picture.To heighten the artistic elements of the photograph, Photoshop CS2 was used to increase the brightness, increase the contrast, reduce the yellow tones in the background color, and curves adjustments were also made.

I am very happy with my image. I feel that it did a good job of capturing dynamic fluid flow while being an interesting and aesthetically pleasing image. One thing that I didn't like with many of the dye-based images from past classes was the accidental or intentional inclusion of the experimental setup in the image. So, I like that the only thing in this image is the fluid flow. I also like the high contrast that the India ink provided between the fluid flow and the medium. There's not really anything that I dislike about this image, although there are things that I would like to try differently with this theme. During my experimentation I was also able to produce vortex rings and interesting turbulent patterns that would also make good flow visualization images. The only drawback of the technique that I used is that my setup is fairly difficult to work with because of the small field of view—it requires extremely precise manual focusing once the ink is introduced to the medium. So, even if interesting behavior is seen, it is hard to frame it so that it is artistically interesting and beautiful while also sharp and scientifically useful. Overall, I believe I fulfilled my intent in communicating the beauty and delicacy of ink behavior in water.

Appendix

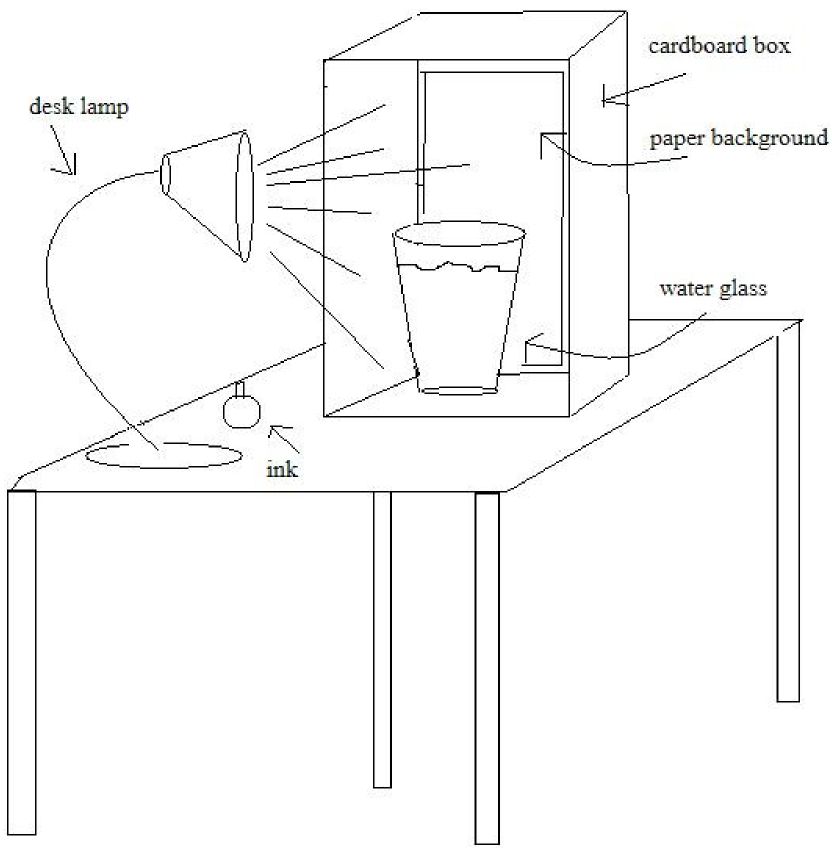

Figure 1

References

1. http://www.geophysik.uni-frankfurt.de/~schmelin/presentations/Rayleigh-Taylornew.html