Rayleigh-Taylor Mushrooms

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Flow Visualization: The Physics and Art of Fluid Flow

Project 4: Team Second

Introduction

This project was intended to be completed in collaboration with others as a team. I unfortunately was unable to join the shoot we had planned and so had to run an experiment on my own. This project was done entirely on my own, there were no other collaborators.

I have seen ink drops in water before, and found it very beautiful and so wanted to capture the phenomena for this project, thinking I could relate the ink movement to smoke. I was pleasantly surprised to find that instead the flow more closely resembled mushrooms. I decided to lean into this angle artistically.

Physics Discussion

The physics on display in the photo is largely the Rayleigh-Taylor Instability. This instability occurs at the interface between two fluids when they come into contact, where one fluid is more dense than the other. In this situation, the food coloring was the fluid with the greater density, as it fell through the water making the 'fingers' that turn into mushrooms. The curling of the 'mushroom cap' is driven by the Kelvin Helmholtz instability, which creates the toroidal wave formation due to the difference of velocities of two shearing fluids.

Bosse et al observed that at Reynolds Numbers equal to or much greater than 1, the drop begins a bifurcation pattern after its first toroidal breakdown.[1] Unfortunately I wasn't aware of this prior to the experiment and did not wait to see the bifurcation of the drops. The Reynolds Number is a dimensionless quality dependent on the density and velocity of the fluids in a flow, that predicts whether the flow will be laminar or turbulent flow. As we can see vortexes formed, that leads me to believe the flow is turbulent, contributing to the idea that this drop would bifurcate further, given more time to flow.

Experimental Setup

This experimental setup was incredibly simple. The ink used was blue food coloring bought from the grocery store. The vessel containing the water and coloring was a graduated glass beaker. I dropped two to three drops into the water and then started snapping pictures as soon as I could get my camera focused.

The lighting used was from a chandelier above the table where the experiment was set up. The chandelier uses light bulbs.

Photography

The camera specifications I used are as so:

Camera Make and Model	Canon EOS 5D Mark III
F-Stop	F/5
Exposure Time	1/200s
ISO	6400
Focal Length	65mm

I feel that one significant point of note of the image is that I don't think the ink is adequately in focus. I ran the experiment entirely on my own, so it was difficult to focus while dropping the food coloring into the water.

However, for the sake of entertaining the blur was due to motion, I calculated the scale of the motion blur. In order to do this, I found the field of view of the image using the fact that the aspect ratio of the image is 3:2 and that the camera used has a sensor size of 22.3 Mpx.

$$FOV = width\ of\ object * (Actual\ width\ of\ image\ /\ size\ of\ object\ in\ image)$$

$$= 8cm\,(\frac{5760px}{2650px}) = 17.4cm$$

$$Width\ of\ image\ by\ sensor\ =\ \sqrt{(3/2)(camera\ sensor\ size\ in\ pixels)}$$

$$=\ \sqrt{(3/2)\ (22.3\ \times\ 10^{6})}\ \simeq\ 5784$$

$$Blur\ in\ real\ life\ =\ FOV\ (Blue\ in\ image\ /\ Width\ of\ image\ by\ sensor)$$

$$=\ 17.4\ (\frac{5px}{5784px})\ =\ 0.015cm$$

Knowing the size of the blur in real life, we can then estimate the velocity of the flow:

$$v\ =\ blur\ in\ real\ life\ /\ exposure\ time\ =\ 0.015cm\ /\ 200^{-1}s\ \simeq\ 3\ cm/s$$

Considering the food coloring was drifting very slowly, a velocity on the scale of 3 centimeters per second seems entirely reasonable.

When it came to editing the image, the following settings were used to manipulate the image. All edits were done in Adobe Lightroom.

Setting	**Percentage Changed**
Contrast	-100 %
Blacks	-70 %
Saturation	0 %
Grain, Texture, Clarity	+5 %

Below are the iterations of the edited image.

Fig.	Notes	Image Iteration
3	The raw image. JPG File	
4	Edited. Uncropped. PNG File exported through Adobe Photoshop	
5	Final cropped image. JPEG File	

Conclusion

The image's flow reveals the first stage in suspension droplets' bifurcation pattern. I'm reasonably content with the outcome of my image, the only stipulation being that I think I could have done a better job of getting the flow in better focus if I had asked another to assist me in the experiment by dropping the food coloring so that I could have my hand free to focus the camera while the drops fell. That being said, I still feel the flow physics are shown very well.

If I were to do the experiment again, I would have someone else assist me, and I would try to get the further iterations of the bifurcation process droplets undergo when dropped in water.

Works Cited

1. T. Bosse, L. Kleiser, J. Favre, E. Meiburg; Settling and breakup of suspension drops. *Physics of Fluids* 1 September 2005; 17 (9): 091107. https://doi.org/10.1063/1.1942520