Schlieren Photography of a Flame

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Team Second Report
MCEN 5151

November 2, 2026

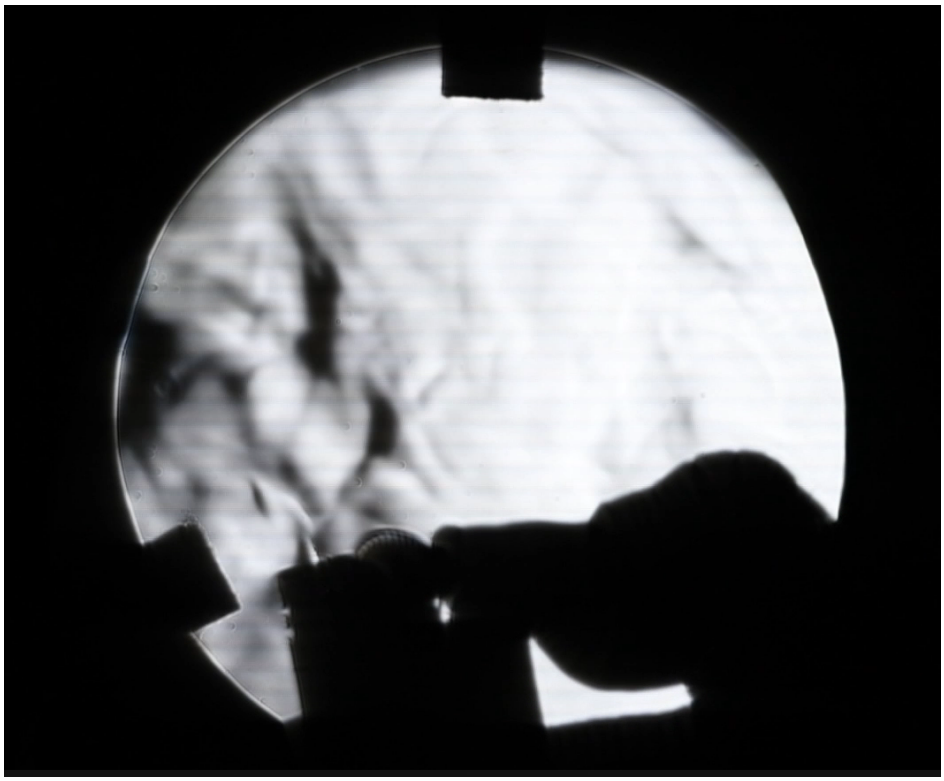


Figure 1: Schlieren photography of a lighter

Context and Purpose

We decided to do schlieren photography for the Team Second project. This method visualizes refractive index gradients, with dark areas representing a change in the medium's properties. We began brainstorming about flame-producing objects and wondered if this kind of photography would yield a unique image: it did! The flow of hot gasses is starkly visible when filtering for density, pressure, and temperature. The visualization was captured in video format, but a frame is included in this report. Each person chose a different flame-producing item. Mine was a standard BIC lighter.

Special thanks to my teammates, Bryce Pfuetze and Gavin Lopez, for their part in creating and executing our experiment.

Flow Apparatus and Physics



Figure 2: Picture of the apparatus

Schlieren photography involves shining a concentrated light source into a concave mirror. The focus of that concave mirror must be found and a slit must block half the light passing that point. The

camera is behind this and focuses on the subject between the mirror and slit. Our experiment involved two mirrors; this only adds one more reflecting surface where the light is shone into. The image below shows the path of light shining into the set of mirrors, being partially blocked by the slit, and entering the camera lens.

The water bottle between the mirrors is shown for scale. The focus length of the mirrors is about four feet. This is the distance between the top, or second, mirror and the slit. The light source is an 800 Lumen bicycle headlight mounted on the blue tripod next to the second mirror. It is covered with tape that has a small hole to create a concentrated beam.

Schlieren photography works because of the change in the refractive index of a fluid. This occurs with changes in temperature, density or pressure, which relate to each other through the Ideal Gas Law:

$$P = \rho RT$$

Light deflected by a refractive index change between the mirrors may strike or pass the slit depending on the gradient direction [1]. Lit parts of the image are from light passing the slit and dark sections are from light being blocked. Darker sections are where the refractive index disturbance is greatest from changes in air properties. This creates an image visualizing the refractive index gradient. Flames are a good subject for this type of photography because of the large temperature and density changes they create.

The flow can be mathematically characterized by the Froude number. This is a dimensionless coefficient describing the ratio of inertial to external gravitational forces. It is defined as:

$$Fr = \frac{V}{\sqrt{gL}}$$

where V is velocity, g is gravitational acceleration, and L is the characteristic length. The characteristic length of the flame is about 2.3 centimeters, g is 9.81 $\frac{m}{s^2}$, and the velocity is 0.3 $\frac{m}{s}$ [3]. Therefore, the Froude number is $Fr = .632$ and external gravitational forces dominate because it is less than one. This is evident in the image because the flow of gasses is easily blown away by wind and gravitational effects. If inertial forces dominated the flow would be fairly laminar. The flow is turbulent in this case and yields a beautiful image.

Visualization Technique

Schlieren photography is an optical visualization technique that displays the refractive index gradient of a medium. The apparatus involves objects that emit and reflect light. The materials sourced from Dr. Sunberg are two concave mirrors with a focus length of four feet and a stand holding a razor blade. A small tripod was used to mount the LED light source. The image was taken outdoors at night with moderate wind. The flame was emitted by a BIC lighter burning butane gas.

Photographic Technique

The camera is a Canon R50 mirrorless camera. The video was taken about four feet away from the experiment. The field of view was about five inches wide. The settings of my camera were 55mm focal length, f/5.6 aperture, 1/200 shutter speed, and ISO 100. The original video file has 60 frames per second with a resolution of 1920 x 1080 pixels.

A frame of the original video is below. I trimmed the video and added music in postprocessing. The video was also inverted because the camera was upside down on the tripod to be level with the setup.

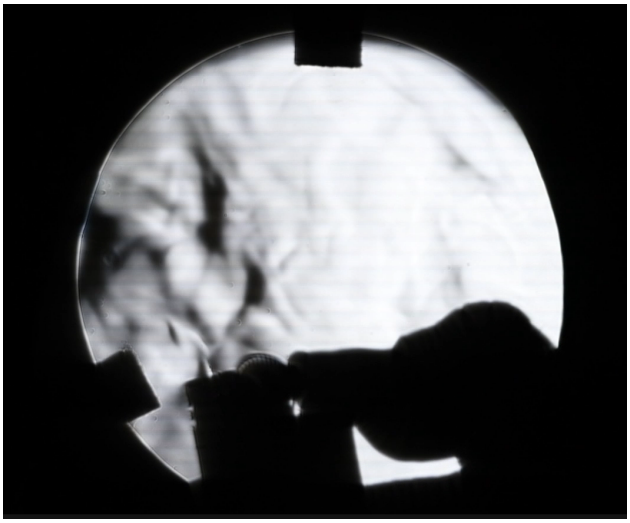


Figure 3: Screenshot of the full video

Discussion

The image reveals the density gradient of hot gasses rising from a flame. The flow is especially turbulent due to the moderately windy conditions. While the intent of the image was fulfilled, I would like to experiment with the focus further. There is potential for the gradient to appear sharper with more finely-tuned focus. The video is temporally resolved because the direction and turbulence of the flow can be continuously pinpointed, but it is not perfectly spatially resolved due to the lack of focus. The video was not sensitive enough to the minutiae of the refractive index gradient.

This experiment should be conducted indoors where there is no relative velocity to the freestream. This would likely show a laminar flow and create a different visualization. Overall, I am happy with the successful execution of a schlieren photography setup and the dramatic visualization it yielded.

References

[1] T.P. Davies, Schlieren photography—short bibliography and review, Optics & Laser Technology, Volume 13, Issue 1, 1981, Pages 37-42, ISSN 0030-3992, https://doi.org/10.1016/0030-3992(81)90089-X. (https://www.sciencedirect.com/science/article/pii/003039928190089X)

[2] Wood, R., 2012: Stratocumulus Clouds. Mon. Wea. Rev., 140, 2373–2423, https://doi.org/10.1175/MWR-D-11-00121.1.

[3] "Velocity and Direction of Flame Propogation: Solved Example." YouTube, Alquaity Decarbonization Lab, www.youtube.com/watch?v=vP9rW6ALK2U. Accessed 30 Oct. 2026.