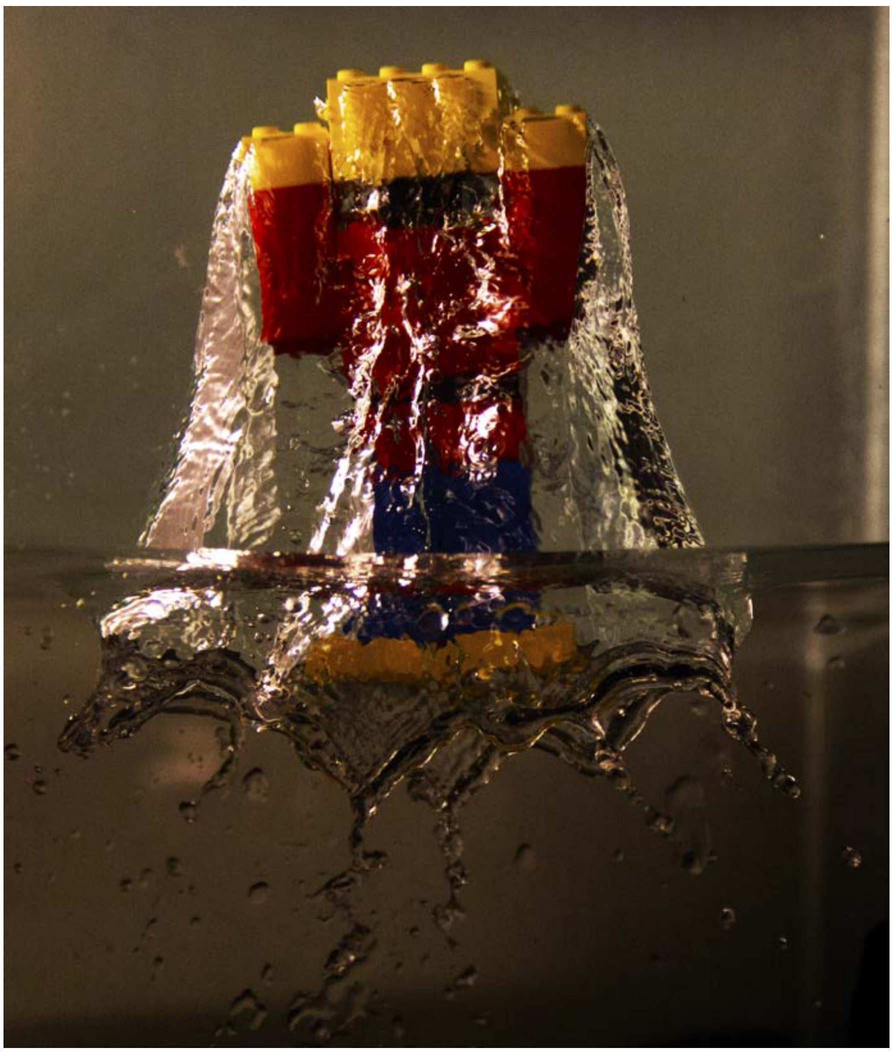
Cavitation Man

April 6th, 2014
MCEN 5151



Lego Man Dropped in Water By: Eric Fauble

In Accordance with Alex Unger, Zac Rice, and Scott Hodges

Purpose:

This is the final of three group photographs taken throughout the semester. After some inspiration from Professor Tadd T. Truscott and his splash lab at BYU the group decided to capture a very dynamics flow. Thus, this photograph is a splash frozen shot in time. It took a lot of fiddling and trials in order to capture this shot, but in the end the photograph turn out great.

Set-Up:

The setup for this photo graph was pretty straight forward. A fish tank, roughly 20 gallons, was filled up ¾ full of water. The camera was mounted on a tripod about 3ft away from the fish tank. The whole setup was illuminated by the bright lights of the room as well as by an LED strip that was place at the bottom right edge of the fish tank. This lighting arrangement did a good job in evenly illuminating the falling objects, however due to the high shutter speed more and brighter lights would have been helpful. Unfortunately, most halogen/work lights could not be used effectively because splashing water caused a safety hazard in the case of the lights accidentally coming in contact with the splashing water.

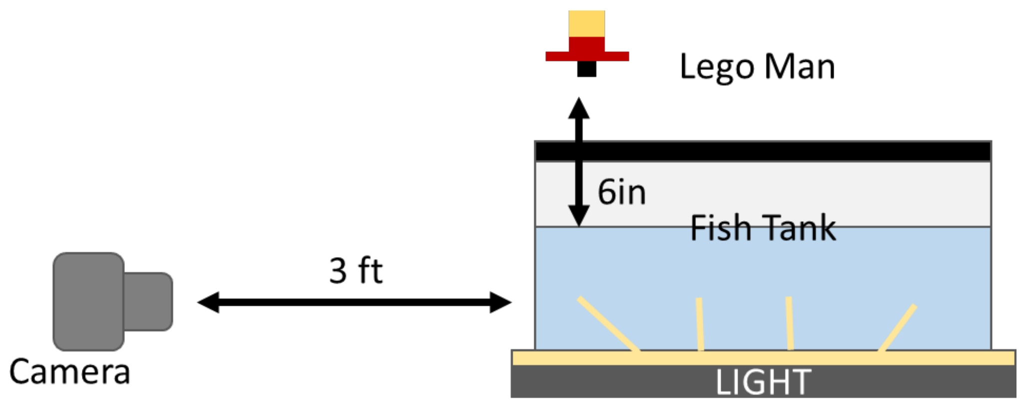


Figure 1: Schematic of setup used to capture splash mechanics

Fluid Physics:

Flow Description:

This experiment investigates the splash dynamics that occur when an object collides with the calm flat surface of water. The mechanics of the splash capture from the non-uniform shape of the Lego man is very similar to the splash mechanics of a sphere. Their differences lie in the irregularity of the shape of the splash, but do not have much of an effect on the overall mechanics.

The compilation of photos seen below were taken by Prof. Tadd Truscott and shows the step by step mechanics of a sphere falling into a pool of water.

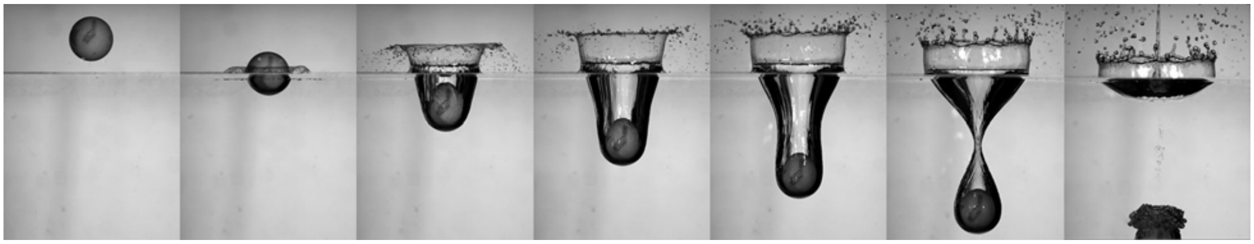


Figure 2: Sphere entering water[1]

When the sphere initially collides with the surface of the water is shoots out a radial jet at 20 to 30 times the speed of the impact velocity.[1] Inertia and buoyancy forces allows the sphere to continue to descend through the water, leaving an air cavity in its wake. However, the air cavity is unstable because it exist at a lower pressure than the surrounding water.[2] The air cavity begins to collapse into an hour glass shape. Once the water causes the air cavity to pinch and separate water rushes into the open cavity. This is the beginning of the Worthington jet that jets up above the surface of the water following a splash.[1]

The photo of the splash taken of the Lego man followed the same mechanics as the sphere described above. By comparing the fourth photo in figure 2 and the original photo you can see the striking similarities.

Figure 3: Comparison of splash mechanics

The radial splash featured in the photo is sometimes called a crown splash because of its resemblance to a medieval crown. It should be noted that this crown splash does not always occur when an object enters a water. The splash could be more like an turbulent explosion like those of a bullet entering water or like a smooth cylindrical wall without the distinguish droplet spikes of the crown splash. What determines the particular shape of a splash is based on the relationship between the Weber number and the Reynolds number. The Weber number is a unit less number that characterizes the ratio between inertial and surface tension forces. The equation below is how the Weber number is calculated, while the Reynolds number is a unit less number that characterizes the ratio between inertial and viscous forces.[2]

$$We = \frac{\rho v l}{\sigma}$$

$$Re = \frac{\rho v l}{\mu}$$

Where ρ is the density of a fluid, v is the velocity, l is the characteristic length, σ is the surface tension, and μ is the dynamic viscosity.

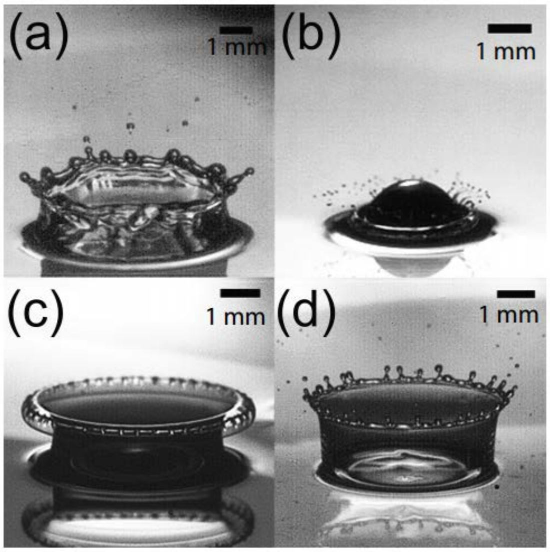


FIG. 6. Morphologies of splashes outside of the crown splash regime: (a) water (Re=6044, We=254, H*=0.2) produces a highly irregular crown sheet and splash, (b) glycerol/water mixture (Re=2566, We=314, H*=0.2) produces droplets immediately upon impact, long before the crown sheet forms, (c) silicone oil (Re=1392, We=1266, H*=0.2) produces a trapped torus of air, and (d) isopropanol for Re=1354, We=406, H*=0.2 produces a wavy crown sheet and continuously ejects droplets as the crown grows upward.

Figure 4: Various crown splashes[3]

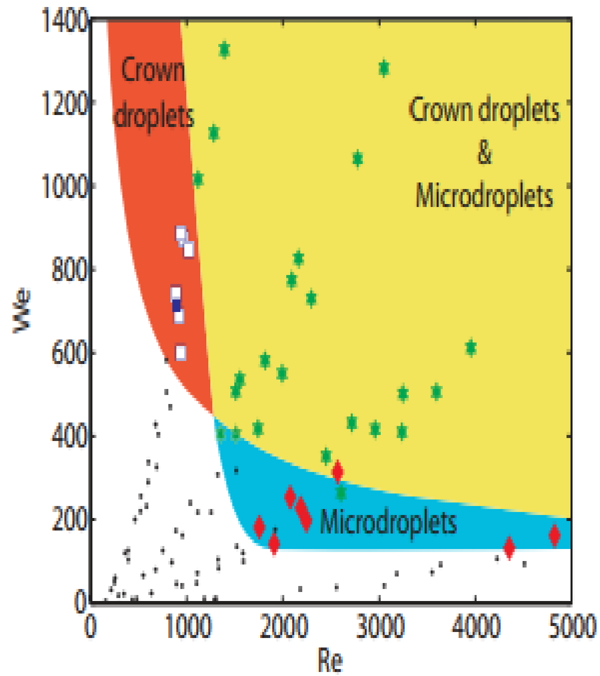


Figure 5: Splash characteristics based on Weber and Reynolds numbers[3]

Figure 4 shows the effects on the crown splash from various Reynolds and Weber numbers. Figure 5 is a graph of that categorizes the splash base on the ration of We number to the Re number. With the help of engineeringtoolbox.com, I was able to estimate the Reynolds and Weber number for this photo to be **Re: 2344** and **We: 1803**.[4] This characterizes the splash to have the crown shape with the existence of micro droplets, which is the same characterization as image **(a)** in figure 4, which also looks the most similar.

Photographic Technique

Camera Settings:

To properly capture this photo and eliminate as much motion blur as possible a Canon EOS 60D with an 18-55mm focal length lens was used. The ISO was set to 2000, the aperture was set to f/5.6, and the shutter speed was snapping pictures every 1/1600 of a second. The focus was set at the depth of the falling object, which in combination with the aperture kept the splash and Lego man in focus. The combination of the high shutter speed and small aperture restricted a considerable amount of light from entering the camera, and the photo graph probably would have benefited from an increase in lighting.

Post Processing:

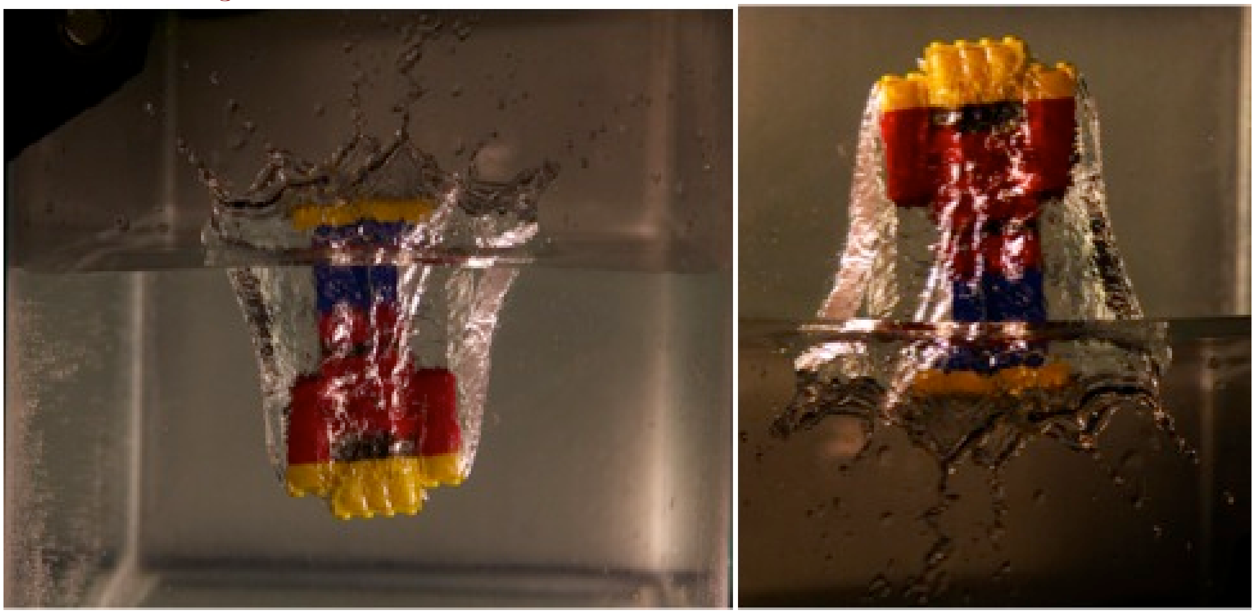


Figure 6: Original photograph on the left and the edited version on the right

The post processing done on this photograph was fairly small. The biggest changes was that the photo was the edges of the fish tank were cropped out in order to only highlight the splash and air pocket that formed behind the falling Lego man. The photo was also rotated 180 degrees to give the illusion that the Lego man was exploding out of the water. This visual tied with the vertical arms of the Lego man gives the final edited photo a super hero aesthetic. Aside from cropping and rotating the original image the saturation and sharpness were increase roughly 5%.

Reflection

I was very happy with the way that this photo turned out. It is always very cool to see familiar dynamics, such as a splash, slowed down. Although it took about 50 trials to finally capture this photo I thought the time spent was well worth it. I was pleased to see the crown shaped splash that has been well researched as well as the Worthington jet that shot into the air. This setup also provided my group to experiment with a large range of objects, providing different but still interesting images. If I was to redo this experiment I would investigating using a timing mechanism as well as a drop mechanism.

Bibliography

[1] "How to Make the Biggest Splash: A Physics Lesson." *Popular Mechanics*. N.p., n.d. Web. 07 May 2014. <http://www.popularmechanics.com/outdoors/sports/physics/physics-of-cannonball-splash>

[2] Young, Donald F. *Student Solutions Manual to Accompany A Brief Introduction to Fluid Mechanics, Fourth Ed*. Hoboken, NJ: Wiley, 2008. Print.

[3] P. Brunet, R. Deegan, J. Eggers, L. Zhang. *Rayleigh-Plateau instability cause the crown splash*. Department of Physics University of Michigan. Sept. 11, 2009.

<http://lmlm6-62.univ-lille1.fr/lml/perso/pbrunet/articles/PoF_submitted.pdf>

[4] "Reynolds Number." *Reynolds Number*. N.p., n.d. Web. 07 May 2014 <http://www.engineeringtoolbox.com/reynolds-number-d_237.html>