

Two Friends One Flame

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Abstract

This experiment used schlieren imaging and a high-speed camera to visualize the flow of the buoyant plume created by butane ignition from a handheld lighter. A one-mirror schlieren imaging apparatus was constructed consisting of a 12 in. diameter mirror with a focal length of 8 ft., a point source of light, a Chronos 1.4 high-speed camera, and a color filter. Immediately after ignition, a large plume of low-density air rose due to buoyant forces. The Grashof number was estimated to be 2.4×10^5 - indicating the dominance of buoyant forces.

The purpose of this visualization was twofold, first, to practice creating engaging schlieren demonstrations, and second, to better understand the flow created by a suddenly started buoyant plume. Anton Ignatenko, Ryan, Cross, and I experimented with many different flow phenomena and found ignition from a handheld lighter to be a stunning process when captured in the right conditions. Anton and Ryan assisted in holding the lighter, aligning the apparatus, and filming the process.

My team and I built a one-mirror schlieren imaging apparatus consisting of a point source of light, a concave mirror, a color filter, the object of interest, and a high speed camera. We used a 12 in. diameter concave mirror with an 8 ft. focal length. The Gaussian mirror equation was used to calculate the distance of the point source of light:

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

The following apparatus was constructed, where the point source was positioned approximately 16 ft. from the mirror:

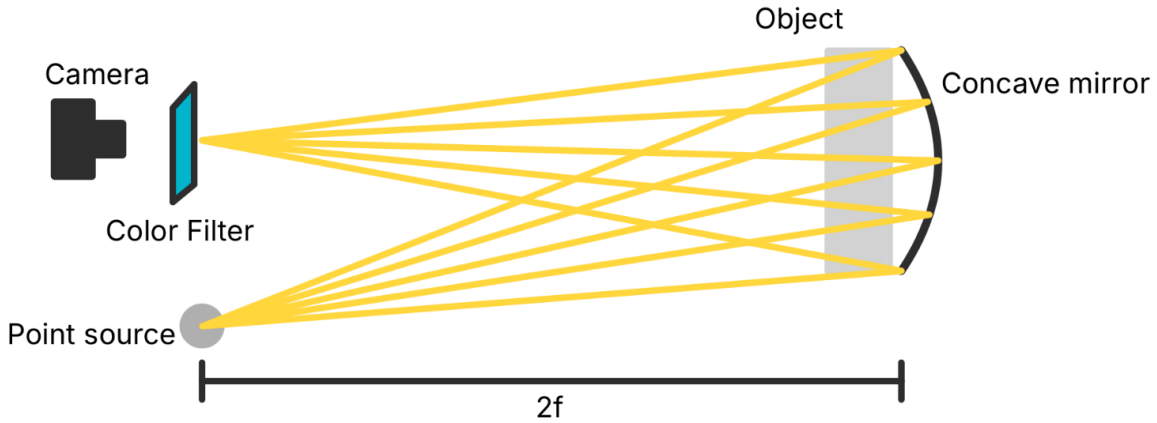


Figure 1: Experimental setup

Since we were interested in analyzing a buoyant plume¹, ignition of the lighter was conducted in the lower region of the mirror, allowing the upper region to display the plume behavior. Figure 2 displays the three main stages of the filmed flow behavior. In the beginning, the small disposable lighter was depressed for a moment to allow excess butane to eject. Subsequently, the long neck utility lighter was used to light the butane. Upon ignition the lighter suddenly created a volume of hot, low-density gas which was accelerated upwards due to buoyant forces. As this plume rose, shear forces along the interface between the plume and ambient air produced vortical structures. Simultaneously, entrainment increased the volume of the plume, incorporating the cooler surrounding air.

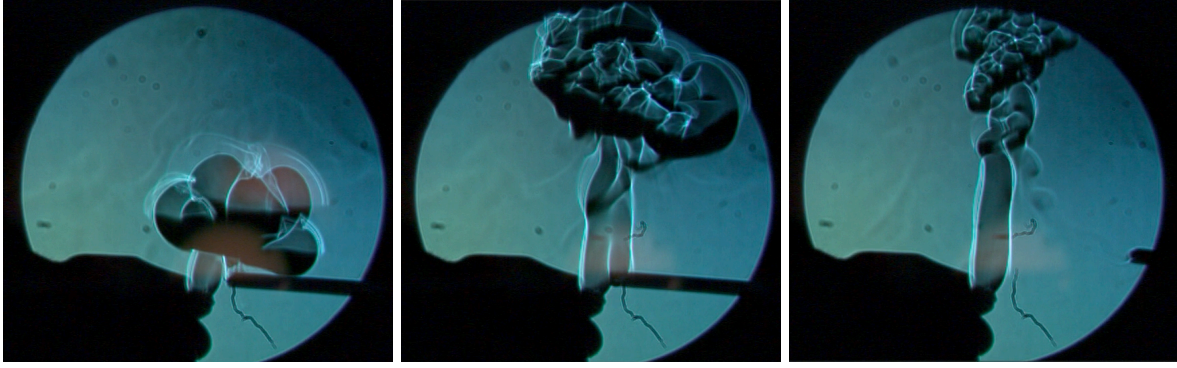


Figure 2: Generalized flow frames taken from video - the images occurred sequentially from left to right

Since the plume behavior is dominated by buoyant and viscous forces, Grashof's number will be most useful in analysis. Since the diameter of the mirror is known to be 12 in., the characteristic plume diameter is roughly 1.35 in. or 0.034 m. The ambient temperature is about 25 C and the ignition temperature of butane was used to estimate the plume temperature directly above the lighter to be 365 C. At this film temperature the kinematic viscosity of air is roughly $3.4 \cdot 10^{-5}$.

$$G_r = \frac{g\beta\Delta TL^3}{\nu^2} = \frac{g(\frac{2}{T+T_\infty})(T-T_\infty)L^3}{\nu^2} = \frac{(9.81 \frac{m}{s^2})(0.00213 \frac{1}{K})(340 K)(3.93 \cdot 10^{-5} m^3)}{(3.4 \cdot 10^{-5})^2 \frac{m^4}{s^2}} = 2.42 \cdot 10^5$$

The resulting $G_r = 2 \cdot 10^5$ indicates that buoyancy effects are more dominant compared to viscous effects at this length scale, which is consistent with the primarily upward motion of the plume.

Schlieren was chosen to conduct this visualization due to its ability to turn refractive-index gradients into measurable image intensity differences⁴. The video process was conducted in a dark room, with little-to-no ambient light. In designing the apparatus, the field of view was set by the size of our mirror. A Chronos 1.4 high-speed camera was used to capture the footage, where the quality was 800x600 pixels shot at 2872 fps. The camera aperture was set to f/1.2, shutter speed was 348 μs , and focal distance was set to approximately 16 ft. The final playback speed was sped up 4x to result in a framerate of 718 fps. For the point source, we used a dc-powered 140 lumen flashlight, covered the front with aluminum foil, and poked a small hole in it with a needle. A transparent film placed between the camera and mirror acted as a color filter, only to alter the appearance of the video.

In conclusion, I am very impressed with the power of schlieren imaging and the utility of basic optics to produce such a cool video. This video reveals the hidden physics of an everyday object, the handheld lighter. I am still curious about how to clean up this video a little more and remove some of the artifacts that fill the frame. Overall I am very proud of myself and my team for

creating this. In order to develop this idea further, I would like to experiment with more complicated flows and try to create expected behaviors with known fluid dynamics models - notably Kelvin-Helmholtz and Rayleigh-Taylor instabilities.

Music attribution:

Music: <https://www.bensound.com/free-music-for-videos>

License code: 3NVPVZE3RQDOVLQA

Artist: : Benjamin Lazzarus

References:

[1] Dartmouth University. (n.d.). Chapter 10: Plumes and Thermals.
<https://cushman.host.dartmouth.edu/books/EFM/chap10.pdf>

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

[3] WHO INCHEM. ICSC 0232 - butane. (n.d.).
<https://www.inchem.org/documents/icsc/icsc/eics0232.htm>

[4] Joanna Śmietańska (2026, September 30). *Kinematic viscosity of Air Calculator*. Omni Calculator. <https://www.omnicalculator.com/physics/kinematic-viscosity-of-air>

[5] Settles, G. S. (2001). *Schlieren and shadowgraph techniques visualizing phenomena in Transparent Media*. Springer Berlin Heidelberg. Page 27.

AI use statement:

ChatGPT 5.6 Sol was used to provide feedback on readability. It did not write any of the text.