Group Project 3 Report: Buoyancy to Negative Buoyancy

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Flow Visualization

This photograph was taken for the third group project in the Flow Visualization class at the University of Colorado at Boulder. In the class we learn photographic techniques specifically used to capture fluid dynamics. For this project I worked with David Oakley, he and I chose to return to a similar set up that I had been using in a previous project. For the “Getting Wet” assignment I had photographed a buoyant plume of smoke impinging upon an oblique surface. This time around I wanted to capture a transition I had observed in the original shoot. A transition takes place as the smoke moves along a surface, it changes from having an upward to a downward buoyant force. Specifically I wanted the smoke to appear like a wave crashing down on the viewer. This specific aspect was only partially realized.

To set up this flow we used a cardboard box about 15x15x30 inches in size, two poster board sized pieces of black paper, some tape, scissors, some incense and a lighter. First, we cut one of the square sides of the box almost completely out, except leaving an arc from the lower back corner to the upper front corner (see diagram below), the front of the box was already open. We then cut one sheet of black paper to a 30 in width and attached it along the curve in the box and along the lower back corner. This sheet acts as the surface which the smoke will move along. In our setup we left about a foot of paper overhanging the upper front corner and left unattached. By leaving it unattached one person could hold it in place and this gave us flexibility in the shape of the curve. Next we covered any visible cardboard surface with black paper. The incense was lit in a long strip and placed against the lower back corner of the box. Smoke enters the frame in the photo’s lower left corner in a buoyant plume about 2.5 inches across and 30 inches from the camera. The front strip of smoke running diagonally across the top of the photo is about 10 inches across and 20 inches from the camera. As the smoke emerges from the incense it is hot and less dense than the surrounding air, giving it a buoyant force upwards. The smoke meets the curved black paper and is forced to follow along this curve. Movement of the warm particles entrains the air to follow it and in the process more air molecules combine with the smoke. Because more and more air mixes with the mass of warm smoke and due the cooling taking place along the paper surface, the smoke quickly comes to thermal equilibrium with the surrounding air. What we see is that the denser sections of smoke begin to form negatively buoyant plumes when gravitational forces on the smoke are stronger than their upward buoyant force. In essence what we see in the photograph is the transition of fluid from having an upward buoyant force to having a downward buoyant force. Assuming a density close to air, and a kinematic viscosity close to air, we can calculate the Reynolds number along the flow. Initially, the smoke is moving at about 20 cm/s, over the course of 40 cm we see the smoke has lost most of it velocity down to about 5 cm/s. The “drips” of negatively buoyant smoke come to a stop compared to the rest of the flow, prior to initiating their downward motion. The dynamic viscosity of air is 1.983x10^-5 kg/(m*s) at room temperature, and the density of air at room temperature is 1.1839 kg/m^3. Assuming a characteristic length equal the midpoint in the flow (about 0.1 m) and a velocity of 0.1 m/s, I have calculated the Reynolds number to be nominally at 596. With Reynolds numbers we expect a laminar flow anywhere with $Re < 2300$, and this is exactly what we see. The smoke is not turbulent in the flow, though the movement at the end changes direction; it still follows smooth laminar paths.

$$Reynolds\ Number:\ Re = \frac{\rho v L}{\mu}\quad where\ \rho\ is\ the\ density, \mu\ is\ the\ dynamic\ viscosity,$$
$$v\ is\ the\ velocity\ and\ L\ is\ the\ characteristic\ length.$$

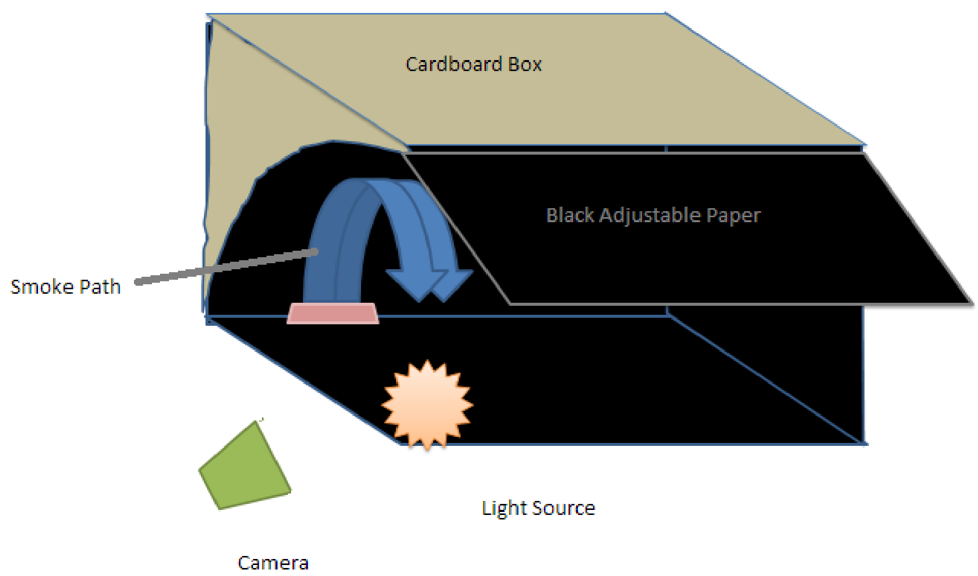

Figure 1: Setup. Please note that the light source is further back than the camera, not in front of it as the diagram may appear.

The smoke in the image is a combination of small solid particles, gases, and water droplets formed during the combustion process of the incense. Smoke is the flow medium and the visualization medium in this case. For lighting we used a small compact fluorescent bulb placed outside the box, a few inches behind and to the side of the camera. The camera sat about 30 inches from the smoke. To shoot the image we used a Cannon 7D with a USM 2 lens. We set the camera to an ISO of 1000, an exposure time of 1/500 sec , and an aperture of f/2.8. The lens focal length was 35mm. Using these settings, we had a narrow depth of field so we could focus in on the formation of the negatively buoyant plumes. The photo itself is 5184x3456 pixels, because of the slow movement of the negatively buoyant plumes, this area of the photo is both spatially and temporally resolved. With our low angle we were able to capture the shape of the flow as it arced over the top of the frame and entered into the focal plane. The image had very little editing done to it, all I really did was adjust the levels to help hide the paper texture and bring out the range of whites in the smoke. An original unedited version is shown below for comparison.

The image captures a movement of smoke that I do not commonly see. Typically smoke is hot and we see it rise and eventually dissipate into the air. By forcing the air to move as we have done here, we have allowed the denser smoke to drop out of the flow and form negatively buoyant plumes.

The focusing in this shot worked well for the flow; by blurring the background, it accentuates the fact that the smoke is coming toward the viewer. I think that with a more elongated source of smoke, an image looking very similar to a crashing wave could be created. If I were to do this again I would continue trying for that image.

Sources:

Web Level:

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