Low Reynolds Number Wave Flow

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Nomenclature

ρ	=	fluid density	$[kg\ m^{-3}]$
μ	=	dynamic viscosity	$[N\ s\ m^{-2}]$
v	=	velocity	$[m\ s^{-1}]$
d	=	characteristic dimension	$[m]$
Re	=	Reynolds number	[ ]

I. Introduction

THIS experiment was designed to capture an image of a flowing fog that is interesting from both an artistic and scientific perspective. The image captured displays a series of waves of fog created by dry ice as it sublimates in a water alcohol mixture. As the dry ice sublimates, it forms bubbles in the water alcohol mixture. When these bubbles reach the surface, they create surges of dry ice fog that propagate as waves across a horizontal surface at the same level as the top of the container of the water alcohol mixture.

The experiment was performed in the context of the Flow Visualization class at the University of Colorado at Boulder. The assignment for this image was titled “First Group Image.” For this assignment, students worked in teams of up to 5 in order to create experiments that would yield worthy images.

II. Flow Apparatus

To create this image, a piece of dry ice was submerged in a water alcohol mixture and allowed to sublimate, creating a dry ice fog. A water alcohol mixture was used for this experiment, because the alcohol reduced the freezing temperature of the mixture, so that the sublimation could occur longer before the water froze into a shell around the dry ice. The container was a rectangular jar of approximately 10x10x20cm and was placed next to a black horizontal surface at the same level as its opening. This placement allowed for a slow horizontal propagation of the dry ice fog that could provide the image captured in this experiment. The setup of the dry ice, jar, and horizontal surface are described in Figure 1.

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III. Visualization Technique

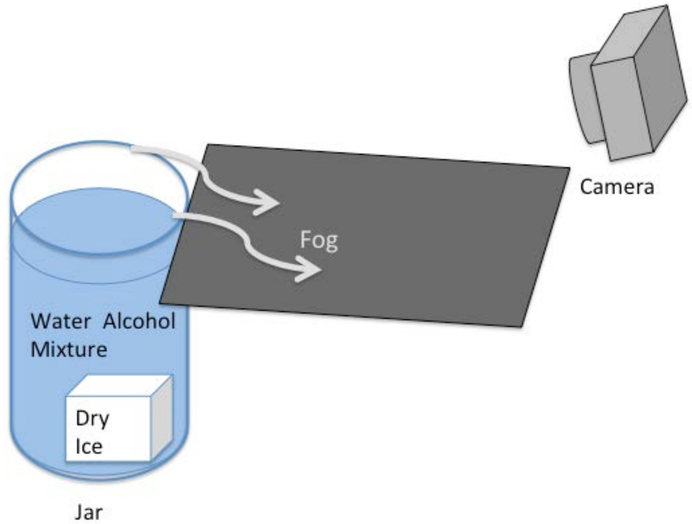

Figure 1: Visualization setup diagram

The initial goal of this experiment was to visualize the popping of a bubble of dry ice fog. While some interesting images resulted from that experiment, the most interesting effect was found accidentally when the jar containing the dry ice and water alcohol mixture was placed next to a horizontal surface. The horizontal surface helped to visualize the dispersion of surges of fog that were generated by large bubbles of carbon dioxide reaching the surface of the water alcohol mixture.

IV. Flow Analysis

The phenomenon captured by the image for this report was the propagation of waves of fog across a horizontal surface. The waves imaged appear to demonstrate either gravity waves or supercritical flow, though they are not true examples of such flow. Rather, the low velocity of the flowing gas means that it has a low Reynolds number, so the momentum forces and viscous forces will have almost equal effects on the fluid.

To calculate the Reynolds number of the flow, one must first calculate the velocity of the flow. This can be accomplished by analyzing the movement of the waves between two images taken at close to the same time. Two

Figure 2: Wave propagation over 1 second

images taken only one second apart are shown in Figure 2. These images show the pocket of fog leaving the container and moving 10cm horizontally in 1 second. This gives the flow a speed of 0.1m/s, which can be used to estimate a Reynolds number of about 6 using the equation listed below and assuming the values of air at 300K and one atmosphere of pressure.

$$Re = \frac{\rho v d}{\mu}$$

The calculated Reynolds number explains why the flow appears to take the same form as a wall of water in a flash flood. Because the viscous forces are acting almost as much as the momentum forces, the initial wave shape will not dissipate and reform like a gravity wave, but will disperse mainly through the dissipation of the individual particles that form the fog.[1,3] Waves can form in low Reynolds number fluid flows with two fluids of different viscosities.[2] One source of wave formation is when the less viscous fluid is next to the wall containing the fluid.[2] This could possibly account for the streaks that appear in the direction of motion, but these are more likely due to momentum forces and irregularities in the horizontal fabric surface beneath the fog.

V. Photographic Technique

The image was captured using a Cannon EOS Rebel T3 and was processed using The Gimp photo editing software. The image was first cropped from an original size of 4272x2848 pixels to a size of 3924x2460 pixels, and then was converted to a grayscale image to eliminate any distraction from variations in color in an image that was nearly grayscale originally. Finally, the brightness of the image was adjusted using a transfer function to enhance highlights and increase shadows. A comparison between the original and final images can be seen in Figure 3.

The image was taken at a distance of approximately 0.5m from the focus area at the juncture between the

Figure 3: Image alteration comparison

container of the water alcohol mixture and the horizontal surface. The image was captured with a focal length of 36mm, an aperture of f/4.5, an ISO speed of 1600, and a shutter speed of 1/160 s. Based on this shutter speed and the velocity of 0.1 estimated from Figure 2, the flow is estimated to have moved about 0.6mm within the exposure time of the image, which gives it good temporal resolution.

VI. Conclusion

The image in this report successfully demonstrated a low Reynolds number fluid flow using dry ice fog as a visualization technique. The image demonstrated wave formation based on irregular flow rates from a fluid source, and these waves dissipated mainly through diffusion. The image was successful from an artistic perspective, because it generated multiple interesting textures that were visible without the influence of distractions other than the fluid flow. For future investigations, the most promise is in the investigation of the formation of streaks in the velocity direction of the flow, which could not be explained by the author.

Acknowledgments

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References

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