Visualization of the Rayliegh-Taylor Instability using Acrylic Paint

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Assignment: Get Wet
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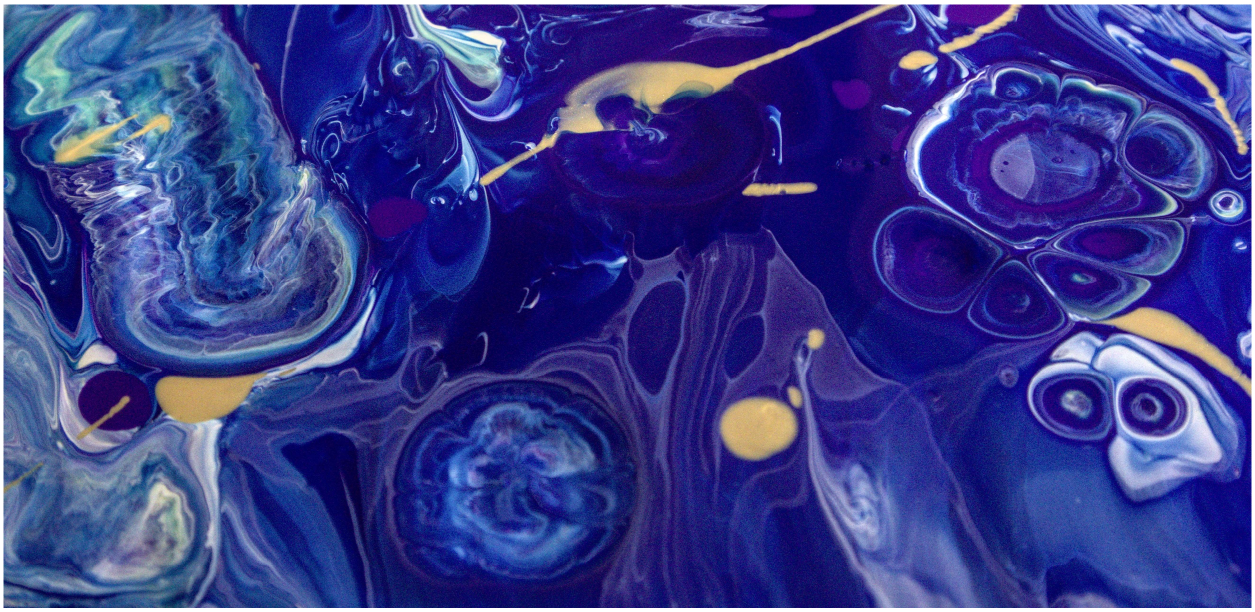

Figure 1. Rayliegh-Taylor Instability demonstrated by Acrylic Paint Pour

Background

The intent of the photograph in figure 1 was to demonstrate the Rayleigh Taylor Instability using acrylic paint pouring. The paint colors were selected such that an aesthetically pleasing image was created, encouraging an artistic angle to flow visualization. Additionally, the fluid dynamic principle of Reynolds Number and the natural repulsion between oil and water influenced the image. Analysis of these principles and the concepts are vital to explaining how the image was created.

Set Up

The materials required to conduct this experiment are one acrylic paint pouring set, one 10 x 10-inch canvas, a plastic cup, a trash bag, Q-Tips, and coconut oil. To set up for this experiment, place the 10 x 10-inch canvas on the trash bag. Pour different colors of paint into the cup, one by one. For this image there all the colors had a one part to one part ration, except white which had two parts. Next, the canvas was placed face down on top of the cup and the two were flipped together until the cup was face down on top of the canvas. The cup was then slowly lifted so that the paint could spill out over the canvas. The canvas was then tilted to ensure it was completely covered and a Q-Tip was used to create patterns in the paint. The paint was allowed to settle for about 10 minutes before coconut oil was dripped into the paint. The oil and water-based paint were given about 5 minutes to react. The complete set-up of the experiment can be seen in Figure 1.

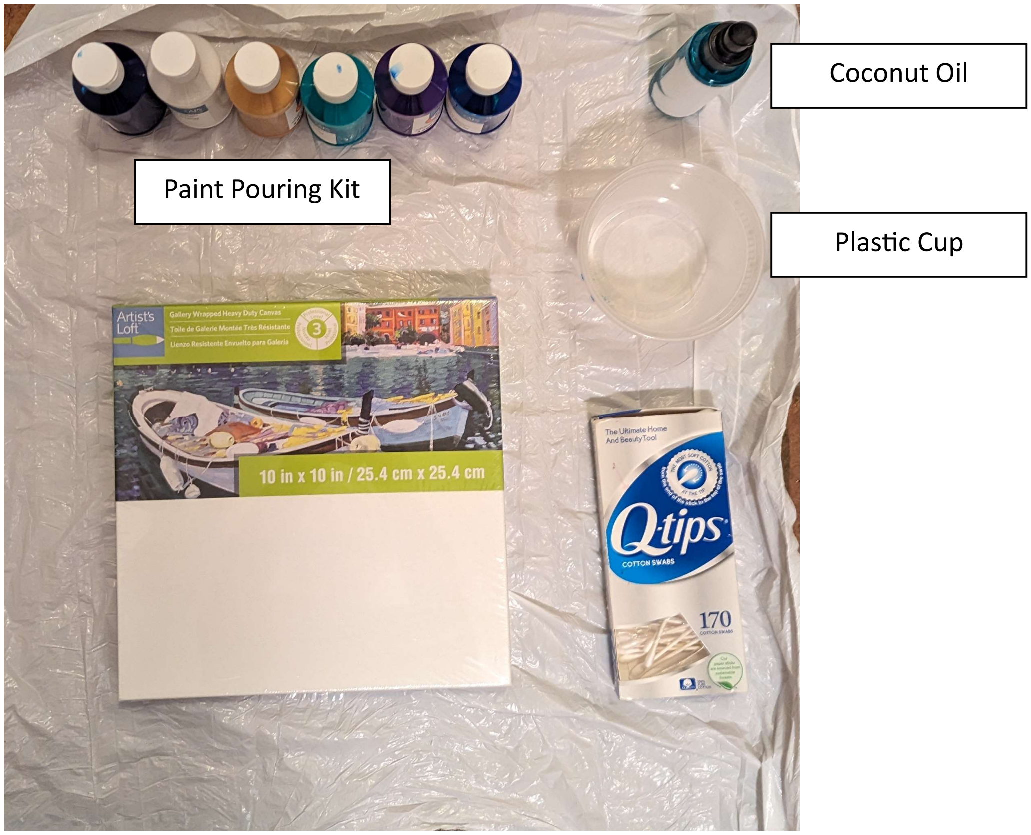

Figure 1. Experiment Set-Up

Physics of the Fluid

Rayliegh Taylor Instability

The Rayliegh Taylor Instability is the interaction between the interface of two fluids that have different densities. More dense fluids will push against less dense fluids, causing a shift in the interface [1]. The Rayleigh Taylor Instability is caused in the experiment because each color of paint has a different density. In general, the lighter the color, the denser the paint [2]. Since the paint was added to the cup from lightest color to darkest color, the densities of the paint naturally caused the Rayliegh Taylor Instability when the cup was overturned onto the canvas. The Instability can be seen throughout the photograph with the clear interfaces between the colors.

Reynolds Number

Turbulent or laminar flow is determined by the calculation of Reynolds Number. Laminar flow has a Reynolds Number of less that 2000 and is visualized by undisturbed layers of fluid. Turbulent flow has regularly mixing layers and has a Reynold Number over 4000. The Reynolds Number for the experiment was estimated to be 294 using equation 1 [3]. The density of paint was estimated to be 1500 kg/m^3 [4] and the viscosity was 0.1 m^2/s [5]. The velocity was assumed to be equal to gravity.

$$Reynolds\ Number\ (Re) = \frac{\rho D V}{\mu} = \frac{1500\frac{kg}{m^3} * .002\ m * 9.81\frac{m}{s}}{0.1\frac{m^2}{s}} \qquad \text{Eq.1}$$

$$\rho = density\ of\ air;\ D = width\ of\ opening\ in\ paint\ bottle;\ V = mean\ velocity;$$

$$\mu = viscosity\ of\ a\ fluid$$

The Reynolds Number is an important facet of this experiment because the paint had to be added to the cup, and subsequently put on the canvas using laminar flow. Laminar flow ensures that the different colors of paint do not mix. There is an example of turbulent flow on the left side of the image which was created by dragging a Q-Tip coated in coconut oil through the paint.

Oil and Water Separation

In the art of acrylic paint pouring, the phenomena created by adding oil to the water-based acrylic paint is known as big cells. The 'big cells' and created by the natural repulsion between the water in the paint and the carbon in the oil [6]. The physical phenomena can best be seen by the formation of the quasi-circular formations on the right side of the image.

Visualization Techniques

To capture this image the experiment was conducted on two occasions. The first experiment was set up with lighter colors added to the cup first. In the second experiment, darker colors were added to the cup first. The lighting was also different between the two experiments. In the first experiment, natural lighting was used while a flashlight with 260 lumens approximately 12 inches to the side of the canvas was used to illuminate the second experiment. A white wall was used to bounce back light onto the experiment to provide further illumination. During each experiment numerous angles and settings were used to take a wide range of photographs.

Photographic Techniques

The camera used to photograph this experiment was the Canon EOS M50 Mark II with a 15 to 45 mm lens. The photograph selected had the camera characteristics listed in Table 1 at the time of the photograph. Throughout the experiment, pictures were taken from various angles. Photographs were also taken in spurts, giving the coconut oil and the paint additional time to react. The final photograph selected was taken approximately 25 minutes after the paint was dumped over the canvas and 15 minutes after the coconut oil was added. The image has a special resolution of 1:1000, or three decades. For laminar flow, this is sufficient to capture the flow fully and accurately [7]. Temporal resolution, calculated using the information obtained on the Flow Vis Website, was estimated to be 1 pixel. This was estimated using a blur of approximately 10 pixels and a field of view of 12 cm. This singular pixel is likely the result of motion blur from the photographer since the fluid was stationary at the time the photograph was taken.

Table 1. Camera Specifications for the Photograph

Specification	Description
Aperture	f/5.6
Exposure	1/40
ISO	3200
Focal Length	24 mm
Focal Distance	0.30 m

Once the photograph was selected, figure 3, it was edited to help enhance the flow and reduce distractions. The original picture size was 6024 pixels wide and 4020 pixels tall. This was then cropped to the dimensions of 5261 pixels wide and 2544 pixels tall, removing the white surrounding area from the picture and focusing the paint swirls on the lower half of the image. Next, the RGB curve was slightly adjusted to enhance the white paint swirling with the darker blue paint. Finally, local contract was increased by 17% to further increase the contract between the white and the blue paint.

Figure 3. Original RAW Image

Conclusions

The process to generate this image was easily my favorite of all the experiments. It yielded the most aesthetically pleasing image while also displaying a wide array of scientific principles. Additionally, though continued use of my camera, I am finally learning how to manipulate the settings to yield my preferred results. Moving forward, I want to develop different ideas and experiments that continue to yield artistic photographs that easily convey scientific principles to the audience.

References

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[6] CICbec. “How to Create Cells When Acrylic Pouring | Expert Tips and Tricks.” *Canvas in Common*, 24 Nov. 2020, canvasincommon.com/acrylic-pouring-cells/#how. Accessed 2 Nov. 2023.