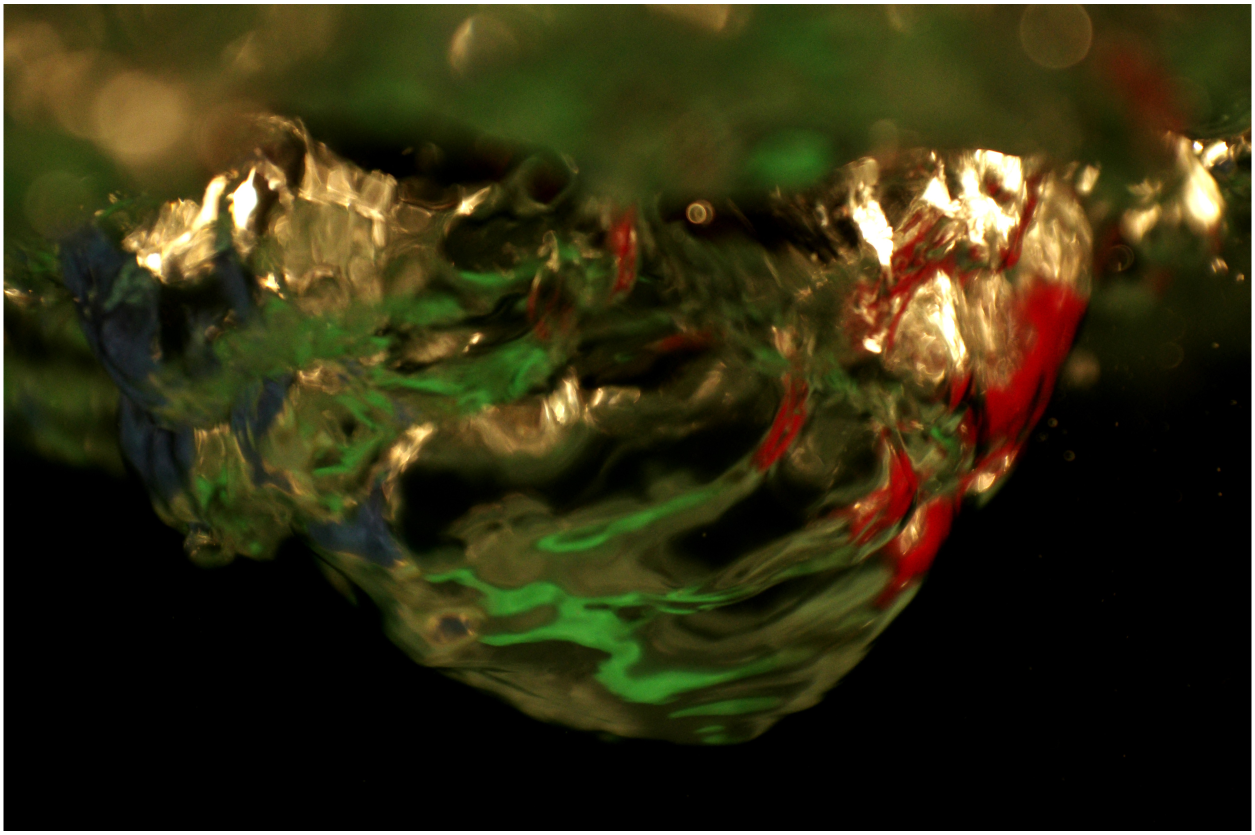
MCEN 5151: FLOW VISUALIZATION



Bubble Beauty

Group Image 1

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Introduction

The intent of this image is to show the complex structures that form in the contest of gravity and inertia between stagnant water and a perpendicular stream of air. This image required assistance; teammates Hans Loewenheath directed the air while Spencer Aguilar ensured adequate lighting.

Conditions

This image was captured on March 4th at 10:52 a.m., in the Integrated Teaching & Learning Program and Laboratory (ITLL) in the Engineering School at Colorado University at Boulder. We were able to use the vibrations laboratory, which is equipped to be a dark room. The dark room was vital to be able to control the lighting. Only white light was used, produced by two 500W Halogen work lamps. Red paper was taped outside the right, blue was taped to the left and green paper was slid beneath the aquarium. The air was moved by a shop vac and focused using a large funnel. The air stream was directed perpendicular to the water surface and hit about 4 inches from the glass. This photograph was captured from the end of a large aquarium about half filled with water. Figure 1 shows a mock up of the arrangement for the photograph. The back of the tank was draped with a dark jacket.

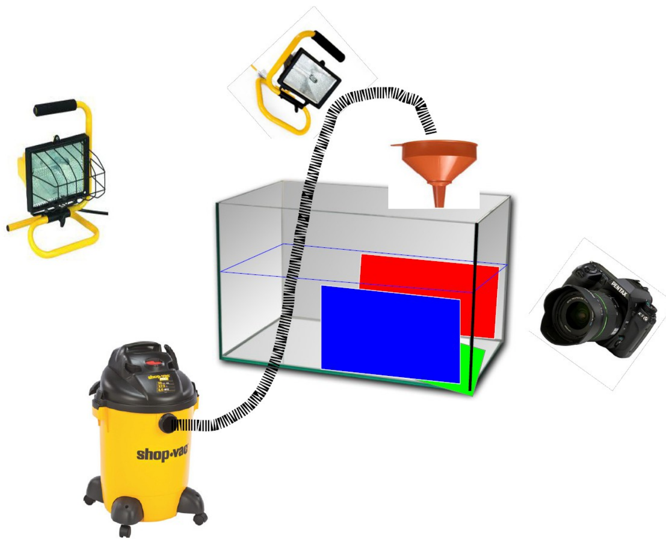


Figure 1. Abstract of Setup

The image reveals the distinction between static pressure and dynamic pressure, also called velocity pressure. Total pressure is static pressure plus the velocity pressure. Exposed to the atmosphere, it is clear that the relative static pressure within the depression is zero. The equation for dynamic pressure is:

$$P_v = \tfrac{1}{2} \rho V^2$$

where P_v is the velocity pressure, ρ is the density and V is the velocity of the fluid.

Measuring the depression of the water to be 2 inches, we can deduce the velocity pressure to be no less than 2 inches of water, which is equal to about 500 Pascals. Assuming water has the density of 1000 kg per m^3, the center stream of air must have had a velocity of no less than 1 meter per second, or about 2.2 miles per hour at the very bottom of the depression. That final velocity pressure converts to a static pressure as the velocity goes to zero and creates the depression.

In addition to over coming the static pressure, the air jet must also displace the water that belongs in that hole. Modeling the bubble as a half a sphere, we find the volume to be:

$$V = \tfrac{2}{3} \pi r^3$$

The bubble is approximately 3 inches wide and 2 inches into the water. If we approximate the radius, r, to be 1.25 inches, the volume is approximately 4 cubic inches, which is just over a quarter cup. So, the mass displaced is approximately 2.4 oz, or 0.067 kg. This shows the inertial force contained in the air stream.

$$F = m\, a$$

Since the force is equal and opposite, the mass of the water displaced times the gravitational acceleration must equal the mass of the air times its deceleration. The force, therefore is .067 times 9.81, which equals 0.66 Newtons, or close to 0.15 pounds of force, or 2.4 oz. The exit of the funnel is 3/4 inch. Water, due to gravity wants to fill the bottom of a container. What we observe here is the inertia of an air stream forcing the water out of its way. Surface tension tries to keep the air completely out of the water, and for the most part, succeeds at this velocity. At first, the artist was concerned about the repeatability of the experiment without any specificity of the air stream velocity, but the equilibrium point is easily found with a steady stream of air and a steady hand. If the air is too fast it will spray water all over, too slow (too far away) and the air will not displace much water, but merely agitate the surface.

They key to seeing the image was the colored paper, provided by Mr. Aguilar. The water – air interface provides a reflection point. This reflection clearly exposes the outline of the depression. No flash was used, only the shop lights.

The Image

Taken with a Pentax K-5, the original RAW image was saved as a DNG file. To utilize the GIMP editing program, I first saved the image as an PNG file using PENTAX Digital Camera Utility 4 (PDCU4). This transformation took the file from roughly 21 MB to 24MB. Alternatively, PDCU4 is capable of exporting 8 or 16 bit TIFF files at around 48 or 94 MB per image, but since GIMP is only capable of handling 8 bit photographs and the color specificity is not recognizable by the human eye, the artist used the PNG images to export the file data. Unfortunately, the PNG format does not keep the EXIF data, so the artist also exported the photo from PDCU4 into JPEG format for less formal digital presentations.

The field of view is 4 inches by 3 inches high. In addition to the Pentax lens, the artist also used a 2x macro screw-on attachment, which was pressed against the glass approximately 4 inches from the water hole. To freeze time, the exposure was limited to one thousandth of a sec.

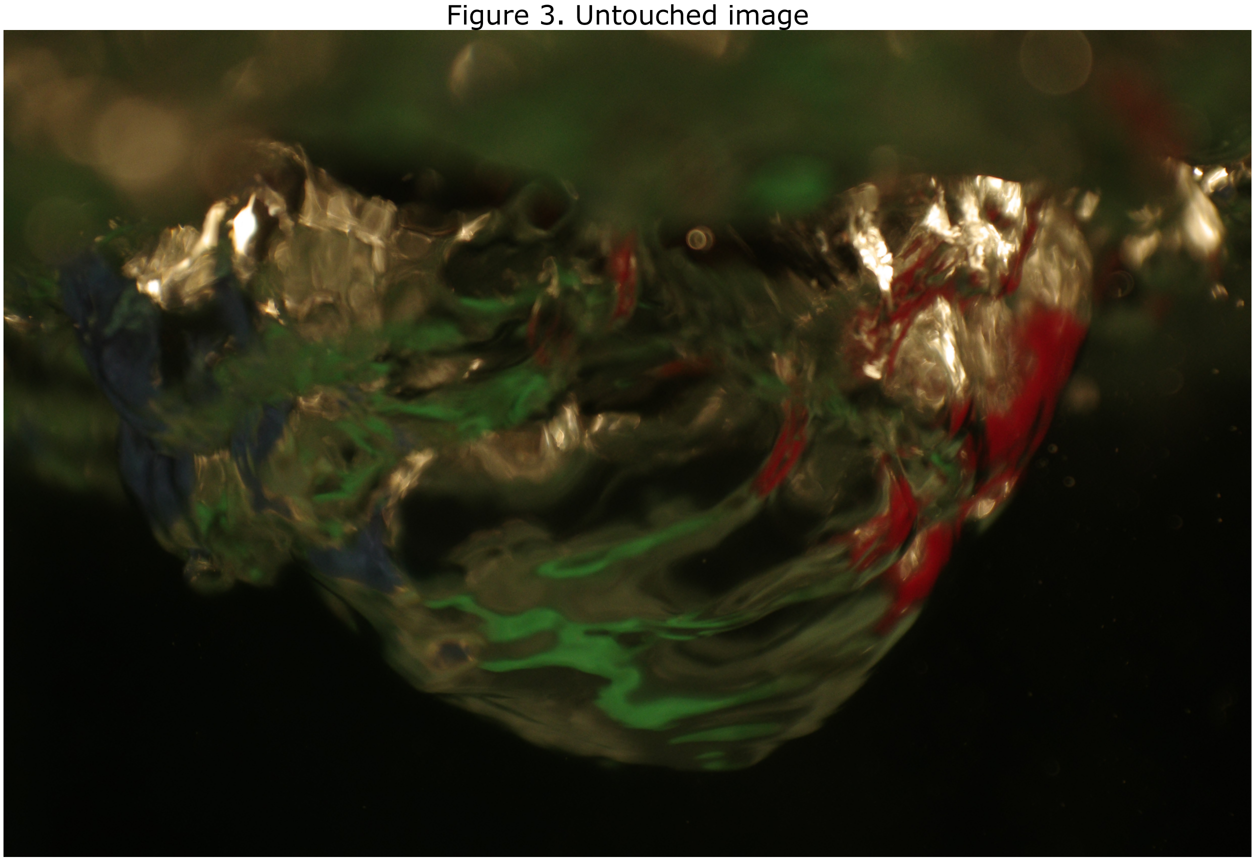
Table 2: Camera and Original Image Data

Camera:	Pentax K-5
Lens:	SMC Pentax-DA L 55-300 mm
Focal Length:	55 mm
F-stop:	f/5.6
Exposure:	1/1000 sec.
ISO Speed:	ISO-1600

Width:	4928 pixels
Height:	3264 pixels
Horizontal resolution:	300 dpi
Vertical Resolution:	300 dpi
Bit Depth:	24
Color Representation:	sRGB

The photograph color was enhanced in GIMP using the color curves modulation, to obscure the background and to brighten the highlights. No cropping was necessary.

Figure 3. Untouched image



Conclusion

I am very pleased with this image. It effectively exposes the hydraulic displacement by a free pneumatic stream. The focus is right at the crest of the well, the colors reveal the surface structures. After hours searching the internet, I could find nothing similar or that added to understand this phenomenon. Further exploration could better reveal the surface and body force interaction. An attempt could be made to quantify the air velocity.