Group Project 1

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Flow Visualization

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A series of several hundred images was captured for the first group project of the Flow Visualization course. The intent of these images was to photograph the lofty, silky features of water fog created by an ultrasonic humidifier. It was hoped that these images would expose the ebbing nature and interesting vorticies of the fog. Unfortunately, this phenomenon was very difficult to capture and required a lot of patience and experimenting due to its highly three-dimensional nature. Many fruitless attempts were made at visualizing the thick fog as it initially poured from the spout of the humidifier. Thus, the challenge of "flattening" the flow while preserving its' features was born. This flatter flow allowed the fog dynamics to be better captured by a camera. Figure 1 displays an image created by this technique. This is the final image chosen for Group Project 1.

Figure 1: Water fog flowing down an inclined plane.

The apparatus used to create the flow in this experiment was a Holmes Production Corporation Family Care humidifier (Model # HM-480) on flow setting II and the highest water vapor setting. As stated in lecture on October 11, 2004, an electric disk in the base of the humidifier is excited by high frequency and vibrates. The vibration leads to the creation of water droplets which emerge from the humidifier as water fog. The humidifier was placed on a short bench and a flat board was inclined at forty-five degrees to the ground to align with the outlet of the humidifier. This board was covered with a layer of black velvet to create a very rich and distinct background. A more complete depiction of the experimental setup is shown in Figure 1.

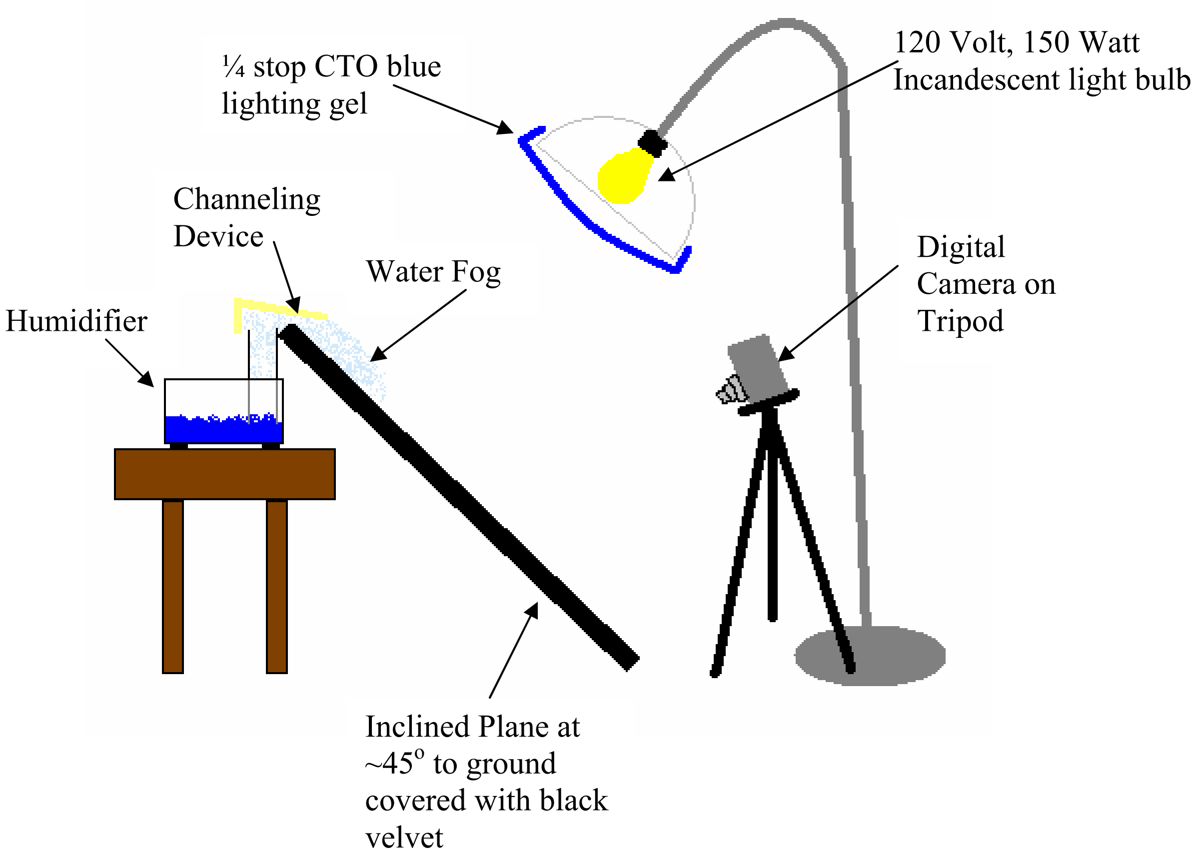

Figure 2: Flow Setup

From the spout of the humidifier, the fog was channeled to the top of the inclined plane and released through a triangular opening. The size of the triangular opening was approximately 3 cm at its peak by 20 cm at the base. A view of the triangular opening as examined from the base of the inclined plane is presented below.

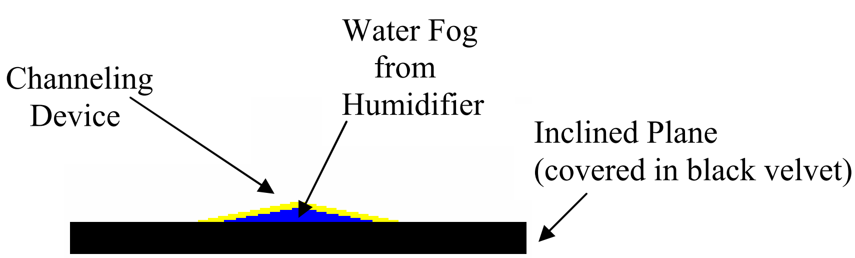

Figure 3: Channeling device (as viewed from the base of the inclined plane).

The basic flows observed were boundary layer effects of water fog as it flowed down the inclined plane. These effects were present on both the bottom and top surfaces of the fog as it interacted with the black velvet and the less moist ambient air. Each of these interactions created multiple flow dynamics, vorticies, and shear layers. The shear layers seemed to roll up as the fog traveled down the inclined plane. The largest of these rollers are very evident in the image as areas of highlights. The fog on the leading edge of these vortex structures seemed to quickly evaporate as it was thrust into the less moist air. The evanescence of the fog was difficult to capture and never created the exact same flow pattern twice.

By assuming that water fog is a saturated water vapor, or steam, at a temperature of 19.4 ^{o}C (67^{o} F) and an ambient pressure of 84.34 kPa (12.23 psia) due to the altitude of approximately 1524 meters (5000 feet), Engineering Equation Solver (EES) can be employed to determine both the absolute viscosity (2.458 lb_m/ft-hr or .001016 N-s/m^2) and the density (998.27 kg/m^3 or 62.32 lb_m/ft^3) of the fluid. The EES code is attached in the Appendix. These values can then be entered into the equation for the Reynolds number,

$$Re_x=\frac{U_\infty x\rho}{\mu} \qquad \text{Equation 1}$$

where U_∞ is the free-stream velocity
x is the distance from the leading edge
μ is the dynamic viscosity of the fluid
ρ is the density of the fluid

The estimation of the free stream velocity of the water fog was .25 m/s (assumed to be constant in the direction of flow), and the value of distance from the leading edge varied from .05 m to .75 m. Thus, the Reynolds number for this flow ranged from approximately 12300 to 184000. The very large value of the Reynolds number at .75 m from the leading edge indicates probable turbulent flow in these regions.

The spatial resolution of the image can be determined by examining the size of the smallest feature and comparing this to the size of the pixel used to capture the image. The resolution of this image is 28.346 pixels per centimeter or .0003527 meters per pixel. For this image, the flow dynamics are present on multiple scales including miniscule ones, such that it would be very difficult to spatially resolve the image more without the use of specialty equipment. The temporal or time resolution can be calculated by multiplying the velocity of the flow by the shutter speed. This value gives the distance traveled during the exposure and for this image is approximately .00417 m. Thus, because the value of the time resolution is greater than the value of the image resolution, the image is not resolved well for time. A strobe or laser could be used to achieve better time resolution.

Water fog created by an ultrasonic humidifier creates both the flow and the visualization technique used to observe the flow. A variety of lighting techniques were utilized to capture this image. The first component of the lighting was ambient light from two windows in my living room on October 17, 2004, a partially cloudy day, at 11:30 am. Each window was located approximately ten horizontal feet away from the flow visualization setup in the configuration shown in Figure 4.   The second lighting component was an incandescent light situated almost directly above the velvet inclined plane. The 120 Volt, 150 Watt light bulb was covered with a ¼ stop blue CTO lighting gel and was approximately 5 vertical feet above the base of the inclined plane. In addition, the standard flash on the camera was used to further illuminate the image and provide a slightly less time resolved strobe effect. The camera and hence the camera flash were located approximately 3 vertical feet above the base of the inclined plane. Originally, the fog was white and gray in nature, however, with the application of the ¼ stop CTO blue lighting filter and the flash, the fog became bluish in color. I feel the application of these techniques increase the aesthetics of the image as a whole. The overall lighting setup is shown below,

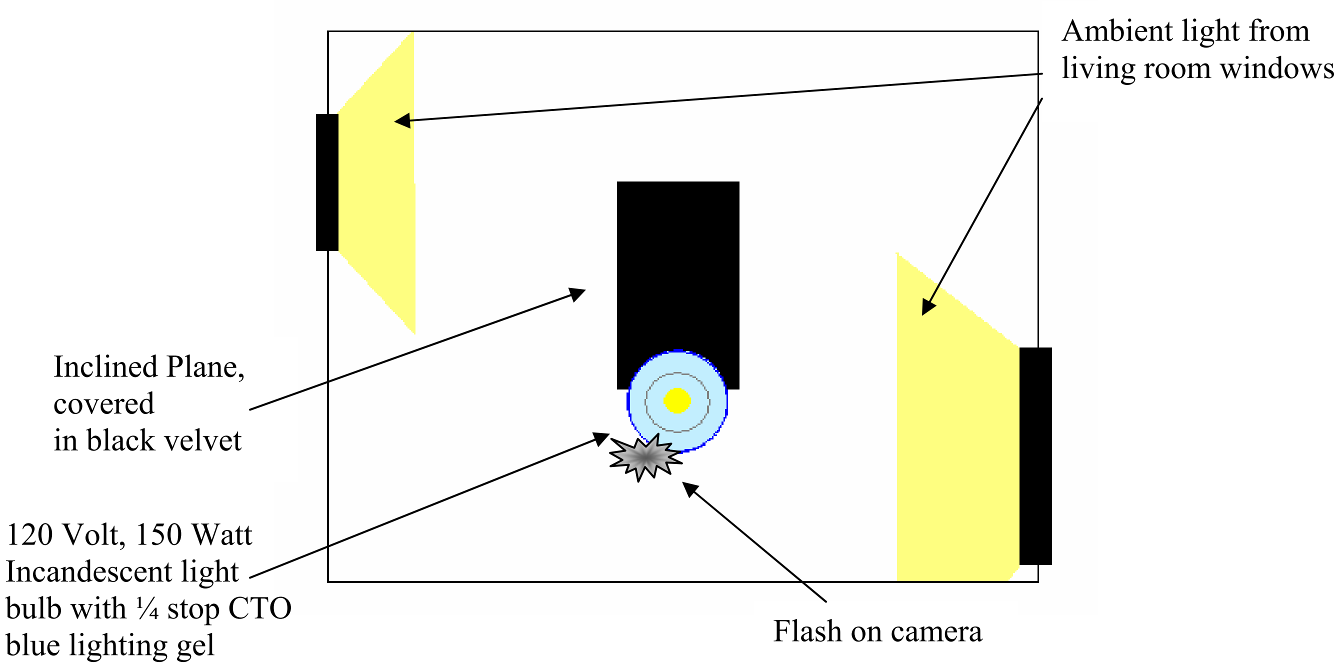

Figure 4: Schematic of lighting placement. (Note: not to scale)

This image was captured with a 4.0 effective megapixel Nikon Coolpix 4300 digital camera on October 17, 2004 at approximately 11:30 am. The camera was in AutoFocus mode and the following settings and attributes were recorded.

Table 1: Camera and Image Settings

Setting	Value
Original File Size	1198
Digital Zoom	1.0x
Focal Length (mm)	f8.0
Apeture Setting	F2.8
Shutter Speed (sec)	1/60
ISO equivalency Number	100 (Auto)
Final Dimensions (pixels)	1392 x 1818
Final Image Field of View	50 cm x 70 cm

Adobe Photoshop post processing was used to create an image that was cleaner and resembled the actual phenomena more closely. The filters, Auto Levels and Auto Contrast, were applied to achieve this balance.

This image reveals some very interesting aspects of the flow phenomena of water fog. It displays the aesthetically beautiful flow and provides insight to boundary layer and shear layer dynamics between the fog, the flat plane, and the ambient air. It also presents an interesting commentary on how fog flows. I really like the composition of the image and the subtle vorticies evident in the highlights. I feel that these are also the most evident fluid physics present throughout the image as well. I would like to know more about what dictates the particular flow patterns I observed while capturing my images. It seemed like any change in the room environment could trigger a new flow pattern. The flow seemed particularly vulnerable to wind currents in the room and hence, extra precautions were taken to keep the ambient air as still as possible. My only problems with the image are that I wish it was more time and spatially resolved. I would like to use the high speed digital camera or a strobe light to attempt further imaging. However, despite these minor disappointments, I feel that I definitely fulfilled my intent both artistically and scientifically because I managed to capture an aesthetically striking and physically intensive fluid flow. At the end of the first photo shoot, my images were so dismal that I almost judged this flow phenomenon impossible to image with my camera and setup. So, after days of work, when the imaging technique and images came together I was delighted. After further mastering the technique, I would like to work with different lighting filters to play with the illusion of warm and cold colors and their relation to the flow as suggested by Professor. Hertzberg. Another way to develop this idea further would be to either alter the flow patterns or the conditions.

Appendix

Engineering Equation Solver Code for determining the absolute viscosity and the density of steam for the conditions listed: