# First Team Project

Flow Visualization: The Physics and Art of Fluid Flow

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The associated image, taken by the sixth group on March 1st 2013, explores the boundary layer interaction between a still body of water and air with some relative motion. The original intent was to capture waves created from air moving parallel to a body of water, similar to wind rippling across the top of a lake. However, the available compressed air hoses would not reach into the dark room of the ITLL on the CU Boulder campus. The team instead explored using a shop vacuum on blow mode. The parallel air motion did not create a visually appealing effect. However, air moving perpendicular to the body of water created a nice dimple beneath the surface. The associated image captured this dimple from air perpendicular to the surface of the water. The teammates who contributed were: Thomas Pohlman, Spencer Aguilar, James Shefchik and Grant Boerhave.

The flow apparatus consisted of a 10-gallon tank of water (filled halfway) and a shop vacuum on blow pointed downward and perpendicular to the surface of the water, as seen in figure 1.

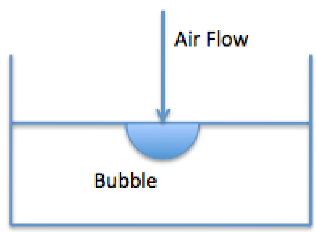


Figure 1: Flow diagram

As the air contacted the surface of the water, the momentum of the air created a pressure distribution along the surface of the water. The air pressure forced the water to depress to a height below the surface of the water. The bubble is assumed to be hemispherical with a radius of about 2 in, or about 0.05 m. If the system is assumed to be in equilibrium and the water is incompressible, the pressure from the difference in height in the water level will equal the dynamic air pressure. The pressures are calculated as follows:

$$P_{water} = \rho g h = (1000\frac{kg}{m^3}) * (9.8\frac{m}{s^2}) * (0.05m) = 490Pa$$

If the pressure of the water at the bottom of the bubble equals the dynamic pressure of the air, the velocity of the air can be calculated as follows:

$$P_{dynamic} = 0.5\rho V_{air}^2$$

$$V_{air} = \sqrt{\frac{P_{water}}{0.5\rho_{air}}} = \sqrt{\frac{490Pa}{0.5 * 1.2\frac{kg}{m^3}}} = 0.035\frac{m}{s}$$

Using the calculated velocity of the air, the Reynolds number for the air can be calculated.

$$Re_{air} = \frac{V * L}{\nu} = \frac{(0.035\frac{m}{2})(0.1m)}{15.11E-6\frac{m^2}{s}} = 200$$

The Reynolds number is much less than 2300, so the airflow is assumed to be laminar between the end of the vacuum nozzle and the surface of the water. This analysis is a simplification of the actual effects. Inside of the cavity of the bubble, the airflow is assumed to contain some vortices. The vortices are formed because there is interference in the air as the conservation of mass theorem is upheld. The incoming air needs to change directions and quickly leave the cavity of the bubble, creating some turbulence.

The image visualization techniques included various background colors and lighting. The exterior of the 10-gallon fish tank was covered with colored construction paper. The red, green, blue, orange and yellow paper was placed in various locations around the outside of the tank. Underneath the fish tank, the colored paper was staggered using equal spacing to create a rainbow of colors to reflect off the bottom of the bubble. The varying background colors gave the bubble more definition and contrast. Two 500 W tungsten work lights were used to illuminate the bubble from above the water surface at two different angles. The lights were either set on a nearby table or held by a fellow teammate. The camera flash was disabled.

The image was captured through one side of the fish tank looking upward from beneath the surface of the water. The size of the field of view was approximately 4 inches, which was the approximate size of the water bubble. The camera lens was about 15 inches from the center of the dimple while up against one side of the fish tank. The lens focal length was 28.0 mm. The original and final images have widths of 3872 pixels and heights of 2592 pixels. The camera used was a Nikon D40X. The aperture was set to f/5.6 using the aperture priority setting. The ISO speed was rated at 200. The shutter speed was 1/30 sec. The image was altered in Photoshop using the follow techniques: curves (to increase contrast) and levels (to adjust brightness levels). The levels adjustment proved to be most useful as it increased contrast and allowed the background to become much darker while leaving the dimple unaffected.

The image reveals a boundary layer interaction between a body of water and air moving perpendicular to the liquid surface. However, the image only captures how the water is reacting to the moving air. I would like to visualize what is happening to the air particles as they contact the water surface. Is the air forming into a vortex? What does the airflow look like outside of the column of air beneath the vacuum exit? I would like to improve on the depth and shape of the dimple, as well as the airflow visualization. I think the image would look best if it were divided into two parts. The top half would show the airflow while the bottom half would show the water flow. The gas should utilize visualization techniques such as streams of fog or ice particles to reflect light.

- http://www.engineeringtoolbox.com/water-density-specific-weight-d_595.html
- http://www.engineeringtoolbox.com/dynamic-pressure-d_1037.html
- http://www.engineeringtoolbox.com/air-properties-d_156.html
- http://en.wikipedia.org/wiki/Reynolds_number