Get Wet

Flow Visualization: The Art of Fluid Flow

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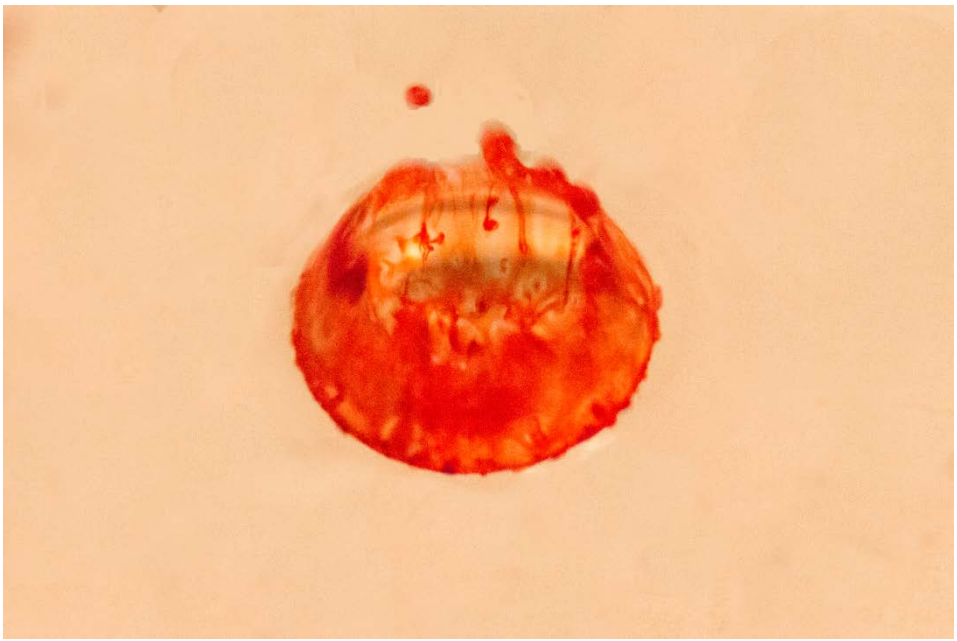

Background: The purpose of this image was to demonstrate a significant physical phenomenon of fluid mechanics in the form a visually striking presentation. This project "Get Wet" specifies some fluid as the subject to the image being captured. While the planning and idea was the work of author Andre Szlendak he collaborated with Liz Whitman as an assistant for the image capturing. While many fluid phenomena (Non-Newtonian shear, dual-phase mixtures, and non-liquid fluids were explored) this experiment was chosen as it is most concise in demonstrating physical characteristics with visual appeal. It was hoped that dropping colored water into a static pool under adequate circumstances could provide striking images and demonstrate surface tension, and radial jets.

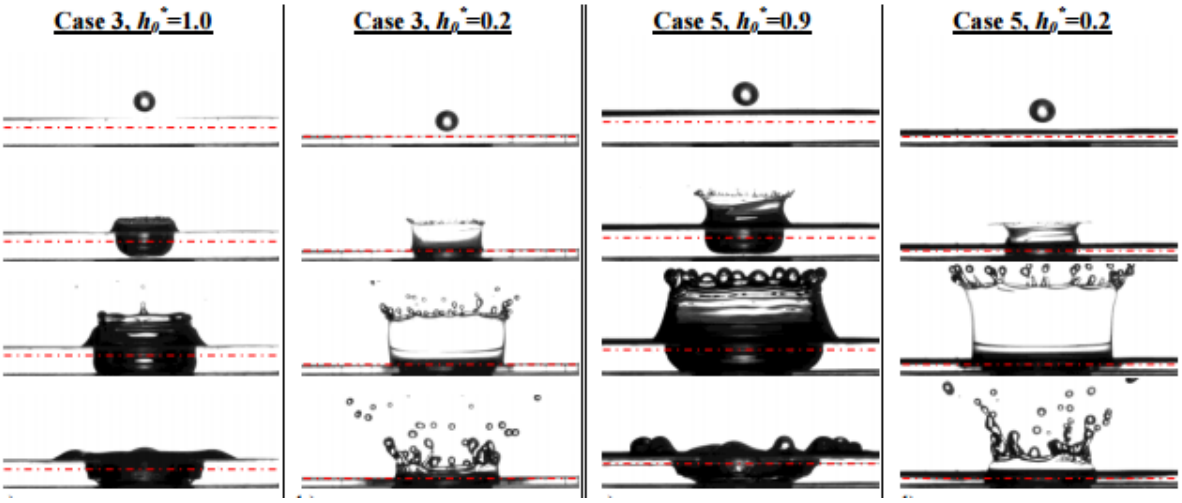

Figure 1 Crowning effect of Weber Number from Hillen's Droplet Impact Time Histories

Image Capture: While conducting the experiment was straight forward, preparing the apparatus and collecting a proper image was an extensive process. The experimented consisted of a dyed water droplet 1[cm] in diameter being released from half a meter above a static 2 [cm] deep pool of water *(see figure 2)*.

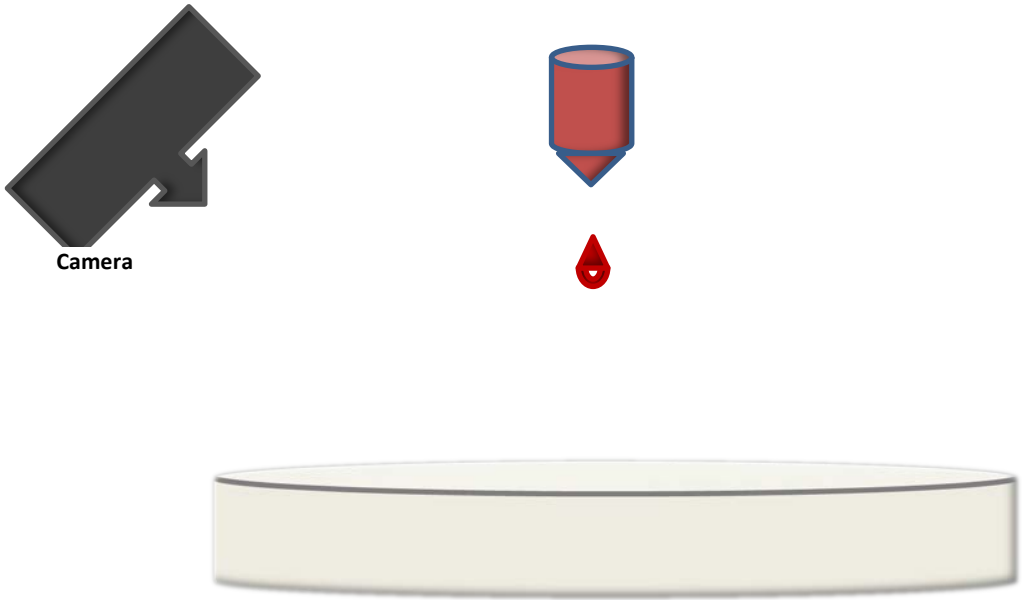

Figure 2: Experiment Orientation

The result of the experiment was a splash captured in time demonstrating the aforementioned characteristics. Harold Edgerton did extensive research of these characteristics and their imaging. The mechanism for such a striking image is labeled the Worthington Jet. In this experiment it works by the droplet causing disturbance on the static water container. That disturbance creates pressure gradients. At first the gradient pushes pressure out away from impact like a shock wave, but the pressure returns here in the form of surface tension of the surrounding liquid and hydrostatic pressure wanting to return to that uniform flat state rather than in waves. The returning pressure gradient back to the impact forces the water up as that's the low pressure release. The result is this explosion leaping from the surface outlined by the colored water originating from the droplet.

The calculated Weber and Reynolds gave an idea for the flow characteristics to be expected. The Reynolds number (3087) predicted a non-laminar flow that isn't completely turbulent. This is intuitive considering the velocities and scale of the experiment. Likewise **Jinyoung Kim's** research at Rochester University suggests substantial crown height under such conditions proportional to the Weber number. Their research explains the cohesiveness and consistency of splash size in this image. The results were predictable, which is substantial considering the unstable nature of the phenomena.

$$Re = \frac{vL}{\nu} \approx 3000$$

$v = droplet\ velocity\ (3.31\ [m/s])$
L = droplet diameter (1 [cm])
$\nu = kinematic\ viscosity\ of\ water$ **at 23° C (1.004 [m^2/s])**

Equation 1: Effective Reynolds Number

$$We = \frac{\rho v^{2} L}{\sigma} \approx .50$$

$v = droplet\ velocity\ (3.31\ [m/s])$
L = droplet diameter (1 [cm])
$\sigma =$ **surface tension of water at 23° C (71.8 [N/m])**
$\rho = density\ of\ water$ **at 23° C** $(1000\ [kg/m^3])$

Equation 2: Effective Weber Number

Image Capture: To show contrast and highlight the physical phenomena, water color dye was used. Dye was ideal in that it clearly demonstrated the different motions and movement of the fluid without compromising the fluid characteristics or behaviors. The dye was sourced from Kroger generic food coloring in a 4 oz. bottle with dropper. All water used was tap water. Tap water has acceptable characteristics and has standards not substantially deviant from distilled deionized water. The experiment was conducted in controlled conditions. It was done indoors away from significant air turbulence or drafts. For lighting, at night with no other sources, two 100 Watt standing lights were

diffused with cotton white pillowcases on either side of the apparatus. No camera flash was used evident in the soft no reflecting results.

Photographic Technique: There was little necessary field of view as the phenomena was small relative to the distance to the camera lens. The field of view was no more than 40 [cm] with a camera distance of .5 [m] and a 47mm focal length. Using a digital Canon Rebel t5i with specific iso6400, f/5.6, and 1/125 second shutter speed gave a 5184 x 3456 pixel original image. That image was edited using GIMP and cropped to 2651x1767 pixels. The image was cropped, removing the irrelevant portions. The background was then brushed for a more homogeneous color to limit distractions. Finally, the contrast was limited to the substantial center of the spectrum and enhanced to increase the contrast between the Worthington Jet and static water. Changing the contrast also changed the transparency of the crown further showing the layers beneath the front side of the crown.

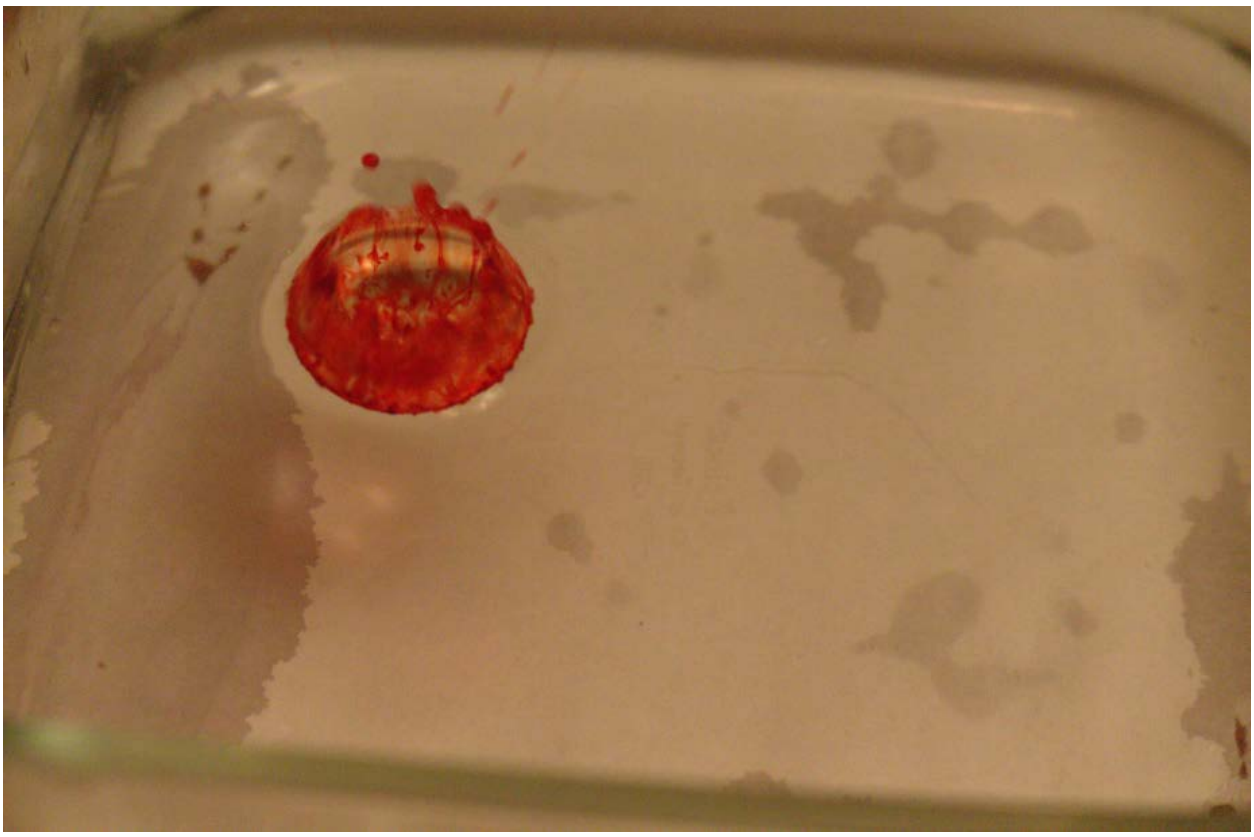

Image 1: Original Image

Takeaways: The image is a good representation of a Worthington Jet. More specifically, it demonstrates the crown effect of a Worthington Jet as characterized according to the Weber number. Personally I think this image is striking for capturing the moment the crown comes together, propelled by the Worthington Jet, but held together with surface tension. I think the physics were demonstrated well, you can almost see the force balances and motion of the different parts. I struggled with motion blur, and think in general the image was grainy. This image could be improved with varying static water depths and drop heights and see the variance in crown sizes both in diameter and height.

References:

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