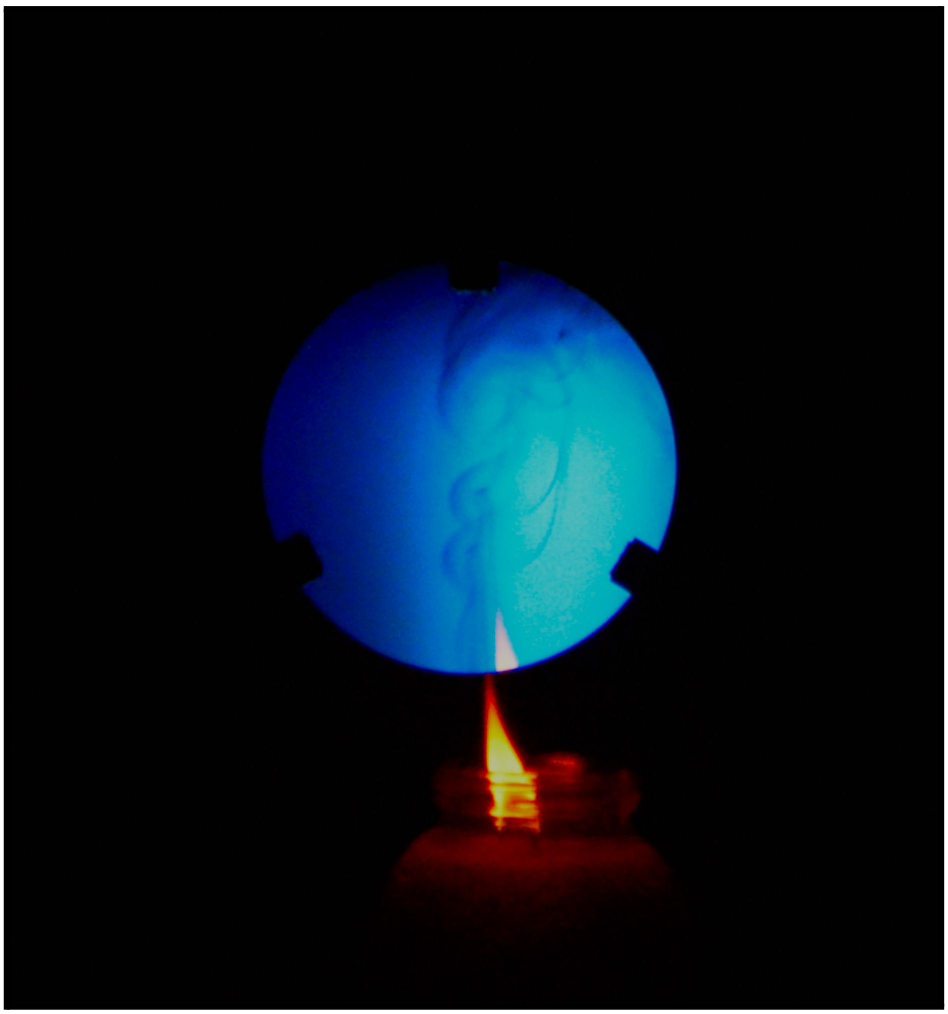
IV 3: Schlieren and Vortex Shedding



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IV 3 - Team First
MCEN 5228: Flow Visualization
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Image Purpose and Context

This photo was taken using a single mirror Schlieren apparatus checked out from Dr. Hertzberg and a small candle. I aimed to capture a photo of the heat emanating off of the flame of a small lit candle. I hoped to catch a still of this phenomenon, since the flow can move so fast in Schlieren videos, it can be hard to appreciate some of the instantaneous changes. This also provides a good visual source for vortex shedding and the production of vortex streets and how the flow progresses from laminar to turbulent as it moves higher from the flame.

Image Circumstances

This photo was taken in a storage room at my job, due to the low light conditions. The single mirror was placed just over 5 feet away from where I intended to take the photo and the candle was 8 inches from there to position the reflection so the flame is slightly visible, but not overbearing. I lit the photo using a Petzl Swift RL 7.8 W headlamp placed at the same location as the camera. The headlamp proved to be too bright and drowned out the flow, so I toned the light down by adding blue paper tape over the plastic the light is projected from. This added a blue hue to the reflection which can be seen in the photo above. This added an interesting contrast between the orange of the flame and the background. I placed the razor blade near the focal length of the mirror, which I determined was 2 feet from the mirror. The experimental setup can be seen below in Figure 1.

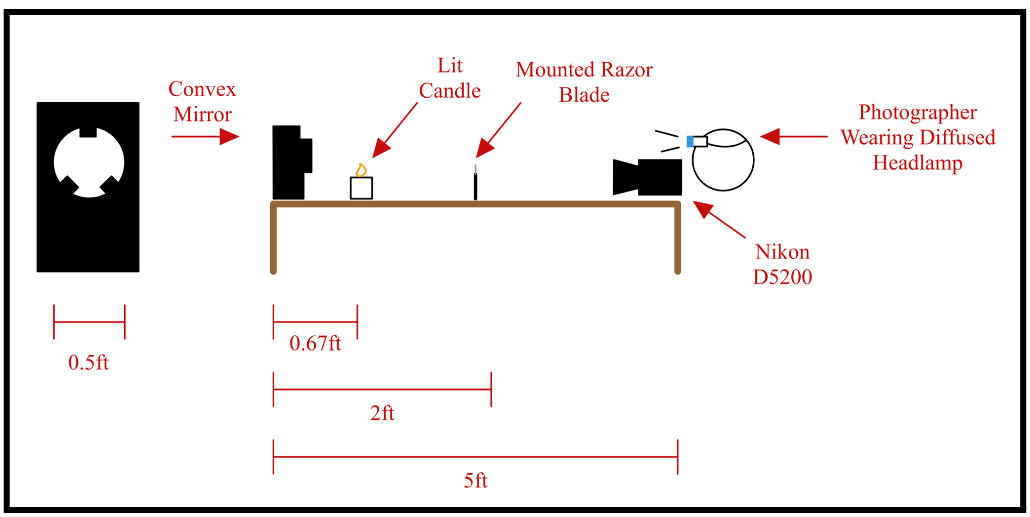

Figure 1: Single mirror Schlieren setup and camera orientation

Schlieren relies on small differences in indexes of refraction to bend light rays behind an obstruction to show the flow of fluids with varying densities[1]. A light source illuminates a convex mirror and a razor blade is utilized at the focal length of the convex mirror to cut off half of the light of the image. The light deflected towards or away from the blade's edge produces a shadow pattern. It leverages inhomogeneities in refractions to develop light and dark areas to visualize the fluid flow that would normally be invisible to the naked eye.

This image provides an opportunity to analyze the role of buoyancy driven vortices caused by heat oscillation. The image has clear vortices that stack on top of each other (a vortex street) as the flame stays lit. This can be characterized using the Strouhal number which is a dimensionless number that defines the ratio of inertial forces due to the local acceleration of the flow to the inertial forces due to the convective acceleration. It is associated with the oscillations of the flow due to the inertial forces relative to the changes in velocity due to the convective acceleration of the flow field[II]. The Strouhal number can be calculated using the following equation:

$$S_{tr} = \frac{fL}{U}$$

Where f is the frequency of the oscillations, L is the characteristic length, and U is the flow velocity. At high Strouhal numbers, oscillations dominate the flow and at low Strouhal numbers the oscillations are swept by the fast-moving fluid. At intermediate values, between 0.2 and 0.3, there is a well known shedding of vortices, which is what we can see in my taken image. A relationship between the Strouhal and Reynold's number can be seen in Figure 2[III], below.

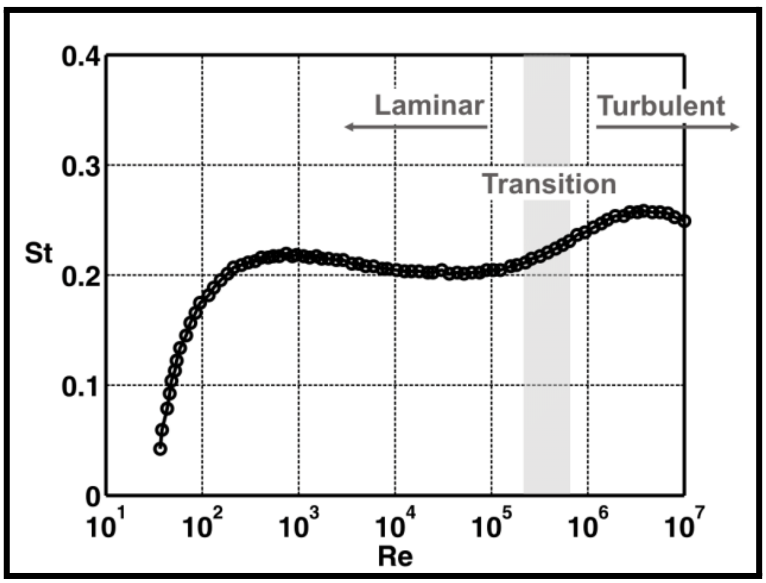

Figure 2: Graphical representation of the relationship between Strouhal and Reynold's numbers

Vortex shedding is an oscillating flow that takes place when a fluid flows past a bluff body at certain velocities. Vortices occur at the back of the body and detach periodically from the sides of the body forming them. In this instance, the body the flow is detaching from is the heated wick of the candle.

Visualization Technique

The camera I initially tried to use did not have a large enough focal length for clarity in the image, so I checked out a Nikon D5200 from Atlas that had a 55 mm length. As mentioned, I lit the candle with the flame slightly visible in the mirror and the flame let off a fairly steady stream of upward, rotating heat. The three visible vortexes span the six inch diameter of the mirror. The unedited photo can be seen in Figure 3.

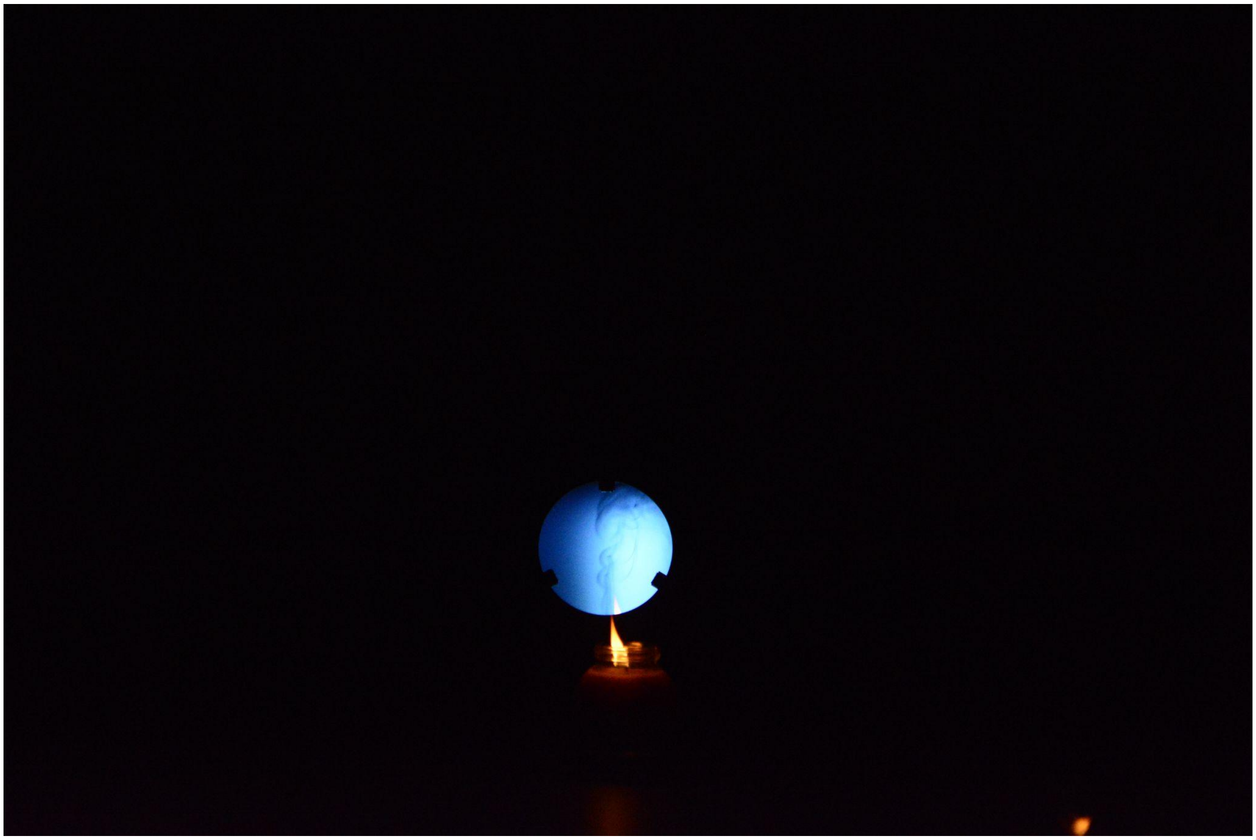

Figure 3: Unedited photo using Schlieren setup

Photographic Technique

The camera I initially tried to use did not have a large enough focal length for clarity in the image, so I checked out a Nikon D5200 from Atlas that had a 55 mm length. The initial image had a resolution of 6000 x 4000 pixels with a focal length of 55 mm and field of view 4.5 feet wide. The photo was taken roughly 5 feet away from the convex mirror, due to the limitations imposed by the focal length of the convex mirror. The camera was used at its maximum zoom with the following settings applied:

- Aperture: f/5.6
- Exposure: 1/3200
- Focal Length: 55 mm
- Focus Distance: 1.41 m
- ISO: 6400

In DarkTable, I performed color correction in the image to increase the contrast between the orange flame and blue background of the mirror. I changed the contrast, brightness, and saturation by -0.15, -0.5, and +0.25 respectively in an attempt to make the shadows and highlights more visible. A small blur was also added, in hopes of reducing the graininess to better show the shape of the flow. The image was also cropped to 1445 x 1543 pixels to leave a bit of the candle itself in frame and to cut out a lot of the distracting negative space.

Image Reveals

I believe this photo accomplishes my goal of visualizing the heat variation of a candle flame as it flows through air. The low light conditions of the room were ideal for having the only light on the mirror come from the point light source of the head lamp. If I were to take this photo again I would try to check out a camera with a larger focal length (at least 200mm) and faster shutter speed to reduce the graininess and increase the focus of the flow. Overall, I am very content with the end result of how it effectively demonstrates the vortex shedding from the wick of a candle, but I do see opportunities to improve the image quality with better camera equipment.

<u>References:</u>

I. *MIT. (2018). Schlieren imaging. Schlieren Imaging | Miles Dai. Retrieved November 7, 2022, from http://www.mit.edu/~milesdai/projects/schlieren/index.html*

II. *Strouhal number. Strouhal Number - an overview | ScienceDirect Topics. (2019). Retrieved November 7, 2022, from https://www.sciencedirect.com/topics/engineering/strouhal-number*

III. *Pochari, C. (2022, August 13). Cable-powered short-range heavy lift technology. Advanced Wind Energy Technologies. Retrieved November 7, 2022, from https://hydrostatussystems.com/author/christophepochari1/*

Image Assessment Form
Flow Visualization
Spring 2013

Name(s) Isaac Martinez

Assignment: IV 3 Date: 11/7

Scale: +, ! = excellent √ = meets expectations; good. ~ = Ok, could be better. X = needs work. NA = not applicable

Art	Your assessment	Comments
Intent was realized	√	
Effective	√	Clear, in focus flow
Impact	√	
Interesting	√	
Beautiful	√	
Dramatic	√	
Feel/texture	!	
No distracting elements	~	Some graininess is distracting
Framing/cropping enhances image	√	Absolutely necessary

Flow	Your assessment	Comments
Clearly illustrates phenomena	√	Clear vortexes
Flow is understandable	√	
Physics revealed	√	
Details visible	~	
Flow is reproducible	√	
Flow is controlled	√	
Creative flow or technique	√	Unique flow to visualize
Publishable quality	√	

Photographic/video technique	Your assessment	Comments
Exposure: highlights detailed	~	Struggled to balance
Exposure: shadows detailed	~	light & shadows w/o graininess
Full contrast range	√	
Focus	√	
Depth of field	√	
Time resolved	√	
Spatially resolved	√	
Photoshop/ post-processing enhances intent	√	
Photoshop/ post-processing does not decrease important information	!	

Report		Your assessment	Comments
Collaborators acknowledged		N/A	
Describes intent	Artistic	✓	
	Scientific	✓	
Describes fluid phenomena		✓	Vortex shedding
Estimates appropriate scales	Reynolds number etc.	~	Room for formal calculations
Calculation of time resolution etc.	How far did flow move during exposure?	✓	Listed in techniques
References:	Web level	✓	
	Refereed journal level	✓	Reputable research
Clearly written		✓	
Information is organized		✓	
Good spelling and grammar		✓	
Professional language (publishable)		✓	
Provides information needed for reproducing flow	Fluid data, flow rates	~	Room for formal calculations
	geometry	✓	
	timing	✓	
Provides information needed for reproducing vis technique	Method	✓	Very simple
	dilution	✓	
	injection speed	✓	
	settings	✓	
lighting type	(strobe/tungsten, watts, number)	✓	Headlamp listed in report
	light position, distance	✓	
Provides information for reproducing image	Camera type and model	✓	
	Camera-subject distance	✓	
	Field of view	✓	
	Focal length	✓	
	aperture	✓	
	shutter speed	✓	
	Frame rate, playback rate	N/A	
	ISO setting	✓	
	# pixels (width X ht)	✓	
	Photoshop and post-processing techniques	✓	
	"before" Photoshop image	✓	