

Schlieren Imaging of Candle

Jay Hall

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Abstract

A schlieren imaging apparatus was constructed and used as a visual aide to see the heat dissipation of a candle. The behavior was recorded in video form by a Sony a6300 mirrorless camera system. In the beginning, as the size of the flame was increasing, the airflow from the candle was unsteady and irregular. As the flame reached its maximum size and the system reached steady-state, the heat dissipating converged to a steady laminar stream.

For this visualization, my goal was to try something challenging to understand a very mundane feature of our daily lives: lighting a candle. I wanted to create a tangible visual showing the initial thermal plume produced when a candle is lit and its corresponding steady-state behavior. In order to achieve this, I built a very simple one-mirror schlieren imaging apparatus in my bedroom consisting of a concave mirror and supplies I had laying around the house.

Schlieren imaging is a precise visualization technique that allows us to see inhomogeneity in the air in real time. The setup includes a point source of light, a concave mirror, a knife edge, the object of interest, and a camera. The most crucial component is the mirror, and while there are many different methods to film and utilize schlieren, I chose to go with a one-mirror setup for simplicity. I chose to use a 115 mm diameter telescope mirror with a focal length of 900 mm. Using the Gaussian mirror equation (Eq. 1), I was able to determine that the knife edge and point source should be located 1800 mm (1.8 m) away from the mirror.

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}, \text{ where } d_o = d_i \rightarrow d = 2f \quad (\text{Eq. 1})$$

The purpose of the knife edge is to decrease the amount of light hitting the sensor and create more contrast in the final image¹. I chose to cut about 50% of the incoming light with the knife using a horizontally-oriented razor blade. The camera was positioned directly in the line of sight behind the knife edge, zoomed in to create an aesthetic frame. For the point source, I used a dc-powered 140 lumen flashlight, covered the front with aluminum foil, and poked a small hole in it with a needle. Each of these components was arranged in an orientation similar to that of Figure 1.

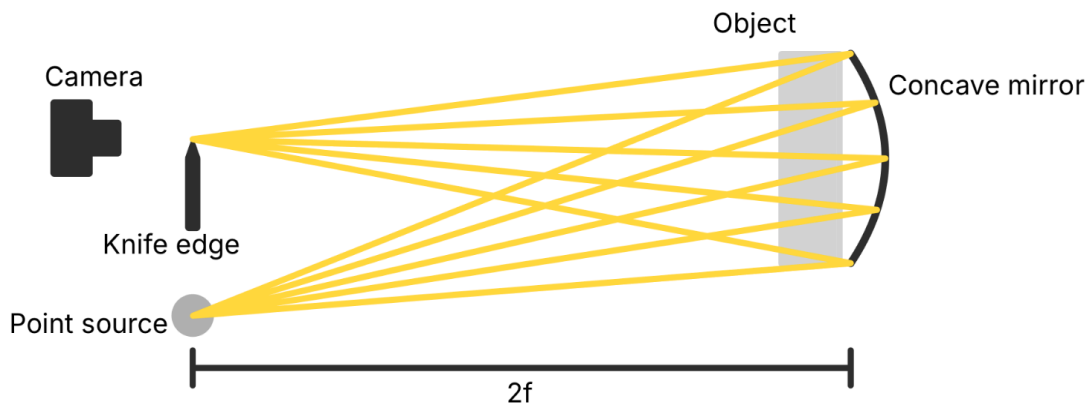


Figure 1: Schlieren imaging diagram

Once the apparatus was in place, I lit the candle, allowed it to burn for approximately 15 seconds then blew it out. Upon reviewing the video, one can see that the heat is causing the

surrounding air to decrease in density and create a thermal plume which rises due to buoyant forces from the surrounding air (e.g. free convection). The initial plume is unstable due to the changing magnitude of the flame and the mixing between the hot air next to the flame and cooler ambient air. As the flame reached its maximum size, the rejected heat creates a smooth laminar stream which moves upward in an organized fashion.

The Grashof number is a helpful tool in understanding how the viscous and buoyant forces are impacting the flow of a fluid². The approximate candle flame temperature is 1850 K³, for my calculation, I am going to estimate the plume temperature to be about 800 K. The ambient air temperature was about 300 K, the size of the plume nearly 70 mm, the coefficient of volume expansion of air at this temperature is roughly 0.00182 T^{-1} , and the kinematic viscosity of air about $0.0000446 \text{ m}^2/\text{s}$. These values can be used to determine the Grashof number:

$$G_r = \frac{g\beta\Delta TL^3}{\nu^2} = \frac{(9.81 \frac{\text{m}}{\text{s}^2})(0.00182 \frac{1}{\text{T}})(500\text{T})(0.000343 \text{ m}^3)}{1.99 * 10^{-9} \frac{\text{m}^4}{\text{s}^2}} = 1.5 * 10^6$$

The Grashof number is on the order of 10^6 , indicating that buoyant forces are more impactful than viscous forces for this flow. The value calculated above was for an instant in time and could be improved with more precise temperature readings.

The math behind Grashof's number is brilliantly visualized with schlieren imaging. Schlieren allows us to see spatial gradients in refractive index. Since the refractive index of air is greatly dependent on density, the video reveals density perturbations of the hot plume. By measuring the size of the plume, I was able to estimate the characteristic plume width used to calculate Grashof's number.

To record the schlieren video, I used a Sony a6300 with a 300mm telephoto lens. This is a mirrorless camera with an APS-C sensor. The ISO was set to 400, aperture to 5.6, and shutter speed to 1/125. I filmed in 1920x1080p at 120 fps and the playback was in real time. The approximate field of view of the video is 200 mm.

To conclude, the behavior of the candle that I initially wanted to investigate was far more interesting than anticipated. The candle initially created disorganized density structures and later formed a steady stream. This transition occurred in approximately 5 seconds and forever changed the way I see the act of lighting a candle. While schlieren imaging is a valuable tool, it has some limitations. For instance, since the plume temperature was not measured directly, the calculated Grashof's number is only an order of magnitude estimate. I am looking forward to further experiment with various types of schlieren systems and flows.

[1] Settles, G. S. (2001). *Schlieren and shadowgraph techniques visualizing phenomena in Transparent Media*. Springer Berlin Heidelberg.

[2] Wikimedia Foundation. (2024, August 15). *Grashof number*. Wikipedia.
https://en.wikipedia.org/wiki/Grashof_number

[3] *Candle science*. National Candle Association. (2025, September 9).
<https://candles.org/candle-science/>