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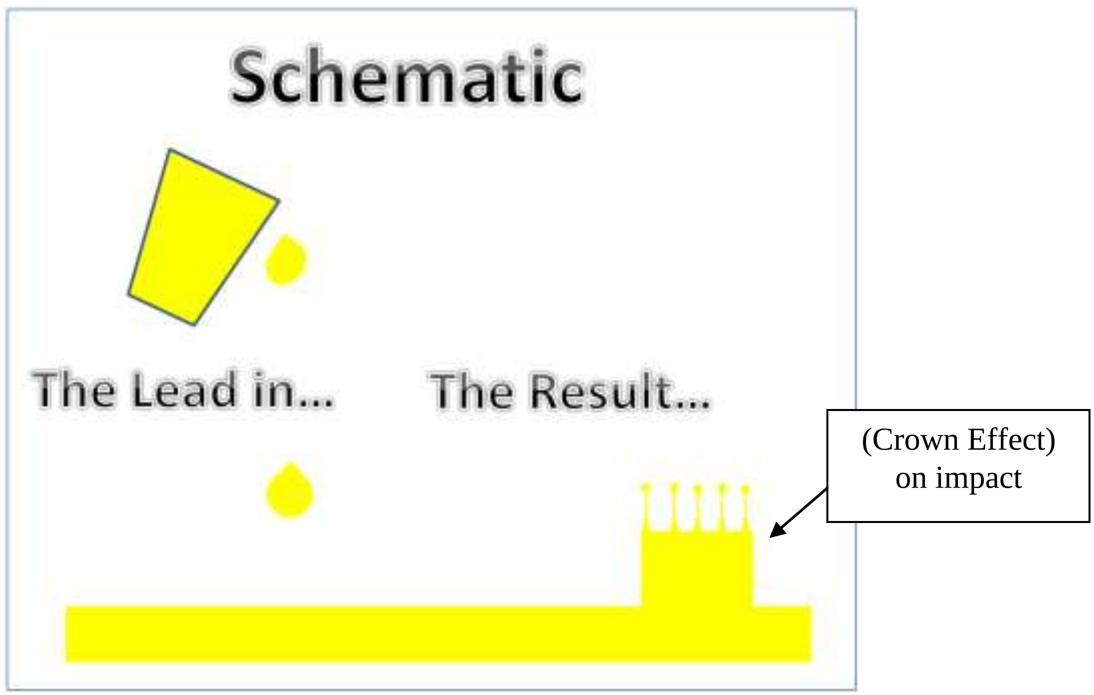
This image was produced as an assignment for a flow visualization class taken at the University of Colorado under Professor Hertzberg. The specific assignment was meant to exhibit the science behind fluid flow in a visually appealing manner. The particular image was taken by students at 1005 Broadway using a Cannon 5D MarkII. The experiment was set-up and orchestrated by a flow visualization team comprised of Stefan Berkower, Scott Christian-dold, Cory Fuhrmeister, Nathan Gust, and Logan Meyer. The team used the University of Colorado's Durning Lab to perform and record the demonstration. The team had to take many photographs in order to get the ideal image exhibiting the desired reaction. The fluid present in the image is 100% canola oil and is the result of small independent portion of the fluid into itself.



This demonstration utilized non expensive household materials in order to observe the characteristics of a crown effect being created upon the collision of a fluid with a larger standing fluid. A large container, as seen in the schematic above, was filled with Canola Oil having a characteristic yellow color and thick viscosity. The Canola oil was also poured into another container which was used to drop the Canola Oil into the standing medium from a height of approximately 5 feet. A photographer then took pictures upon impact. This process was repeated many times over in order to get the proper timing required to visualize the ideal crowning effect. The amount of liquid canola oil released at a time was approximately a few cubic centimeters at a time. Today, It is still largely unknown why the exact shape, and number of plumes are created during the splash of a given medium, but many theories have been proposed to best describe these behaviors.

"Fullana and Zaleski [3] put forward the idea that the crown formation in problems like drop splashing on thin films is due to the Plateau–Rayleigh (RP) capillary instability of the cylindrical rim that develops at the end of the planar sheet. Their analytical study, based on one-dimensional macroscopic balance, showed that "the growing cylindrical end rim does not typically break into droplets for moderate wavelength," i.e. the authors could not detect an instability with their model. Gueyffier and Zaleski [5] speculated that a possible instability mechanism in a drop splashing on thin liquid films might be of the Richtmyer–Meshkov (RM) type as opposed to the Rayleigh–Taylor (RT) instability[2] deemed present in the drop splashing on dry surfaces [6], but did not provide any evidence to support or refute the conjecture.

To date the drop splash problem has been studied most extensively by experimental means, e.g. [7], [8], [9] and [10]. Despite these and many other experimental studies, the instability mechanism responsible for the crown formation and the details of the crown spike dynamics remain open questions."

-From Krechetnikov, R., and G. Homsy

If one neglects the influence of surrounding air, the governing physical variables are the fluid properties μ, ρ, and σ (dynamic viscosity, density, and surface tension, respectively), the physical lengths d, h, and H (drop size, layer thickness, and height of the drop release measured from the tip of the nozzle), and the acceleration of gravity g. Since we work with fluids with comparable viscosities, the Ohnesorge number

$$Oh = \mu / \sqrt{\sigma \rho d}$$

which measures the ratio of viscous and capillary forces, does not vary significantly. Thus we have a two parameter problem, controlled by the Weber number

$$We_{\text{drop}} = \rho v^{*2} d/\sigma$$

which relates inertial to capillary forces, and the inertia ratio:

$$\alpha = d/h \text{ (or } We_{\text{film}} = \alpha^{-1} We_{\text{drop}}\text{)},$$

where

$$v^* = \sqrt{2gH}$$

is the impact velocity.

In this image, regular 100% Canola Oil was used both as the pouring fluid and the medium being poured into. The image was captured in the Durning Lab located at the University of Colorado. The lighting was supplied through the use of a 200 watt industrial light and the ambient light present in the Durning Lab. The image was front lit with a white background to capture as much detail as possible. In the future additional, a backdrop should be used to reduce reflection and lighting should be adjusted to minimize glare.

In the original image, the field of view is approximately 8 inches across and the image was approximately 18 inches from the lens. . The specific lens used is a 100mm macro lens present on the Cannon 5D MarkII. The camera is of course a digital camera and the aperture was f4, Shutter Speed was 1/125th of a second and ISO settings were 250. The image was further processed using Photoshop in order to increase the contrast, make the image black and white, and crop the image to its final size. Black and white coloring made fluid motion present within the crown more apparent and made for a more appealing image to the eye.

This image reveals the incredible high speed behavior that is present with every collision of a drop of fluid, but normally goes unnoticed. It is interesting to think of all of the interactions that occur that are far beyond the capabilities of human sight, and yet we get to observe the macroscopic effects of what is occurring billions of times on such a small scale. Specifically as seen in this image, the impact of every drop of fluid results in a highly complex and very beautiful pattern replete with vertical walls and fluid protrusions extending from the top of these walls at regular intervals around the impact. What is also interesting about the phenomena observed is that it is very scalable behavior. Whether it is a small drop, a large bucket, or a very large meteor into a planet, there are similar deformations that occur at impact and shortly thereafter. If possible in the future, I would find it interesting to investigate the reaction of water and other liquids when subjected to the canola oil medium. Furthermore the use of a low pressure chamber could provide considerable insight into the physics of the fluid flow. Lastly a zero gravity high speed liquid collision would be interesting and could provide insight into the dynamics of the different mediums interacting. Specifically it would be interesting if the crown tips would be recreated in this zero gravity environment. , the splash crown effect is very appealing aesthetically and also has some very complex behavior that scientists will continue to attempt to completely understand for years to come.

References:

[1] S.K. Betyaev, *Phys. Uspekhi* **38** (1995), pp. 287–316.

[2] H.E. Edgerton and J.R. Killian, Flash! Seeing the Unseen by Ultra High-Speed Photography, Charles T Branford Co., Boston (1954).

[3] J.M. Fullana and S. Zaleski, *Phys. Fluids* **11** (1999), pp. 952–954.

[4] A.L. Yarin, *Annu. Rev. Fluid Mech.* **38** (2006), pp. 159–192.

[5] D. Gueyffier and S. Zaleski, *C. R. Acad. Sci. Paris Ser. II* **326** (1998), pp. 839–844.

[6] R.F. Allen, *J. Colloid Interface Sci.* **51** (1975), pp. 350–351.

[7] R. Rioboo, C. Bauthier, J. Conti, M. Voué and J.D. Coninck, *Exp. Fluids* **35** (2003), pp. 648–652.

[8] S.T. Thoroddsen, *J. Fluid Mech.* **451** (2002), pp. 373–381.

[9] G.E. Cossali, M. Marengo, A. Coghe and S. Zhdanov, *Exp. Fluids* **36** (2004), pp. 888–900.

[10] A.-B. Wang and C.-C. Chen, *Phys. Fluids* **12** (2000), pp. 2155–2158. [11] R.S. Shaw, The Dripping Faucet as a Model Chaotic System, Arial, Santa Cruz (1984).

[12] A.W. Adamson, Physical Chemistry of Surfaces, Wiley, New York (1990).

[13] S. Residori, N. Olivi-Tran and E. Pampaloni, *Eur. Phys. J. D* **12** (2000), pp. 15–20.

[14] O.G. Engel, *J. Appl. Phys.* **44** (1972), pp. 692–704.

[15] C.D. Stow and M.G. Hadfield, *Proc. R. Soc. London A* **373** (1981), pp. 419–441.

[16] M. Rein, *Fluid Dyn. Res.* **12** (1993), pp. 61–93.

[17] C. Josserand and S. Zaleski, *Phys. Fluids* **15** (2003), pp. 1650–1657.

[18] D.H. Sharp, *Physica D* **12** (1984), pp. 3–18.

[19] I.V. Roisman, K. Horvat and C. Tropea, *Phys. Fluids* **18** (2006), p. 102104.

Krechetnikov, R., and G. Homsy. "Crown-forming Instability Phenomena in the Drop Splash Problem." *Journal of Colloid and Interface Science* 331.2 (2009): 555-59. Print.

Liu, S. "Unified Model for Splash Droplets and Suspended Mist of Atomized Flow." *Journal of Hydrodynamics, Ser. B* 20.1 (2008): 125-30. Print.

Saint-Jean, S. "Modelling Water Transfer by Rain-splash in a 3D Canopy Using Monte Carlo Integration." *Agricultural and Forest Meteorology* 121.3-4 (2004): 183-96. Print.

Fernández-Raga, María, Roberto Fraile, Jan Jacob Keizer, María Eufemia Varela Teijeiro, Amaya Castro, Covadonga Palencia, Ana I. Calvo, Joost Koenders, and Renata Liliana Da Costa Marques. "The Kinetic Energy of Rain Measured with an Optical Disdrometer: An Application to Splash Erosion." *Atmospheric Research* (2009). Print.