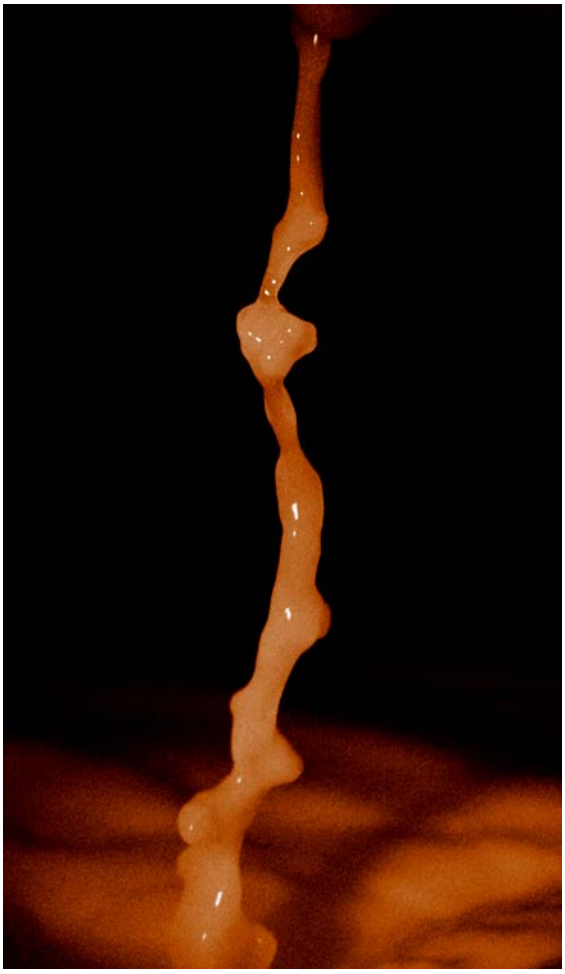
MCEN 5151: FLOW VISUALIZATION



A Column Following a Quick Removal

Get Wet Image

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11 Feb 2013

Cameras are magic. They capture a moment in time and preserve it for all who see. To see is a miracle itself. When the two combine, I wondered if I could see a moment through a camera that I would miss with my own eye. To capture the unseen was my inspiration for the first assignment. We all know that fluid follows an object removed from a pool, but what does it look like? The answer is varied and exquisite. The displayed photo shows the momentary structure created by a rapid removal demonstrating the propensity for fluid to stay together, even when stretched.

The photo was created using a semi-professional DSLR camera and objects common in American homes. As shown in Figure 1, the object, a foot in this case, was rapidly removed form a glass pan filled with heavily diluted reconstituted powered milk. The camera was level with the fluid and the lighting was augmented with the direct beam of a powerful flashlight. To maximize the contrast, a dark background was added by simply draping an open zipper hoodie over a hamper.

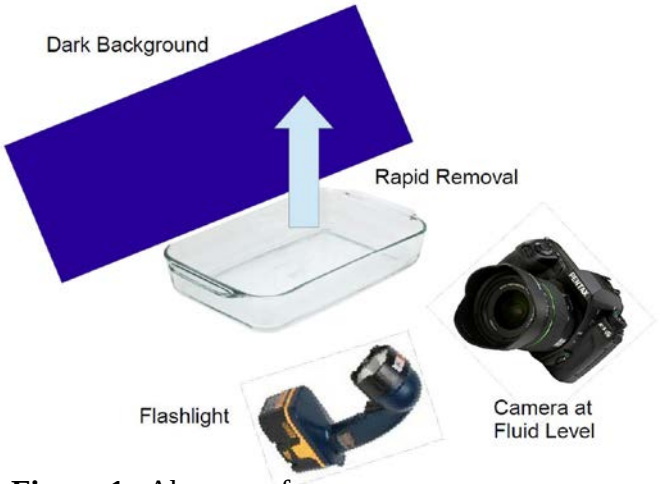

Figure 1. Abstract of set up.

Surface tension, the no slip condition, inertia and gravity are notable in the construction of the fluid structure. As it is not a traditional "flow", the common non-dimensional descriptors are not helpful to describe the motion because the the primary descriptor, the Reynold's number, is directly proportional to the fluid velocity. At the moment of capture, the velocity of the fluid was near zero, as it is the moment before the inertial forces were dissipated by gravitational acceleration. After this moment the structure broke into pieces. The majority was quickly over come by gravity and the minority that was compelled by surface tension and interface adhesion to remain close to the toe.

This interaction of adhesion and gravity has been shown to be the principle by which cats drink. Pedro Reis and Roman Stocker of MIT with Sunghwan Jung of Virginia Tech and Jeffrey Aristoff of Princeton demonstrated this in a *Science*[1] article. They found that the pinch-off height of the column was closely related to the Froude number,

$$Fr = U_{MAX}/(g*R)^{1/2}$$

where U_{MAX} is the maximum velocity of the removed body, g is the gravitational acceleration and R is the radius of the removed body. They found that the volume of the fluid in the column is maximized just before pinch-off occurs. With the estimated height of 3 inches, the water will fall in about a tenth of a second. The researchers Reis et al. measured the time to fall approximated the time to rise, so I infer that the picture was taken $^1/_{10}$ second after removal, assuming this photo captured the maximum of the column apparition.

The primary fluid property observed is viscosity. According to the Computer Support Group website[2] the viscosity and density, comprising kinematic viscosity, of milk is nearly equal

[1] P.M. Reis, S. Jung, J.M. Aristoff and R. Stocker, "How Cats Lap: Water Uptake by Felis Catus", Science Vol. **330**, 26 November 2010

[2] http://www.csgnetwork.com/specific_gravity_viscosity_liquids.html

to the properties of water; this was confirmed by the artist's observation, as he could not distinguish the fluid's response from how water behaves.

The intent was to demonstrate the momentary reactions of water when acted on by sudden motion. As water can be difficult to capture, the water was stained with milk, creating diluted milk. The 9.5” x 13.5” x 2” baking dish contained approximately 1 gallon of fluid, which was stained with $^{1}/_{3}$ cup of powdered milk. when properly reconstituted $^{3}/_{4}$ cup of powered milk should be added to 1 quart of water, making the solution roughly 11% milk.

Lighting was the greatest challenge of the set up due the the shutter speed required to freeze time. The flash could only accommodate a 1/180 shutter speed, so a flashlight was directed at the subject at approximately 45° from the camera to supplement the 8 vanity lights installed in the hygiene station where the image was created.

The original photograph captured an area $4^{1}/_{2}$ by 3 inches from a distance of approximately 6 inches using a Pentax 18-55II lens, using 42 mm focal length. This produced a 10 MP sRGB JPEG, dimensioned 33936x2624 pixels at 300 dpi using +5 step exposure basis at 1/8000 second exposure time and ISO-12800 with aperture of f/4. The body used was a Pentax K-5 Digital camera. The final image finished using Gimp. Manipulations were minimized, it was cropped to 1448x2396 pixels to remove the toe, leaving only the subject fluid column. The colors were optimized using color curves, finally the brightness and contrast were adjusted to maximize the appearance of the structures in the stream.

The captured column successfully reveals a complex structure of fluid force interaction; most impressive to me is the three spherical bodies in the large congregation roughly 2 thirds the distance to the top of the cropped image. It reveals the propensity of the weightless fluid to pull together. In another instant, these forces will pull the column into drops, but for now we see a momentary structure that cannot be appreciated without the magic of photography.

- Appendix -
alternate images, untouched