Interaction Between Two Smoke Streams

Get Wet Report

https://vimeo.com/85770537

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MCEN 4151: Flow Visualization
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I. Introduction

This project was the first assignment for the course "Flow visualization: the art and physics of fluid flow" offered at the University of Colorado at Boulder. The assignment was called "Get Wet" and its objective was to introduce students to techniques for creating and capturing fluid flow phenomena. This required developing a methodology for producing the flow phenomenon as well as accurately capturing the phenomenon with photographic techniques. I chose to create a video that captured the interaction between two adjacent smoke streams.

II. Fluid Mechanics

A schematic of the setup used to create the video is shown in Figure 1. Two incense sticks were used to create the smoke streams. I poked two slits in a small cardboard box about half of an inch apart and placed the incense in the slits so that they stood vertically. When incense burns, the air around it is heated, causing it to become less dense than the ambient, cooler air. As such, the hotter and less dense air rises, carrying ash particles upwards, creating a smoke plume that can be observed.

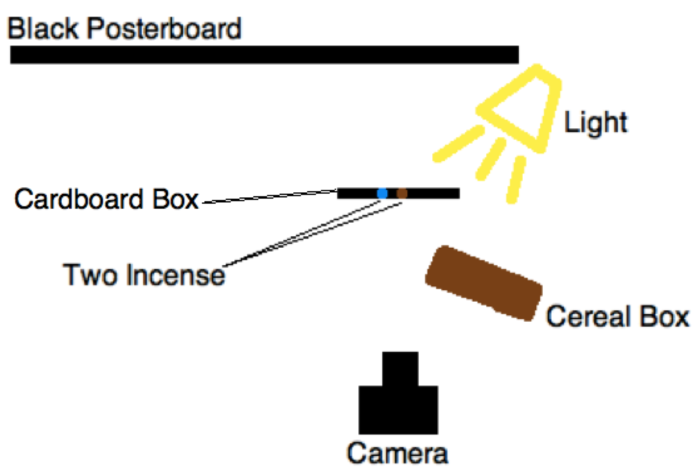

Figure 1: Set-up used to capture video, as viewed from the top

The video I captured highlights the transition from laminar to turbulent flow. The laminar or turbulent conditions of a fluid flow are characterized by the Reynolds number, which is a dimensionless number defined as the ratio of inertial forces to viscous forces acting on the fluid. The equation for the Reynolds number is given below.

$$\mathrm{Re} = \frac{\rho V L}{\mu}$$

Where V is the fluids velocity, L is the characteristic length, ρ is the density, and μ is the absolute viscosity.

The transition from laminar to turbulent flow typically occurs between a Reynolds number of 2,000-4,000 (1). Reynolds numbers lower than this will exhibit laminar flow and Reynolds numbers higher will be turbulent. By knowing the approximate Reynolds number, and other properties of the flow, it is possible to estimate the viscosity of the incense smoke. For this analysis, the flow will be modeled as flow in a pipe, where the colder air represents the outer boundary layer and it will be assumed the Reynolds number is 3000. The characteristic length then becomes the diameter of the two smoke plumes, which is estimated to be 2 inches, or 0.0508 m. The velocity is at the transitional region is estimated to be 1.5 inches per second, or 0.0381 m/s. The density was assumed to be 1.1 g/cm^3, or 1100 kg/m^3 (2). The absolute viscosity is then estimated as:

$$\mu = \frac{\rho V L}{\mathrm{Re}} = \frac{\left(1100 kg/m^3\right)\left(.0381 m/s\right)\left(.0508 m\right)}{3000} = 7.097 \times 10^{-4} Pa \cdot s$$

A boundary layer also exists between the two smoke streams. Since the two smoke streams have slightly different densities and velocities, a shear force is created at this interface. This results in the Kelvin-Helmholtz instability, which is seen when one of the smoke streams forms a sinusoidal pattern. As the sine waves grow, the waves eventually collapse and roll into spirals (https://vimeo.com/85770537). Kelvin-Helmholtz instabilities are characteristic of transitional flow, as the video shows (3).

III. Camera and Lighting

The video was captured at 29.98 fps with a Canon EOS 60D DSLR camera equipped with an 18-135 mm zoon lens at 53 mm at a resolution of 1920 x 1080 pixels. The camera was approximately 18 inches away from the smoke, and the frame begins about 2 inches above the tip of the incense. It was rotated 90^o on a tripod, causing the smoke to appear as if it is moving in the horizontal direction. This was done not only for aesthetics, but also in order to fully utilize the frame space. To illuminate the smoke but eliminate glare on the black poster board backdrop, a 50 W halogen light was placed in front of the backdrop and tilted upwards towards the smoke. A cereal box was placed partially between the light source and the camera to soften the intensity of the light entering the lens.

There was some post-processing done in Adobe After Effects. The saturation was altered to increase the contrast between the smoke and the backdrop. A frame from the original video and a frame from the edited video are shown in Figure 2 on the following page. Note that the stills shown in Figure 2 are not the exact same frame. The video was also slowed down to 20 fps to reveal more detail of the flow patterns.

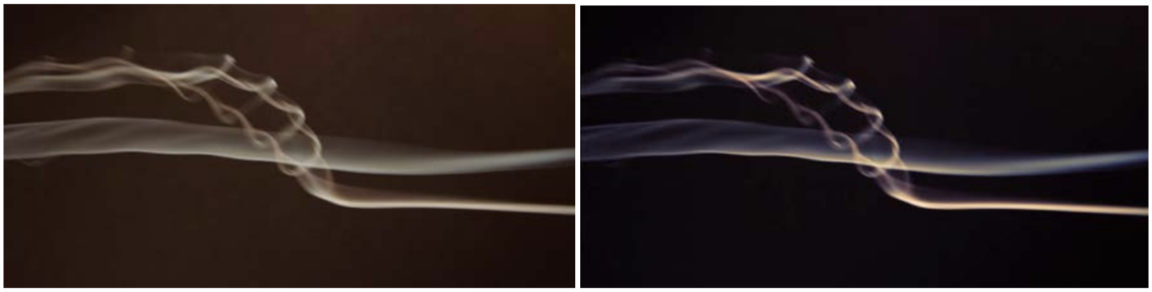

Figure 2: Stills from video before and after digital editing

IV. Conclusions

This video succeeded in capturing the physics and beauty of transitional flow and its associated instabilities. The black backdrop and digital editing create a stark contrast, which really highlights the smoke. For future work related to this project, it would ideally be shot at a higher frame rate and resolution. This would reveal more about the fluid mechanics and provide crisper still images. Adjusting the position, types, and number of incense, as well as the position and intensity of lighting, could also produce interesting effects.

V. References

(1) "Overview of Fluid Mechanics Theory." EFunda.com. EFunda, Inc, 2012. Web. 10 Feb. 2014. <http://www.efunda.com/formulae/fluids/overview.cfm>.

(2) Ji X, Le Bihan O, Ramalho O, Mandin C, D'Anna B, Martinon L, Nicolas M, Bard D, Pairon J-C. "Characterization of particles emitted by incense burning in an experimental house" 2010. Web. 10 Feb. 2014. <http://www.ncbi.nlm.nih.gov/pubmed/20409193>.

(3) "Kelvin-Helmholtz instability." *Wikipedia.* Wikimedia Foundation, inc. 7 Jan. 2014. Web. 10 Feb. 2014 <http://en.wikipedia.org/wiki/Kelvin%E2%80%93Helmholtz_instability>.