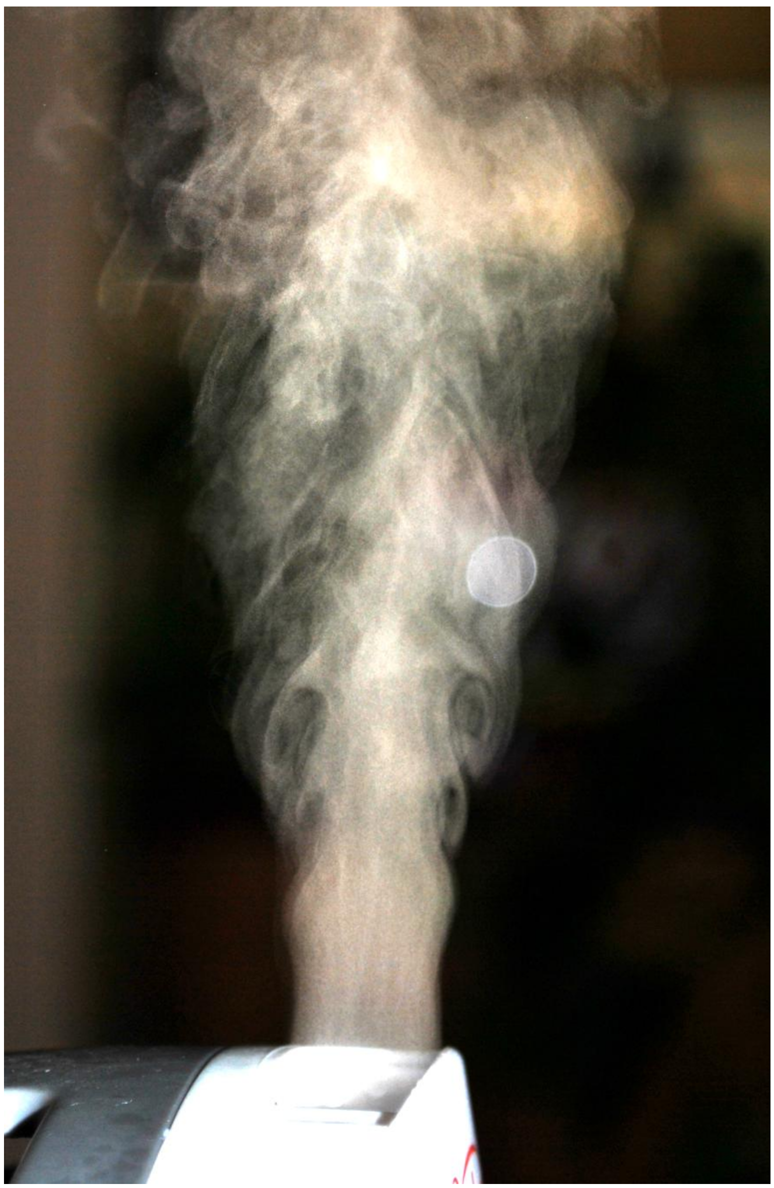
Water Vapor Leaving an Ultrasonic Humidifier

Michael Chilton

2/26/12

Flow Visualization 2012 – Get Wet Assignment



Introduction

For this assignment, my time with the camera being used was very limited and I did not have appropriate resources or time to design an experimental set-up. With this in mind, my focus was to find a flow that was either naturally occurring or occurring as a result of everyday actions. After finding numerous examples, I settled on the flow of water vapor leaving an ultrasonic humidifier. This was the most dynamic I could find locally that presented the most interesting and clearly defined phenomena. This flow was a good source for study as it was easy to photograph and required minimal adjustments from the camera. My experience with Photoshop was limited going into this assignment, and this study proved to require little post-processing due to the clarity of the original image and the "un-processed" theme desired. The purpose of this study is to demonstrate the transition between laminar and turbulent flow occurring in a non-experimental, uncontrolled situation.

Experimental Set-up

The flow apparatus used for this study was a Sunbeam Ultrasonic Humidifier set atop a three foot tall stool.[1] This set up is demonstrated in Figure 1. The camera was mounted on a tripod approximately three feet from the humidifier and the lens was made as level with the humidifier opening as possible. As the main focus of this image was to capture fluid flow in an already occurring process, the humidifier was not specially positioned or mounted and was left just as it is typically used. The humidifier's power level was set to the highest setting to make the flow more apparent and easier to capture. The room temperature was not adjusted and any movement inducing actions near to the humidifier were controlled so as to further promote a clear and undisturbed flow.

Figure 1: Flow Visualization Set-up

Flow Analysis

Within this humidifier, water vapor is created by way of a piezoelectric oscillator vibrating at an ultrasonic frequency producing capillary waves on the surface of a thin layer of water. These waves cause droplets to break off of the surface, creating a fine cool jet of vapor travelling upwards through the device's opening. The size of these droplets is a constant fraction of the capillary wavelength and follows the relation shown in Equation 1, where D_{drop} is the aerosolized droplet count medium diameter, d_1 liquid density, T_s surface tension, and f the Ultrasonic transducer frequency.[2]

$$D_{drop} = 0.34\left(\frac{8\pi T_S}{d_1 f^2}\right)^{\frac{1}{3}} \tag{1}$$

The density of the tap water being used at approximately 50°F was found to be 1000 kg/m^3 and the surface tension was 0.0742 N/m.[3] The frequency of the ultrasonic transducer was assumed to be 1.65MHz, as this is standard for nebulizers and humidifiers of this type.[3] Using this data, the aerosolized droplet count medium diameter was calculated to be 76.3 microns, which is slightly smaller than the diameter of a human hair.

The rectangular opening of the humidifier was measured to be 19 mm by 55 mm, resulting in an area of 1045 mm^2. Equation 2 was used to calculate the Reynolds Number of the flow as it leaves the device's opening, where U_∞ is the free stream velocity, x the distance from the leading edge, ρ the density, and μ the absolute viscosity. [4]

$$Re_x = \frac{U_\infty x \rho}{\mu} \tag{2}$$

The vapor's flow was estimated to be approximately 6 m/s, based off measurements from previous experiments.[3] A distance of 5 mm- 80 mm was used to examine the flow following the opening. The density of water vapor at an ambient temperature of 68° F was found to be 17.3 g/m^3.[3] The viscosity of water vapor was found to be 0.89cP.[3] At a distance of 5 mm from the opening, the Reynolds Number was calculated to be 33,700, which is below the turbulent transition point, indicating laminar flow. The distance of 80 mm was chosen as the farther reference point after examining the image and measuring the point at which flow becomes turbulent. At 80 mm from the opening, the Reynolds Number was calculated to be 539,000, which is just beyond the turbulent transition range, indicating turbulent flow. Figure 2 clearly demonstrates the turbulent transition point shown within the image.

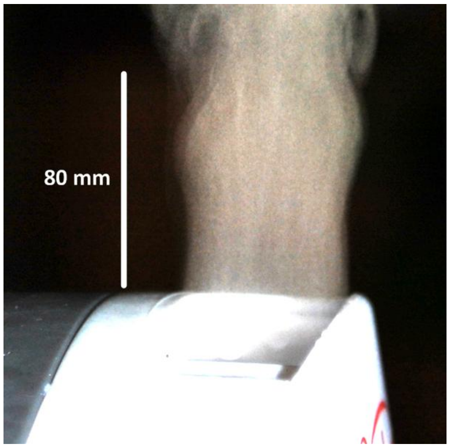


Figure 2: Turbulent Transition in Flow

Upon studying the image, the Kelvin-Helmholtz instability is clearly demonstrated at the turbulent transition point. There are two easily identifiable Kelvin Ovals on each side of the flow. These vortices are created by the denser cool water vapor moving against and mixing with the less dense ambient air outside of the humidifier. The instability occurs as a result of velocity shear across two different fluids of differing densities, forming surface waves at the interface of the two fluids.[5]

Visualization Technique

There were no special visualization techniques used in this study, as the purpose was find a flow representation already occurring through everyday actions. The most difficult part of visualizing this flow was properly illuminating the water vapor as it left the humidifier. The camera's built-in flash was used for this as it reflected the most amount of light off the water vapor. It required numerous attempts to properly capture the flow with the camera's flash. There was a significant amount of glare created by the camera's flash against the water vapor, the final image used represents one with the least amount of this. The camera's direction was moved around to utilize the darkest background available, which was used so as to promote the contrast between the illuminated water vapor and its surroundings.

Photographic Technique

The image was taken using a Nikon D3000 with an AF-S DX NIKKOR 18-55mm VR lens mounted to a tripod set 3 ft away from the humidifier. From this, the field of view was found to be approximately $3ft^2$. The NIKKOR lens' focal length was 48mm and the aperture was f/5.6 with a shutter speed of 1/60 and a film speed of ISO 100. The ISO was lowered as much as possible in effort to create a sharper image that better reflected the flow's movement.

The original image incorporated a lot of distracting elements surrounding the flow and also did not provide a clear contrast between the background and the water vapor leaving the humidifier. To better exemplify the flow, Photoshop was used to adjust the contrast and color curves. I made every effort to black out the background without deteriorating the Kelvin instability occurrence on the outer edges of the flow. The colors scales were adjusted slightly with a focus again on blacking out the background without washing out the edges of the flow. I was careful to not adjust the colors too much, as I wanted to maintain a “non-processed” theme. The image was also cropped to remove distracting elements outside of the flow and bring it into the image’s center, further focusing attention to the flow itself. A small portion of the humidifier was left within the image to provide a reference point for dimensioning and also to reiterate the image’s original purpose of typically occurring fluid flows. I felt if the humidifier was left out of the image completely, it would look too much like a set-up experiment, which was not my intent. Removal of the glare created from the camera’s flash against the water vapor was attempted within Photoshop using the brush tool, however, I could not properly remove it without adversely affecting the flow image and turbulent definitions.

Conclusion

The captured image shows a good representation of the transition between laminar and turbulent flow and also the propagation of the Kelvin-Helmholtz following this transition. This photo is interesting because of the ultrasonic method of how the fluid was created and propagated through the humidifier coupled with the combination of upwards vapor flow impinging on a less dense gas and ultimately evaporating. It was really interesting to see that such flow could be found regularly occurring within my house. If I could re-do this image, I would add a solid color background with a useful scale. This way the flow properties would be clearer and their measurements would be more accurate. I would like to know just how the vapor behaves at its point of generation within the humidifier and whether it was turbulent before leaving the device. Conducting a pipe-flow study of this internal flow could help to better assess the flow’s properties as it left the humidifier opening. It would be interesting to take this study further by removing the casing from the humidifier, use a slow-motion camera, and study the wave propagation at the ultrasonic plate to better capture this initial state of flow. I have been able to find a few examples of this type of image capture, further motivating me to experiment with this idea.

References

[1] *http://www.drillspot.com/products/579454/jarden_consumer-heater_hum_sul496-um_ultrasonic_humidifier*

[2] Lang, R. J. *Journal of the Acoustical Society of America.* 1962, 34, 6-10.

[3] Howard, Benjamin, et. al. (2010). "High Speed Photography of Ultrasonic Atomization." *http://ultrasoundatomization.com/ultrasonic_atomization_thesis_text.pdf*

[4] *White, Frank.* Fluid Mechanics*. 6. New York: McGraw-Hill, 2008.*

[5] John W. Miles (1959). On the generation of surface waves by shear flows Part 3. Kelvin-Helmholtz Instability. Journal of Fluid Mechanics, 6, pp 583-598