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Flow Visualization – MCEN 4047

Team Project 3

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Introduction

For my third group project in my flow visualization course at the University of Colorado I wanted to use cigarette smoke to visualize the flow of the smoke over a cylinder. I worked in the Integrated Teaching and Learning Laboratory fume hood in order to have a space where I could safely dispose of the smoke and control the lighting. I was intending to be able to capture Karman Vortex's as they were formed by the smoke traveling past the cylindrical PVC pipe, but this proved to be very hard to capture not only because the smoke was difficult to get a good image of but the flow was very chaotic because it was being pulled from the top by the suction within the fume hood. Nonetheless, I was able to capture one clear vortex ring on the right side of the image and a less defined vortex on the left side. Even though the Karman Vortex phenomenon was hard to capture, I was still able to obtain a beautiful image of the cigarette smoke flowing over the cylinder which was creating a very chaotic wake. I had help from my friend Matt Heinrich and fellow flow visualization student Zach Brunson.

Flow Apparatus

The flow apparatus was a fume hood; the experimental set-up can be seen in Figure 1. The black backdrop is a black cloth sheet that is draped over a poster board. The PVC pipe was long enough (approximately three feet) so that it could be hand held on the end protruding from the fume hood without affecting the flow. We lit an entire pack of cigarettes in order to get enough smoke to be visible, and those were hand held approximately two inches below the PVC pipe in the orientation shown. The flow direction was up and to the right as shown in Figure 1 due to the fan sucking the flow up and into the center of the fume hood. This fan caused the flow to speed up and become very chaotic even though based on the Reynolds number the flow was not turbulent.

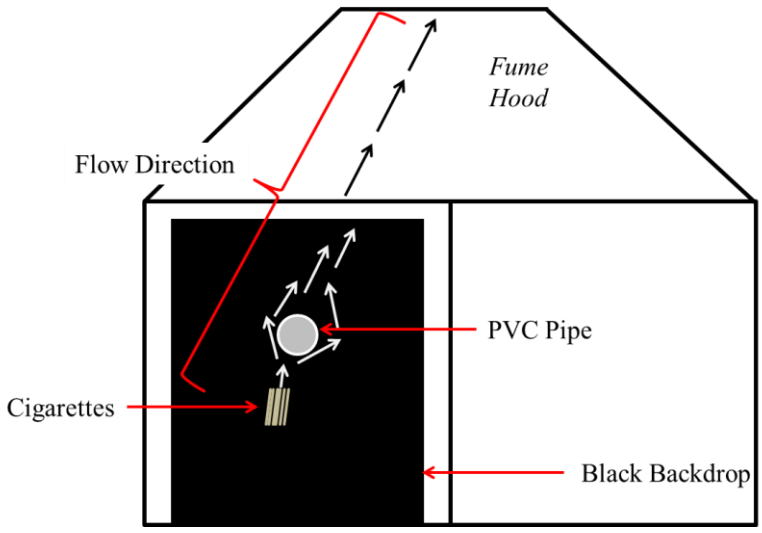

Figure 1: Fume Hood

Flow Physics

Buoyancy, along with the fume hood's upward suction, is the force that drives the smoke particles upwards. The buoyant force pushes upwards because the pressure that a fluid applies on a body increases as depth gets greater, and therefore the pressure is greater at the bottom of a body than on the top of a body.[3] The cigarette is on fire, and it therefore heats up the air around it. That heated air is less dense than the surrounding air, and because it is less dense the heavier and denser surrounding air pushes up on that hotter air with a buoyant force. The smoke particles are heavier than the surrounding air, but because they are in the hot air they a forced up with it.

As stated in the introduction, my original goal was to visualize Karman Vortex's as they moved past a cylinder. This is called a Karman Vortex Sheet[1], and this can be seen in Figure 2.

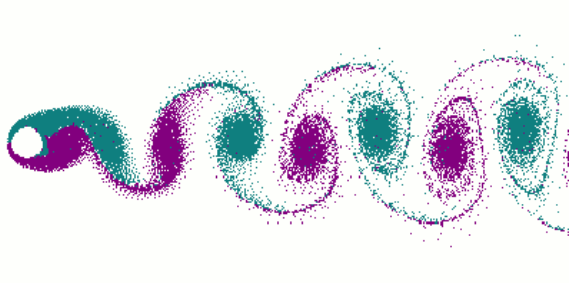

Figure 2: Karman Vortex Sheet[1]

"A Karman Vortex Sheet is a repeating pattern of swirling vortices caused by the unsteady separation of flow of a fluid around blunt bodies."[1] The flow cannot remain attached to the cylinder because it is not an aerodynamic object, and subsequently this pattern of vortices forms in the wake of a cylinder. The vortices alternate on both sides of the cylinder so that every other vortex comes from the opposite side and is halfway between the vortices from the opposite side.[1] Karman Vortex Sheets are formed for Reynolds numbers between 47 and 10^5 when the flow is over a cylinder.[1] The kinematic viscosity of air at room temperature is $1.64\text{x}10^{-4}\frac{ft^2}{s}$, the diameter of the pipe is two inches, and the velocity of the smoke upwards is approximately three feet per second.[2] The Reynolds number is calculated in where V is the velocity of the fluid, d is the diameter of the pipe, and υ is the kinematic viscosity of the fluid.[1]

$$Re = \frac{Vd}{\upsilon} = \frac{3\frac{ft}{s} * 0.167ft}{1.64 * 10^{-4}\frac{ft^2}{s}} = 3049 \approx 3000$$

According to this Reynolds number of 3000, the Karman Vortex Sheet should be able to form. I hypothesize that because there is an increasing acceleration field due to the upward force of the fan pulling the smoke to the top of the fume the Karman Vortex Sheet cannot form. I hypothesize that this force breaks up the Karman Vortex sheet so that it cannot form past one vortex on each side of the pipe.

Visualization Technique

I lit an entire pack of Diamond brand cigarettes in order to get enough smoke to be visible. I used a small amount of ambient light in the room in order to be able to see what I was doing. I used the flash on my camera because the smoke showed up best when the flash was utilized. The flash seemed to bounce of the smoke that would otherwise look faint. The combination of very low lighting and the camera flash made the smoke most visible.

Photographic Technique

The field of view for the final image after it was cropped is approximately five inches wide by six inches tall. This can be determined by looking at the PVC pipe which had an approximate diameter of two inches. The object was close enough to the lens for both my camera and hand to smell like cigarette smoke afterword. The object was no more than four inches from the lens. The focal length of the lens was 4.5 millimeters. The camera was a digital Canon PowerShot SX260 HS. The original image was 4000 pixels wide by 3000 pixels in height as seen in Figure 3.

Figure 3: Original Image

The final image is 2466 pixels in width and 3000 pixels in height. I had to use a fast enough shutter speed in order to freeze the smoke and not get motion blur. To do this I used a shutter speed of 1/200. Because of this fast shutter speed in low light I had to use my lowest F-stop of F/3.5 and a relatively high ISO of 1600. Nonetheless the image still turned out well defined and not too grainy. I cropped the width of the image in order to focus in on and center the smoke in the image. I was very uninterested in the original color scheme; so, I played with the individual red, blue, and green portions of the curve function as well as the RGB curve. I came up with several images, but in true University of Colorado Buffalo spirit I decided to go with the black and gold image. I was able to maintain essentially all of the information in the image while changing the colors to be more appealing. The final Photoshop curves setting that I settled on I had manipulated in the RGB, blue, and red settings as seen in Figure 4.

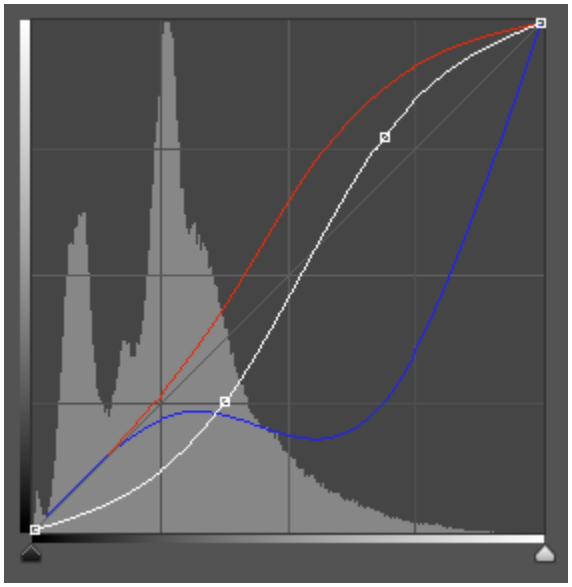

Figure 4: Photoshop Curves Function

Conclusion

The image reveals the formation of two vortex's as well as chaotic and beautiful flow past and behind a cylinder. I like the flow pathway shown in the image, and I like that I was able to freeze the smoke in the image without having motion blur. I did not like the black and grey colors, and that is why I changed the smoke to gold. The physics of a Karman Vortex Sheet is not shown as well as I would have liked it to be shown, but I was able to show two vortex formations. In the future I would improve my experiment by finding a location with completely still air that I would still be allowed to use smoke as my medium. After I changed the colors of my image I was very satisfied with the results that I was able to produce; my intent was to create an image that was both artistic and revealed a physical phenomenon.

References

[1] "Kármán Vortex Street." *Wikipedia*. Wikimedia Foundation, 28 Apr. 2013. Web. 30 Apr. 2013.

[2] "Air - Absolute and Kinematic Viscosity." *Engineering Toolbox*. N.p., n.d. Web. 30 Apr. 2013.

[3] "Buoyancy." *Wikipedia*. Wikimedia Foundation, 05 Mar. 2013. Web. 03 May 2013.