Team First: Pressure Differential of a Small Hole

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Flow Visualization: The Physics and Art of Fluid Flow

The goal of this project was to work in teams and explore a fluid flow phenomena of choice. Initially our group had the idea to run food dyed water over various surfaces to demonstrate flow. The object that I decided to bring to the group meeting was a candle lid which had an interesting geometric shape and holes on the top. Similarly to my previous project, my inspiration was taking a relatively hydrophobic object and running water over the top of the unique geometry to demonstrate flow and surface tension. After opening my pictures from the photoshoot I noticed that the small hole in the candle lid was showing a pressure differential and was noticeable by the water being drawn into the hole.

Although surface tension may be visible in this photo the main phenomena that can be seen is a pressure differential caused by the hole in the candle lid. This is due to bernouili's principle which relates pressure, fluid velocity, density and height to relate two fluids. These fluids can be the same fluids just at different points of flow or two completely different fluids solving for different variables. For the purpose of this experiment we are only using 1 fluid, that being water with green food dye mixed into it. The sketch below shows how this pressure differential causes a suction force through various velocities and flow properties.

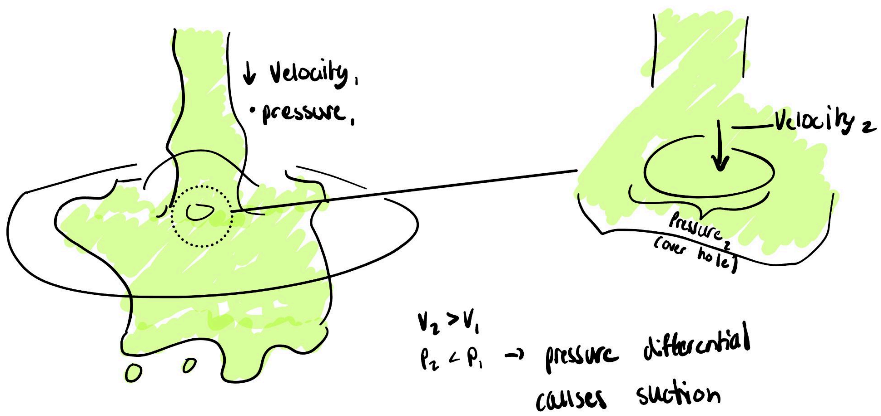

Fig. 1: Pressure Differential Sketch

To make more sense of this sketch Bernoulli's Equation must be introduced. The equation below shows how from one location to the next, in this example the starting of the pour to the hole, pressure, velocity and height can be related to solve various elements. In the equation below "P" is representative of pressure, rho or "ρ" is density, "v" is velocity, "g" is gravity, and finally "h" is height. These values are all measurable or constants which make this equation the baseline for all flow calculations.

$$\mathbf{P + (\tfrac{1}{2} \times \rho \times v^2) + (\rho \times g \times h) = Constant}$$

Eqn. 1: Bernoulli's Equation

Connecting the image to the sketch we see that $v_1 < v_2$ and $P_2 < P_1$ and this allows us to create two uses of Bernoulli's equation. For the first case and second case we can neglect the portion of bernoulli's that utilizes height because the height is so small. This sets up the following two equations to show the pressure difference. This equation can be understood through the logic that they equal one another, so by having an increase in pressure in one, there must be a decrease in pressure in the other, vice versa with the velocities.

$$\mathbf{P_1 + (\tfrac{1}{2} \times \rho \times v_1^2) = P_2 + (\tfrac{1}{2} \times \rho \times v_2^2)}$$

Eqn. 2: Bernoulli's Applied

The set up for this experiment was rather rudimentary due to working in a group and having to capture 3 individual images for each team member. The ITL has an all white plastic backdrop that we found in the basement and were able to use to create focus on the object and its flow. To replicate this it is possible to create a backdrop of white towels that will allow for similar lighting and focus. Below is a better image of the setup, in which we used a plastic container to pour the liquid into and a formed structure made of laser cut rectangles to hold the objects in the air or at an angle. We struggled with lighting a little bit due to the ITL's overhead lighting which created problems with capturing only one light source but with the help of multiple team members we were able to achieve proper lighting with two flash lights and constant angle adjustment. The hardest part of setting this up was lazer cutting out rectangles to hot glue together and onto the tupperware so that the object would be suspended. I would recommend a different method, perhaps using a glass or different clear object that doesn't need manufacturing.

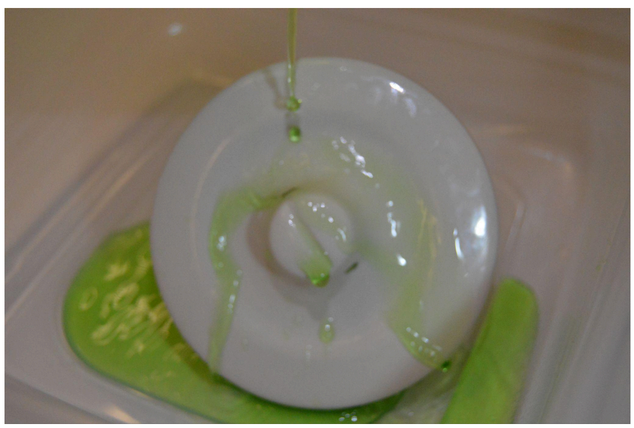

Fig. 3: Setup of Flow Visualization

The camera I was using to shoot was a Nikon D3200 DSLR on a fixed tripod to reduce blur and keep the same angle. I tried using different settings throughout the photo shoot, like the image above had a 1/1000 shutter speed and f/4.5 but the image looked rather washed out and the lighting was too bright. The final image was roughly 4 inches from the object and had a base raw pixel size of 6016x4000, this was scaled down after editing to 1300x867. The lens used was a AF-S Nikkor lens that had a 18-55mm focal length. The settings that I landed on for the final image were a 1/60 shutter speed, f/5.6, 449 ISO and the focal length was at 52 mm. The two images below show the final raw image and the edited image. I made these choices in the editing process to try and make the suction near the hole as focus as possible, this included changing the saturation, light and dark scales, and also changing the color of the liquid.


Fig. 4: Edited

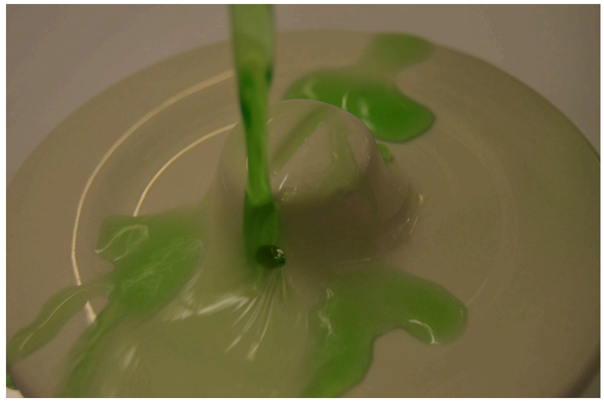
Fig. 5: Raw Image

I believe that initially this project seemed like I wasn't going to have a phenomena to relate to these images, it ended up being successful. Although I think there are better ways to demonstrate this property of suction, this was accidental and was a perfectly timed shot to show the pressure differential. Going forward I will think through the logistics of my projects more before attempting them and really contemplate the phenomena I'm looking to simulate.