

A Systematic Study of Splashes

Project Completed by

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Introduction:

The first person to complete a systematic study of splashes was A. M. Worthington in 1894 in his book A Study of Splashes¹. Later on, Harold E Edgerton also photographed splashes in Stopping Time² and Moments of Vision³. Our project differs from Worthington's because we examined water splashes from above and below the water at the same time.

Goals:

The goal of our project was to examine the splash of a water drop from above and below the water level and its formation with a constant change in time interval. We examined the drop from right before it hit the water until the spout reached its pinnacle.

Equipment:

Sony Digital Still Camera- DKC-FP3

Apple II+ Computer with interface and Intervalometer 2 program⁴

Light Box

Milk Drop Station

Photogate

4x4, c-clamps, and tripod screw to secure camera

Clear plastic container to hold water

One Vivitar 283 flash

Technique:

To study the splash of a water drop, we started taking pictures before the drop hit the water and then every 10 milliseconds after until the spout reached its pinnacle. To accomplish our goal we overcame many challenges. The obstacles in our project were the lighting of the subject, focus, and timing.

Water is very hard to light and capture in a photograph because of its transparency and its ability to refract light. We tried to use a stroboscope to produce a flash at a given time interval and light our subject. This was a good tool to help us study the formation of the drop, however the light emitted by the stroboscope was not bright enough to light the subject from the side. Finally we decided to light the subject from beneath. We accomplished this task by using an apparatus designed by a former student. This device was made from an old overhead projector (see appendix for drawing). The device allowed us to use a Vivitar 283 flash to illuminate the small container of water and the drop from beneath. This lighting worked well.

The next problem we faced was focus. Because water is clear and it refracts light, the subject was very hard to focus on at such a close distance. We had several photo shoots before we finally got the focus clear. Part of the problem was the stability of the camera base. We were able to use a 4x4 and a tripod mounting screw to secure our camera and minimize movement. Because the drop was moving we had to focus on another object that was where the drop would be. We put a pencil in the water and focused until we could read the writing on it.

Timing was the biggest problem. When the water dripped into the small container, it raised the water level, which changed the distance between the photogate

and the water, therefore changing the stage of the splash captured by the flash at a constant time interval. In the end we were able to shoot the pictures quick enough that the height of the water did not change significantly.

The procedure began by connecting the Apple II+ to the photogate and the flash. Then we filled the small plastic container with water to a certain level marked on the side. Then we put water in the dropper. Next we had to experiment to find when the drop hit the water and how long afterwards the spout reached its peak. Last was the stage for taking pictures. We mounted the camera, zoomed and focused on a pencil in the water, and then it was time to take photographs. The lights were turned off and the drip was started. We took several pictures at each time using a shutter speed of one second to ensure that we got a picture for that time interval and to minimize ccp noise. Then we examined our pictures.

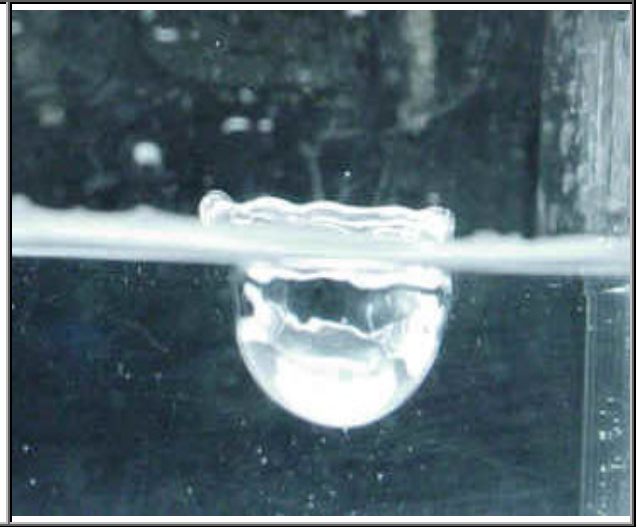
Photographs:

In our experiment we used a Sony digital still camera to capture the pictures below. On the camera we had an f-stop of 6.7 throughout the experiment. The shutter speed remained constant at 1 second. The focal length was 5.2 mm. The ISO or film speed was 400. The flash mode was on the zero K resistance and adjusted to minimize the flash at about 1/30,000 of a second. The image resolution of the pictures was 1344 X 1024 when we took them. The camera was approximately 10cm from the subject. We also used a Vivitar 283 flash unit that was triggered by a delayed photogate for the light source. The subject distance to flash was .3 meters through a mirror. The photogate was about 15 cm above the water. When the water drop passed through the photogate a signal

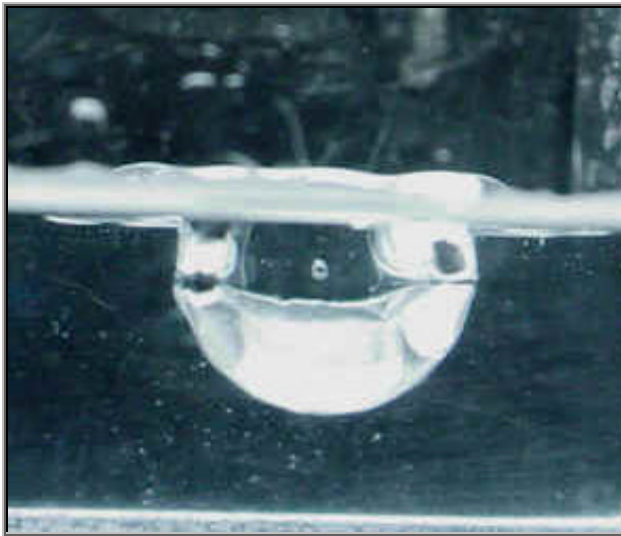
was sent to the flash unit to go off after a certain time. This flash unit provided the light needed to expose the film since we were taking pictures in the dark. The delay time between the subject going through the photo gate and the flash unit going off varied to get the different pictures below. We first found the delay time for a drop above the water. Then we found a delay time for a drop to be half way in the water. Finally we found the delay time for when a drop first impacts the water. After we found the impact delay time we took a sequence of pictures with the delay time being 10ms between each other. In all the pictures we had a water height of 2.35 cm for experimental control.



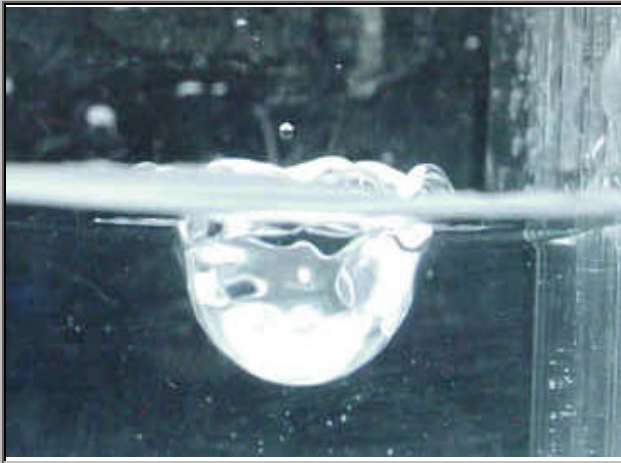
dye40002.jpg	dye40004.jpg
<p>Delay time: 207 ms In file dye40002.jpg, the water drop is just about to impact the water. It is oval because of the surface tension on the water.</p>	<p>Delay time: 215 ms In file dye40004.jpg, half the drop is above and half is below. This is just when the water drop has impacted the pool. You can't see the bottom half because the water has ripples at the water level.</p>



dye40011.jpg	dye40016.jpg
Delay time: 216 ms In file dye40011.jpg, all the drop has entered the water to make a small depression.	Delay time: 226 ms The depression widens and deepens in file dye40016.jpg, and a crown has formed at the top.



dye40018.jpg	dye40021.jpg
Delay time: 236 ms The depression continues to widen and deepen and shows distinct facets on the depression in file dye40018.jpg.	Delay time: 246 ms In file dye40021.jpg, we believe that the depression is now shrinking and is beginning to get flat.



dye40023.jpg

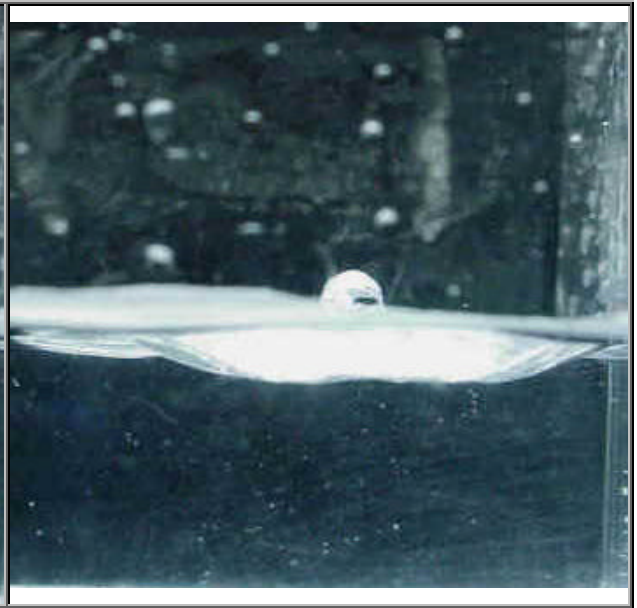
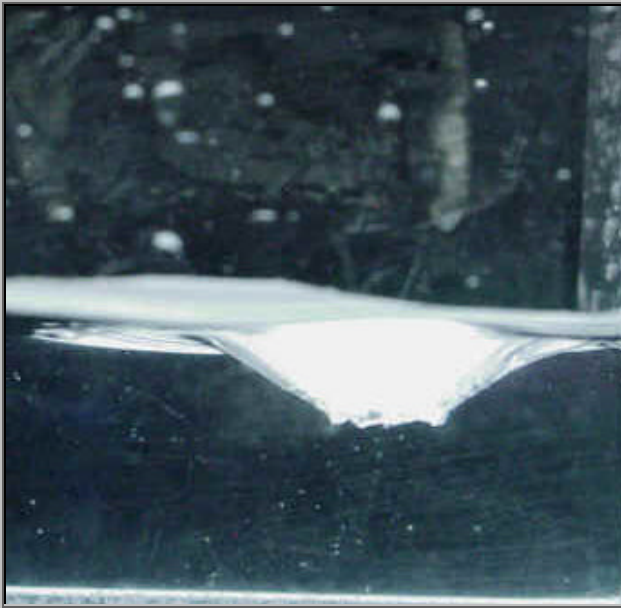
Delay time: 256 ms

In file dye40023.jpg, the depression is basically staying the same. The waves could be caused by ripples in the container.

dye40026.jpg

Delay time: 266 ms

In file dye 40026.jpg, the depression is losing its bowl shape and is starting to flatten. Also note the small bubble on the bottom.



dye40029.jpg

Delay time 276 ms.

In file dye40029.jpg, the depression is flattening into a funnel form with a flat bottom.

dye40031.jpg

Delay time 286 ms.

In file dye40031.jpg, the depression continues to flatten, and the spout is now forming above the surface of the water.



dye40036.jpg

Delay time 296 ms

In file dye40036.jpg, the spout continues to heighten, take notice that the spout is ribbed and the big drop at the top is a separate drop coming down.

dye40038.jpg

Delay time 306 ms

In file dye40038.jpg, the spout smoothens and continues upward.



dye40040.jpg

Delay time: 316 ms

In file dye40040.jpg, the spout is at its pinnacle and a drop is now separating from the spout.

Discussion of Results:

With the observations we made from the sequence of pictures, we can conclude that once a drop hits a body of water, a depression is formed. The depression has very symmetrical form and looks almost bullet-shaped. This depression widens and deepens as time goes by. We observed that this depression then contracts and loses its shape to form an upside down volcano shape, which is flat at the bottom and evenly sloped on the sides. This crater shrinks and then a drop appears which rises to form a pillar. This pillar rises and a secondary drop then separates from the pillar at the top.

For this project we used an Apple II computer running Intervalometer 2. After several trials, we learned that the computer was not sensitive enough to detect the photogate. We then switched our setup to include a modified milk drop setup using the black boxes and photogate but keeping the overhead lighting and the computer. In the final photo session, we didn't use dye and instead took pictures of the water splashes since the dye made things more difficult and time consuming. This setup proved to be our most successful and was the setup used to capture the majority of our images.

Throughout this project, we discovered that this project was more difficult than we had imagined. Things such as the water level in the container, the amount of time the dye took to go through the dropper and the height of camera all had to be factored into the project. This turned out to be quite a challenge for us. The constant changing of the setup also proved to be a challenge as it took up some of the time needed to take pictures. Some sources of error in our determination of the delay could be attributed to the fact that the water level was always changing. This meant that even though the delay was the same in two pictures, they weren't necessarily at the same stage of development. The

changing of water levels could have affected our delays by a small amount. The time changed by about a millisecond for every cm in height difference.

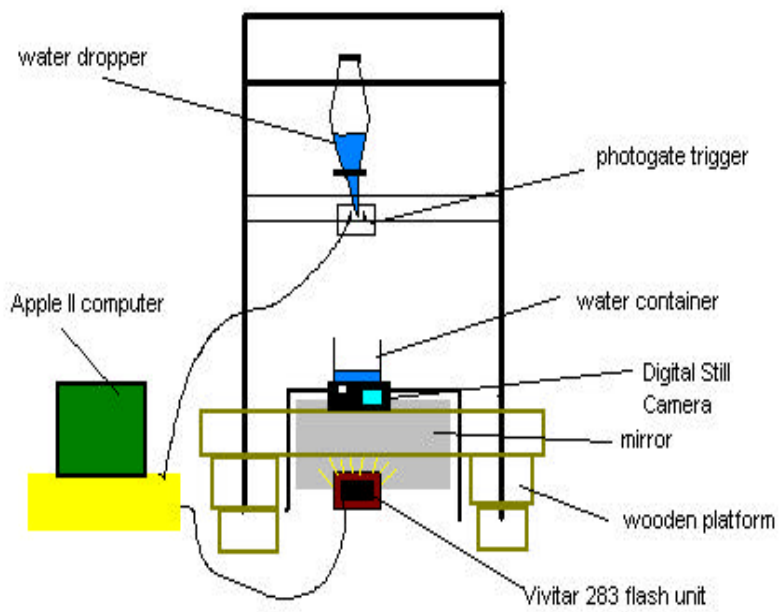
Conclusion:

In conclusion, we were able to achieve our goals in this project by taking pictures throughout the time interval from drop to spout at equal time intervals. Because of the relatively big time interval (10 milliseconds), some developments in the splash were not seen. With additional experimentation, we could examine the splash using smaller time intervals to see the changes. All in all though, the changes in the splash were extremely interesting to see and to take pictures of and we were successful in meeting our goal.

References:

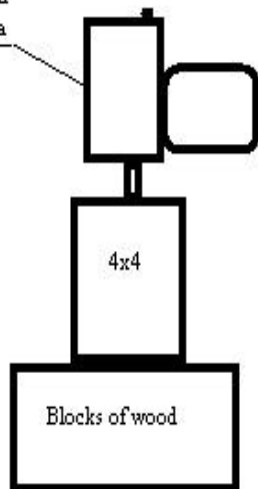
Thanks to Dr. Winters for making the base for the camera and the use of the Intervalometer 2 software, and for his help throughout the project.

1. Worthington, A. M. A Study of Splashes. The MacMillan Company. New York. 1963.
2. Edgerton, Harold E. Stopping Time: The Photographs of Harold Edgerton. Harry N. Abrams Inc. New York. 1987
3. Edgerton, Harold E., Killian, James Jr. Moments of Vision: The Stroboscopic Revolution in Photography. MIT Press. Cambridge, MA 1985.
4. Winters, Loren. "High Speed Photography with Computer Control" The Physics Teacher. 1991.



SIDE VIEW

Sony Digital
Still Camera



Clear container
of water

Old overhead
projector used as
lighting apparatus

Vivitar 283
Flash Unit

