Worthington Jets visualized *via* a Water Drop

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1. Introduction

The goal of this report is to describe the process and scientific background behind the captured image depicting the impact of a water droplet upon the surface of still water. This image was captured as an assignment for the course "Flow Visualization" (ATLS 5519).

The experimental setup and photography was done with assistance from Sophie Adams, Shalil Jain, and Kensue Kiatoukaysy.

2. Worthington Jets

In fluid mechanics, the Weber number is a useful concept in analyzing how two different fluids flow when interacting with each other. As a mathematical expression, the Weber number is written [1] as:

$$\mathrm{We} = \frac{\rho\, v^2\, l}{\sigma}$$

Equation 1. *The Weber number, We, is calculated from the fluid's density (ρ), the fluid's velocity (v), the diameter of the droplet (l), and the fluid's surface tension (σ).*

Droplets with higher Weber numbers have the right amount of energy to produce a splash when it lands on a fluid surface. High Weber numbers can also be attributed to droplets having non-spherical or oblong shape.

The term "drop impact" describes the outcome of the collision of a liquid droplet and another surface, either solid or liquid in nature. If the surface is liquid, one of several outcomes can occur: bouncing, spreading or splashing [2]. If the collision creates a splashing effect, the drop creates a crater in the surface, resulting in a crater that moves outward and creates a "crown" shape around it. In addition, as the impacted water rushes back into place, a stream of water moves outward from the center. This resulting stream is called the Worthington jet, also known as the Rayleigh jet [3]. When the droplet impact velocity is sufficiently high, the resulting jet will sometimes neck down to such a narrow diameter that a new, separate droplet forms.

3. Apparatus and Visualization Technique

The liquid used in this experiment was a dilute solution of tartrazine dye in tap water, creating a yellow hue. The thick, sticky dye was added to the water by stirring a dye-dipped toothpick around in the water until the desired intense yellow color was obtained. A wine glass served as the container for the liquid surface, while the droplets were produced with a small plastic dropper. The dropper was placed approximately one foot above the apparatus. A 50-Watt tungsten light served as the light source; the room was moderately lit by daylight. A black drape was used for a black background.

In the image in Figure 1, the water released from the dropper has already landed onto the liquid surface. The resulting crater is the most prominent feature of the resulting impact, as well as the crown spreading toward the wine glass. The Worthington jet itself is not seen in the final image. The colors of the original image were then inverted to yield a blue color scheme.

5. Photographic Technique

The following camera settings were used to capture the photograph:

Camera and Image: Nikon D7200, 6016 x 4018 pixels (w x h)

Focal length: 70 mm

Exposure settings. ISO 6400, shutter speed 1/2500 sec, f-number of 1.8.

Figure 1. *Final edited version of the image, with colors inverted.*

Figure 2. *The original image.*

6. Image Commentary

As a team, we took a great many photos similar to the above. Some had very pronounced Worthington Jets, while others, such as this one, captured multiple jets shooting up from the reservoir simultaneously. I found this feature quite striking, in addition to it being quite well centered in the middle of the cup. This image came out slightly noisier than some of the others we took, so I tried a number of filtering options to improve the photo. Since filtering came at the cost of some of the sharpness in the jets, I elected to instead invert the image colors. Many reflections and several small water droplets clinging to the glass were edited out, with the overall goal of focusing the viewer's eye just below center.

References

[1] Arnold Frohn; Norbert Roth (27 March 2000). *Dynamics of Droplets*. Springer Science & Business Media. pp. 15–.

[2] Philip Day; Andreas Manz; Yonghao Zhang (28 July 2012). *Microdroplet Technology: Principles and Emerging Applications in Biology and Chemistry*. Springer Science & Business Media. pp. 9–. ISBN 978-1-4614-3265-4.

[3] Rein, Martin. "Phenomena of liquid drop impact on solid and liquid surfaces." Fluid Dynamics Research 12.2 (1993): 61-93.