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Image-Video Assignment 3
Flow Visualization MCEN 4151-001
Thanks to Dr. Hertzberg for equipment rental

For my third image-video assignment, I wanted to combine Dr. Hertzberg's model cities and fog machine to visualize the flow of the fog over the city. I wanted to see how the city would interact with the fog and what types of flow the fog machine created. I also wanted to learn about how to photograph fog effectively and create a whimsical and beautiful image.

In order to capture my image, I set up my equipment as shown in Fig. 1. I placed the fog machine on the same level surface as the model city. Then, I placed a barrier over the fog machine to direct the fog over a bowl of ice sitting on the same surface. Then, about 1 inch above the table, the fog was allowed to escape the barrier and flow over the city. I placed the camera so that the lense was approximately one foot from the focal point of the image. I hung a black, sparkly fabric backdrop behind the model city. I placed a 25-Watt LED worklight in the location shown in the figure. I also took this image inside where there would be less air movement.

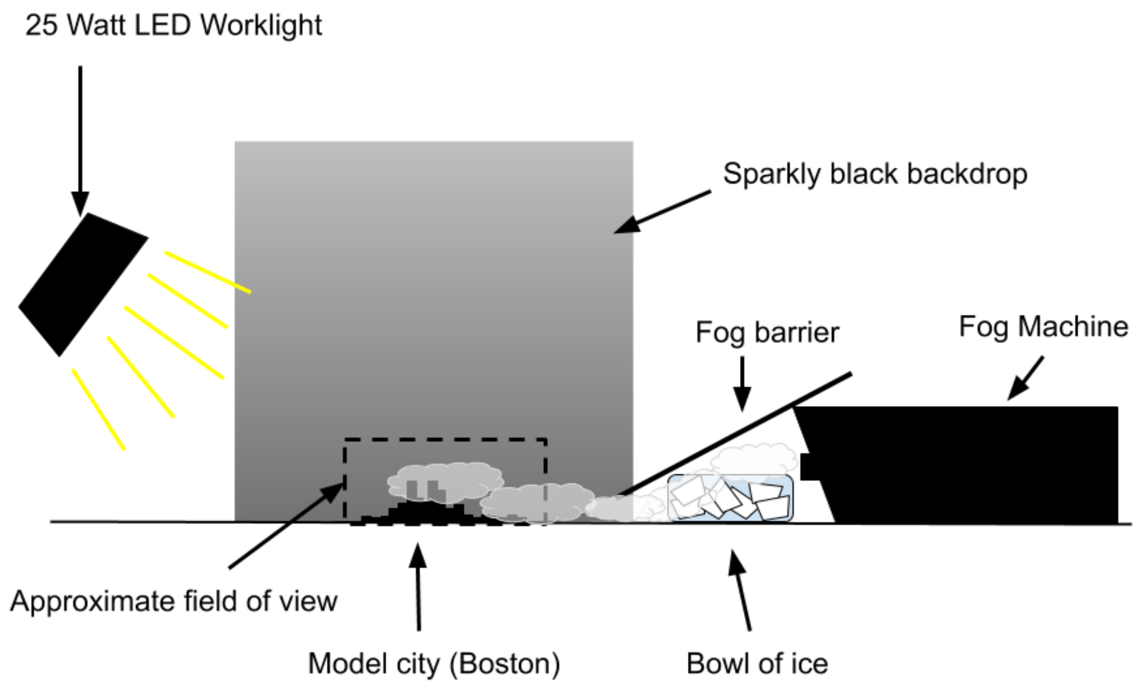

Figure 1. Diagram of flow visualization setup.

To get my final image, I turned on the fog machine and started to take pictures as the fog encompassed the city. I did this because letting the fog machine run for too long resulted in overly foggy photos where the city was much less visible and the flow less interesting. The goal of the passing the fog over ice before reaching the city was to decrease its buoyancy by cooling the fog (since it was heated to vaporize the fog fluid). That way, the fog would not rise as quickly away from the city. Thus, the intention was to make the fog closer to neutrally buoyant which means that it neither rises nor sinks in regular air at room temperature [1]. In class, Dr. Hertzberg identified the flow in my image as not fully turbulent. For transitional flow over a flat plate, the Reynolds number should be greater than 5×10^5 where the Reynolds number is $Re_x = \rho U x / \mu$ [2]. We can use this number to verify the flow in my image. By assuming neutral buoyancy, we can tell that the density ρ is approximately the same as that of the air. Thus, the density would be approximately 1.2 kg/m^3 [3]. Next, we can approximate the length scale to be about the width of the city: 0.3 m. We can also assume that the fog fluid is composed of glycerin which has a viscosity of 0.950 N*s/m^2 [4]. I also estimate that the fog was ejected from the machine around 0.5 m/s, which would be the fluid velocity U. Thus, we can calculate the Reynolds number as follows:

$$Re = \frac{\rho U x}{\mu} = \frac{(1.2\ kg/m^3)(0.5\ m/s)(0.3\ m)}{0.950\ Ns/m^2} = 0.2$$

This Reynolds number is vastly below the threshold for transitional flow. However, the equation I used was for flow over a flat plate. The city and the experimental setup is much less stable than a flat plate. However, because of the drastic difference, we could still be seeing laminar flow in my image. Additionally, Dr. Hertzberg pointed out the possible vorticity on the left side of my image as the fog curls around some of the buildings.

In order to visualize the flow in my experiment, I used a black, sparkly backdrop to visualize the milk-colored fog. I also used a bright, 25-Watt LED work light to illuminate the fog at an angle about 120 degrees from the flow of the fog, as suggested by Dr. Hertzberg. The light itself was probably around 3 feet from the model city. I angled my camera to be approximately perpendicular to the fog flow and adjusted the camera settings to better visualize it.

The size of my field of view was approximately the same as the width of the model city: one foot. I wanted to capture the city without including much of the surrounding setup. I placed my camera lens about one foot from the city and used the zoom feature to adjust the field of view and the focus to capture a lot of the city skyline while focusing on the tall buildings. I used 17-55 mm lens on a Nikon D7000 DSLR camera. Shooting in Raw mode, my original image was 4928 x 3264 pixels. I used an aperture of f/7.1, and ISO of 200, and a focal length of 35 mm. Additionally, I shot with an exposure of 1/125 sec. I adjusted these settings by taking some photos and then viewing them on my computer. When I found some I liked, I adjusted the next batch of pictures based on those settings with some improvements until I got something I was happy with. For instance, if the photo was too dark, I would see what I could do to change the aperture and shutter speed, while maintaining my desired depth of view and minimal motion blur. I edited my image in Photoshop by adjusting the lighting. I changed the lighting levels by decreasing the threshold for the lights and the blues. Thus, I increased the lights in the image and added a slightly blue tint. My final image was the same size as my original at 4928 x 3264 pixels. My original image is shown next to my edited image below.

Original image

Image after editing

My image reveals how fog flows over an uneven surface. I like the focus and lighting in my image. I think the post-processing especially helped reveal the fluid flow and vorticity around the front edges of the fog (on the left). Additionally, I like how the black background contrasts with the fog and reveals the detail and shapes within it as the layers of fog form lines and swirls. I think this helps reveal the fluid physics. The lighting and the shape of the fog helped fulfil my intend. One question I have is why do the swirls in the fog form? Is this vorticity due to transitional laminal-turbulent flow? Was this effect specifically caused by the shape of the buildings as the fog interacted with the city? How much of an impact did the model city have on the flow of the fog? To start to answer these questions, I could take more accurate measurements and find more applicable equations to determine the state of the flow. To develop this idea further, someone could try different fog rates and more controlled flow. For instance, they could try with a lower volumetric flow rate or possibly a smaller opening in the fog machine.

References

[1] Moore, Emma. "Three Types of Buoyancy" *sciencing.com*, https://sciencing.com/three-types-buoyancy-10036718.html. 22 November 2020.

[2] Chin Ngo, Chean, and Kurt Gramoll. “FLUID MECHANICS - THEORY.” *ECourses*, OU ECourses, www.ecourses.ou.edu/cgi-bin/ebook.cgi?doc=&topic=fl&chap_sec=09.3&page=theory#:~:text=For%20flow%20past%20a%20flat,to%20turbulent%20at%20this%20point.

[3] Engineering ToolBox, (2003). *Air - Density, Specific Weight and Thermal Expansion Coefficient at Varying Temperature and Constant Pressures*. [online] Available at: https://www.engineeringtoolbox.com/air-density-specific-weight-d_600.html [Accessed 22 Nov. 2020].

[4] Engineering ToolBox, (2008). *Dynamic Viscosity of common Liquids*. [online] Available at: https://www.engineeringtoolbox.com/absolute-viscosity-liquids-d_1259.html [Accessed 22 Nov. 2020].