TEAM EXPERIMENT 2: BOUNCING FLUIDS

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Introduction

The image shown was created for MCEN 5151-Flow Visualization for the Team 2 assignment. The intent of the assignment was to plan and conduct an experiment that demonstrates a fluid phenomenon of interest to the team and image the results. For this experiment, our team chose to investigate how non-Newtonian fluids can bounce, also known as the Kaye Effect. As an added challenge we sought to capture the effect twice over, resulting a repeated bounce from one jet to the next. The following report will detail the experimental setup and photographic techniques used to capture the Kaye Effect in the image shown, as well as the fluid mechanics driving the dynamics illustrated in the image.

Fluid Physics

The “bouncing fluid” effect was initially noted in 1963 by a British engineer named Arthur Kaye (1). He noticed the phenomenon while experimenting with various mixtures of obscure organic compounds. He was intrigued when he found that when a viscous mixture was poured onto a surface the, pool of liquid would suddenly through up a jet, downstream of the incoming stream. The effect was thus named the Kaye Effect, after the engineer whom discovered the puzzling fluid behavior. While the fluid mechanics driving this unique effect remained a mystery for almost 40 years, Dutch scientists, Michel Versluis and colleagues, finally solved the physics of the mysterious, bouncing fluid effect in 2006.

After diligently studying the effect with high-speed cameras, the researchers have concluded that the Kaye Effect is actually very common, occurring in many household fluids such as shampoo, kitchen soap, paint or even yogurt. The effect was documented to only take 300 milliseconds to occur and is would is not likely to be noticed within such a brief time scale (2). Versluis indicates that the Kaye Effect can occur in any liquid that demonstrates shear thinning behavior. Meaning that as the liquid flows, its viscosity will decrease relative to the velocity.

As our team noticed during the experiment, the key to instigating the fluid bounce, was to impact a stream of soap onto another pool of soap that had settled against the surface of the glass. As the incoming stream of soap collides with the stationary pool, the shear thinning effect acts as a lubricant between the two volumes and prevents them from combining immediately. The linear momentum of the incoming stream causes the collision to create a dimple in the fluid below that bends the flow into a new direction, similar to a ski jump. The result is a jet of fluid, that is actually just the first, incoming stream, that has been rerouted by the lower fluid. Predicting the speed and direction of the exiting jet is very difficult and this unpredictability of the exit jet was what made our experiment so challenging.

Figure 1: Kaye Effect as Documented by Versluis

Experimental Setup

To facilitate the Kaye Effect, we experimented with a variety of fluids and experimental setups. Of all the fluids we brought to the experiment, the large jug of simple hand soap proved to be the most reliable, because the large jug offered a large reservoir that offered more flow control for consistent pours. This became valuable, as the other inputs to triggering the Kaye Effect are much more difficult to control. Prior to attempting the double bounce, we first tried a variety techniques and geometries to produce just a singular bounce in order to understand the mechanics more clearly. The experimental setup that had the most success was to position the soap vertically above a Pyrex dish with curved edges. The nozzle of the soap jug was located 19 inches above the glass surface and the Pyrex dish was approximately dimensioned: length: 21.8cm, width: 16.8cm, height: 6cm, radius of curvature of edge chamfer: 1.1cm. While the jet impacted the dish in the same location, it became key to keep varying the pressure applied to the jug, to create a jet of soap with variable flow rate and velocity to instigate the Kaye Effect.

Once a successful setup was determined for the single jet, we simply added a second dish below the first dish to act as a second surface for the next bounce to occur. It was challenging to determine the correct positioning for the lower surface because it had to be precisely located relative to the exit jet from the first bounce, which was already rather unpredictable. After much trial and error, the final position was about 2.5 inches inform of the first surface, while both dished were angled about 20 degrees of the horizontal axis. The camera was positioned 39 inches from the location of the first impact and was angled slightly off the normal axis of the dishes to capture both bounces clearly. An image of the setup as a whole is shown below, while more detailed images and distances are documented in the appendix.

Figure 2: Experimental Setup

Photographic Technique

The image was shot on October 28th, 2016 in a conference room in Fleming building at the University of Colorado, using a Canon EOS 7D DSLR Mark I camera. The following equipment and parameters were used to capture the image:

- Lens: Canon 24-70mm f/2.8 Lens
- Shutter Speed: 1/200 Second
- Exposure Settings: ISO 200, F/6.3
- Image Resolution: Original- 5184 × 3456pixels, Edited- 3442 × 1390 pixels
- Editing: Photoshop CS6 was utilized for post processing the image

A shutter speed of 1/200s was utilized to capture the double bounce as the second bounce and final jet of soap were very unpredictable and often very fast. We initially had difficulties with staging the correct amount of light to get a deep, black background without putting too much light on the glass surfaces and the result was very dim images of the subjects. To accommodate for this, we eventually employed a flash that was bounced of a wall to diffuse the light around the experimental setup. A tripod and remote were used to stabilize and capture the images.

Photoshop CS6 was used to post process the original image and focus the viewer's attention toward the Kaye Effect being visualized between then jets of soap. The resolution of the initial image was 5184 × 3456 pixels and was cropped down to 3442 × 1390 pixels to remove any distracting elements from the photo and focus on the physics of the jets and bounce being illustrated. The image was cropped to isolate the individual jets of soap and the Kaya effect occurring between each jet. The image was then rotated to put the jet streams into a horizontal orientation. This rotation made black spaces in the upper-right and lower-left corners which had to be synthetically filled with matching textures using the clone stamp and spot healing tools. The glare from the flash was rather intense at certain points off of the jet and this was blended into the background to be less distracting. Lastly, a 10% cooling filter was applied to give the jets and glass a cooler hue, in an effort to give the glass surfaces a frozen, icy appearance. The original and post-processed images are shown below.

Original Image

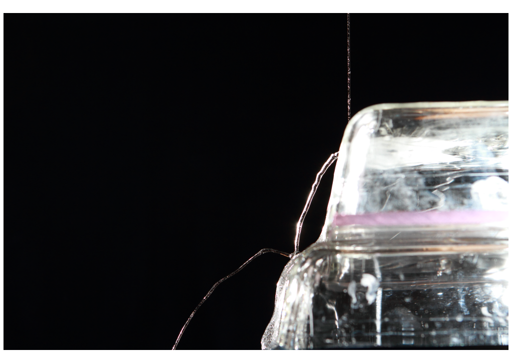

Figure 3: Original Image, Unedited

Edited Image

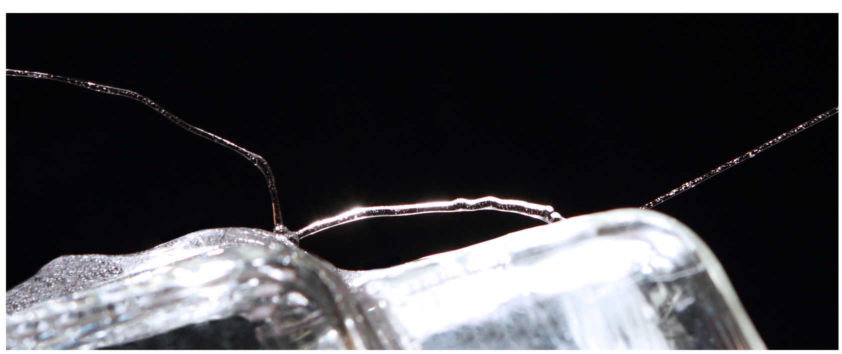

Figure 4: Final Image, After Post Processing

Commentary

This was a fun and challenging experiment for a variety of reasons that lent to the overall experience in documenting the fluid mechanics driving the Kaye Effect. It was difficult to create the first bounce and adding a second bounce dramatically compounded the complexity tin the setup. It required all three sets of hand to man the different aspects of the setup we had constructed, a true team effort. I am pleased with the image, as the quality reflects the effort and teamwork required to create and image the effect.

Acknowledgements

I wish to acknowledge Joseph Straccia, Max Scrimgeour and Peter Brunsgaard for their collaboration on our Team Second assignment. They were instrumental in conducting the experiment and creating the images shown that aid in illustrating the physics of the Kaye Effect. Please refer to their work as well for more imagery and information regarding this experiment.

Citations

1. Versluis, Michel, Cor Blom, Devaraj Van Der Meer, Ko Van Der Weele, and Detlef Lohse. "Leaping Shampoo and the Stable Kaye Effect." *J. Stat. Mech. Journal of Statistical Mechanics: Theory and Experiment* 2006, no. 07 (July 20, 2006). Accessed November 7, 2016. doi:10.1088/1742-5468/2006/07/p07007.
2. Ball, Phillip. "Puzzle of Leaping Liquid Solved." Nature.com. April 6, 2006. Accessed November 8, 2016. http://www.nature.com/news/2006/060403/full/news060403-10.html.

Appendix

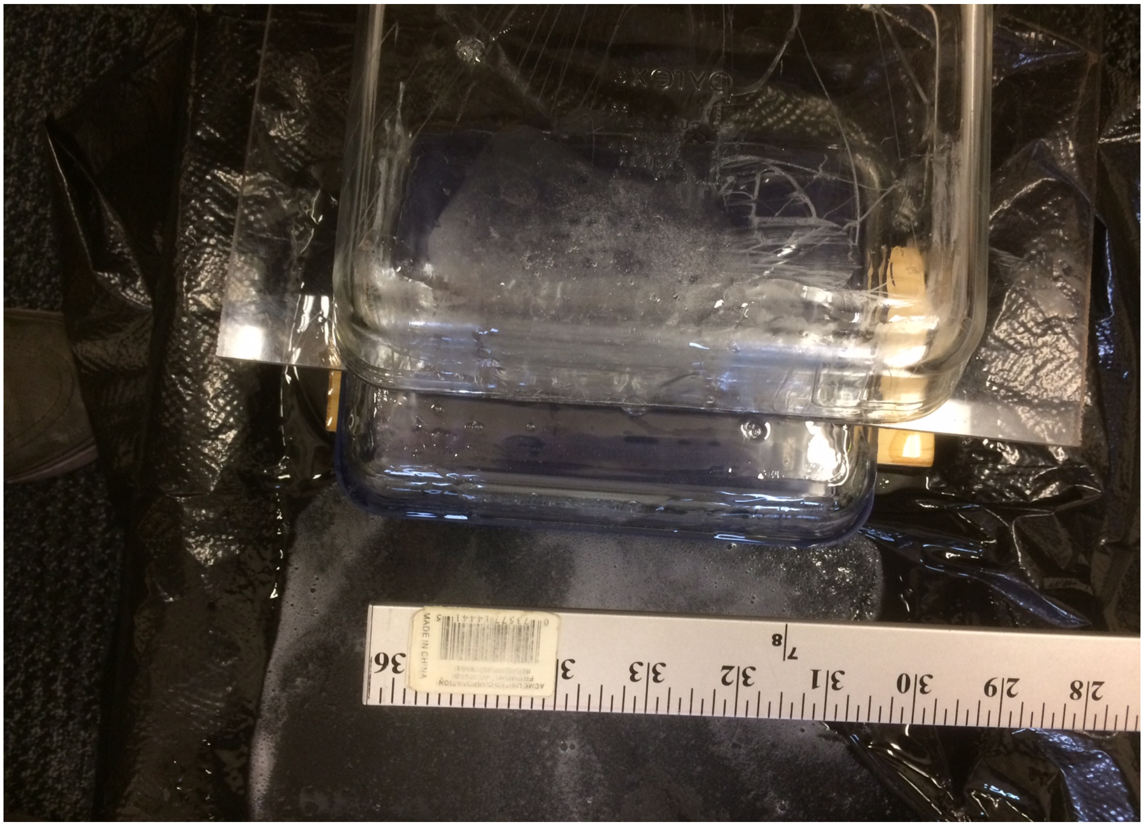

Figure 5: Width of The glass Surfaces

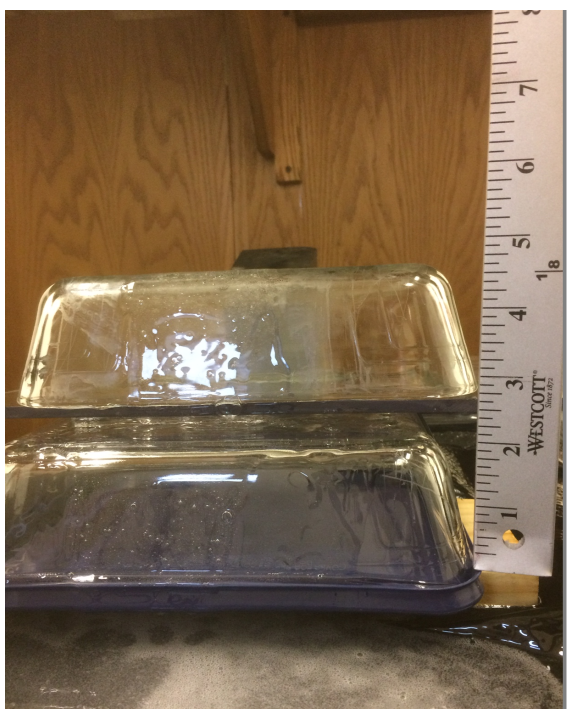

Figure 6: Height of Glass Surfaces

Figure 7: Distance from the Sensor of the Camera to the Location of the Effect Illustrated

Figure 8: Distance from Soap Reservoir to the Glass Surface