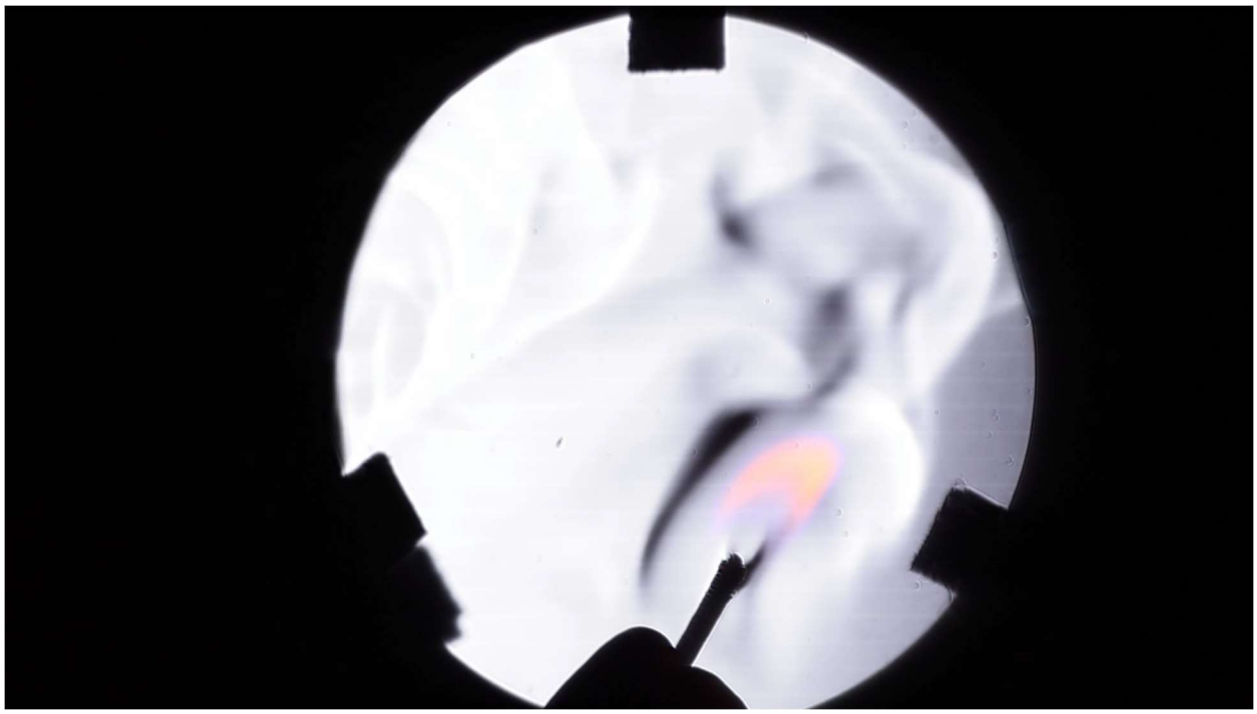
Team Second – Schlieren Match Ignition

Gavin Lopez

Team 8: Gavin Lopez, Antonio Jimeno-Fernandez, Bryce Pfuetze

11/02/2026

MCEN 5151: Flow Visualization



Full video can be found at:

https://vimeo.com/1237825540

Abstract:

In the video linked on the title page, a burning match is videoed using Schlieren imagery. This technique captures the density differences in the air around the match, effectively showing how the heat from the match travels and dissipates. This video was made for the Team Second assignment in MCEN 5151: Flow Visualization at the University of Colorado Boulder. The artistic intent was to capture an aesthetically pleasing video of the heat lines coming from a fire. Scientifically, the intent was to see what the Schlieren looked like right after ignition, and to capture the transition from the initial, turbulent flow to the later steady, laminar flow.

To capture the image, a two-mirror Schlieren apparatus was used with an LED bike light as the light source. A tripod-mounted Canon R50 DSLR camera was used to take the video, recording at 120 fps. The match was held in the final light beam heading towards the camera, and the high rate of recording allowed for a very fine time resolution of the heat lines. For this specific shot, I held and ignited the match while my teammates assisted with alignment and camera operation.

Flow Apparatus and Characteristics:

To create the image, the setup shown below in Figure 1 was used.

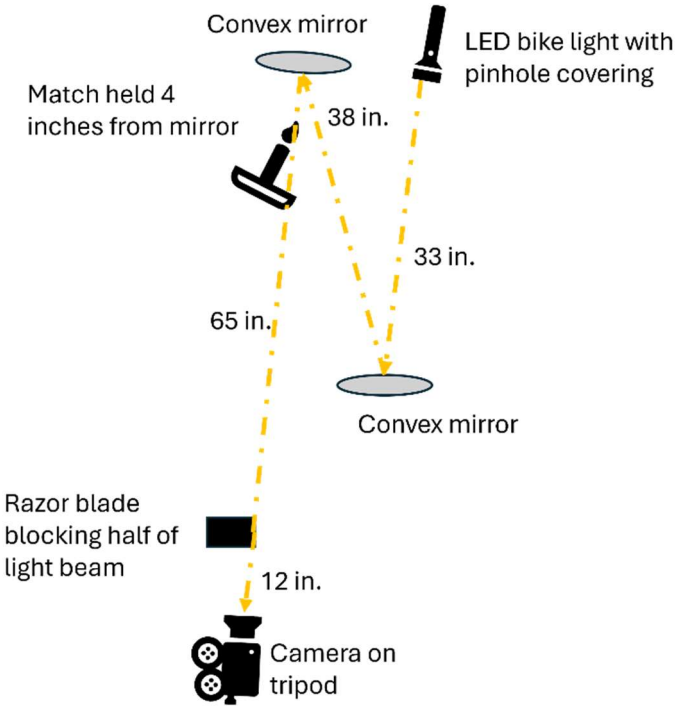


Figure 1: Schematic of the setup used to capture the image. The lengths notate the path length of the light beam. To create the LED pinhole, a small hole was punched in a piece of black gaffer tape using a safety pin, then placed over the bulb.

To image the match, it was held in the path of light headed from the second mirror to the camera, then struck and ignited. Because the flame was in the final light path, it still disrupted the beams of light but the color and outline of the actual flame was preserved at the camera. The head of the match was 0.143" (3.63 mm) in width and takes up about 40 pixels, giving a spatial resolution of 0.0036" (0.091 mm) per pixel. For temporal resolution, it is hard to distinguish between motion blur and shadows or diffraction from the Schlieren setup. However, each frame of the video had a relatively fast shutter speed of 1/320 of a second and the video appears sharp overall, so the time resolution of the video is at least moderately fine.

To describe the flow of the flame and smoke, the Rayleigh number (Ra) can be used. The Rayleigh number describes how a Rayleigh-Bénard convective flow behaves. Rayleigh-Bénard convection occurs when fluid is heated from below and cooled from above, causing convective currents to form [1]. It is extremely commonplace in nature and occurs everywhere from currents in the ocean to clouds in the sky. In the case of the ignited match, the flow can be approximated as Rayleigh-Bénard with the air being heated at the match and cooled by the ambient air above it.

The Rayleigh number describes the "amount of convection" in a flow [2] and represents the ratio between gravity and the thermal diffusivity of the fluid. It is defined as:

$$Ra = \frac{\alpha g \Delta T L^3}{\nu \kappa} \quad (\mathbf{1})$$

where α is the thermal expansion coefficient of the fluid, g is the acceleration due to gravity, ΔT is the temperature difference between the hot boundary and the cool boundary, L is the characteristic length scale of the flow, ν is the kinematic viscosity of the fluid, and κ is the thermal diffusivity of the fluid. For the burning match, the flame temperature was assumed to be 700°C [3] and the length scale was assumed to be the height of the flame, which when compared to the size of the match head was approximated as 1.5 cm. For the fluid properties, they were evaluated at 360°C, which was the average between the flame temperature and the ambient air temperature. A full table of the values used to calculate the Rayleigh number for this flow is shown below.

Table 1: Constants used to calculate the Rayleigh number

Constant	Value
α	1.62×10^{-3} K^{-1} [4]
g	9.81 m/s^2
ΔT	680°C
L	0.015 m
ν	56.05×10^{-6} m^2/s [5]
κ	31.4×10^{-6} m^2/s [6]

Plugging these numbers into Eqn. 1, Ra is found to be:

$$Ra = \frac{\left(1.62 * 10^{-3}\frac{1}{K}\right)\left(9.81\frac{m}{s^2}\right)(680\ K)(0.015\ m)^3}{\left(56.05 * 10^{-6}\frac{m^2}{s}\right)\left(31.4 * 10^{-6}\frac{m^2}{s}\right)} = 2.07 * 10^4$$

According to [2], there are three main regimes of the Rayleigh number. Below Ra of ~1700, convective currents do not flow, and the bulk of the heat transfer occurs through conduction instead. Between 1700 and ~3x10^5, laminar convective currents form, without turbulent motion. Above values of 3x10^5, the convection becomes turbulent. For this burning match case, the Rayleigh number implies relatively laminar convection, with a steady flow and calm mixing. In the video, this can be seen in moments where the ambient air was calm, and the match flame was very steady. However, occasional bursts of wind interfered with the flow, obscuring the visibility of some of this laminar convection.

Visualization Technique:

The flow was visualized using a refractive index technique. Schlieren imagery is made by using a point source of light and two mirrors to create a collimated beam of light, between which the flow to be studied is placed. Wherever the flow creates a density difference in the air, it deflects the light slightly. The collimated light is brought back to a point where it passes by a blade. Any light that was disturbed is blocked by the blade, and only the undisturbed light is able to make it past the blockage. By imaging after the blade, the places where the density difference were show up as darker. A diagram of the general workings of Schlieren are shown below:

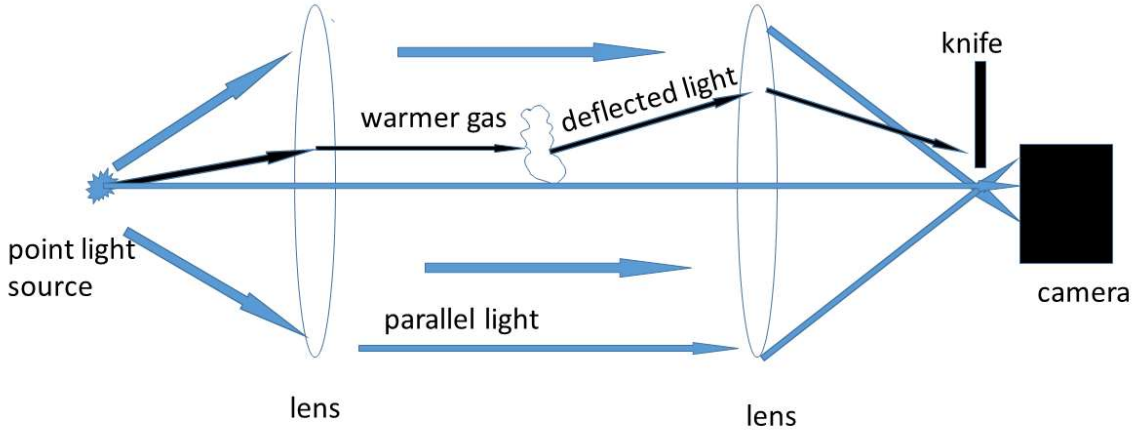


Figure 2: Generalized diagram of Schlieren operation. Image credit JeanBizHertzberg, CC BY-SA 4.0, via Wikimedia Commons.

For this project, a bicycle light was used as the point source, with the light covered in a black piece of tape with a pinhole poked through. Two 4.5 in diameter convex mirrors were used as the lenses, and a razor blade was used to cut off the light. Because the experiment took place on the ground, the camera had to be mounted upside-down on a tripod to get it low enough. Pictures of the setup are shown below:



Figure 3: Images from the experiment. From left to right: The bike light with pinhole used for the light source. A side view of the experiment setup, with the light on the right and the camera on the left. The view from the camera's perspective, with the razor blade close to the lens and the second convex mirror further away.

Imaging Technique:

The DSLR camera, lens, and exposure specifications are shown in the table below.

Table 2: Camera and image specifications

Camera model	Canon R50
Lens model	RF-S 55-210mm F5-7.1 IS STM
Focal length	210mm
Aperture	f8
Shutter speed per frame	1/320”
ISO	100
Distance from Subject	12 in. from razor, 77 in. from second mirror
Field of View	6.8° diagonal
Video resolution (as shot)	1920 x 1080 pixels
Video resolution (final)	1920 x 1080 pixels
Video framerate (as shot)	120 frames per second
Video framerate (during playback)	30 frames per second
Tripod Model	Benro TSL08AN00

Videos were recorded on two different cameras, but the DSLR used was chosen for its ability to record video at 120 frames per second. This allowed the video to be played back in slow motion without looking choppy. Additionally, the long focal length lens meant the mirror took up more of the frame, reducing the amount of cropping necessary.

For post processing, the video playback was set to 30 frames per second, resulting in a slow motion that was ¼ real time. Because the camera was mounted upside-down on the tripod, the video also had to be flipped 180°. The video was cropped slightly to enlarge the size of the Schlieren in the frame. Additionally, to bring out the orange color given off by the flame, the saturation of the reds and oranges was increased, and the saturation of the blues was decreased. Calm background music was chosen as the video felt almost meditative. All editing was done in DaVinci Resolve. Below, a frame from the original and edited videos can be seen, as well as the color curve used to adjust the saturation.

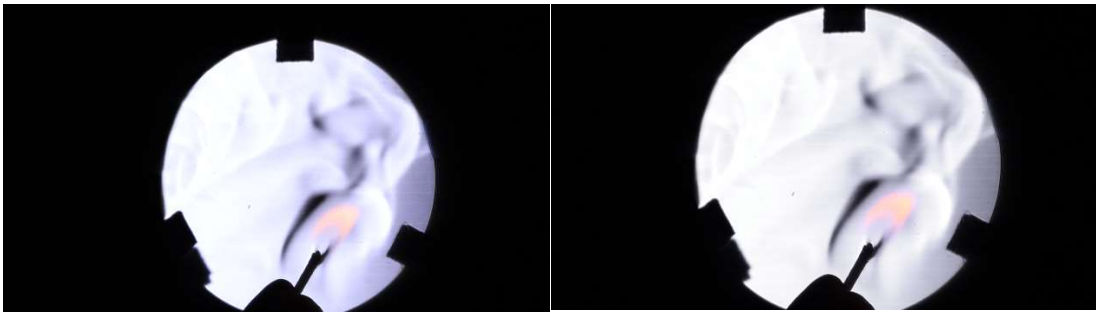


Figure 4: A frame of the unedited (left) and edited (right) video.

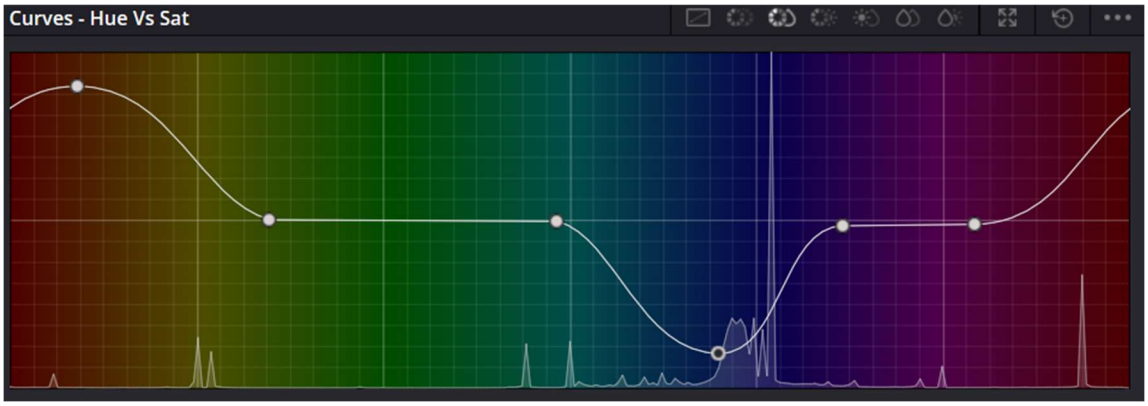


Figure 5: The hue vs. saturation curve used for the edited video.

Conclusion:

This video and experiment reveal the flow of heat output by a burning match. By using a Schlieren imaging setup, the ignition, burning, and extinguishing of a match was captured, all while visualizing the heat it gave off. The effect is really clear, and I'm excited that our team was

able to get the Schlieren setup working. My favorite part of the video was right after ignition, where soot and other colored compounds are seen coming from the ignition reaction of the phosphorus match head. Going forward, it would be interesting to investigate these more and determine the identities of some of the colors. I believe the final video fulfilled both my scientific and artistic intents, although performing the experiment indoors could help with reproducibility and make the laminar flow of the match more visible. Additionally, using a high-speed camera could capture even more detail and improve the temporal resolution of the video.

References

(1) Ranjan, D. *Shock Tube & Advanced Mixing Laboratory*. Gatech.edu. https://staml.gatech.edu/Research/rayleigh_benard.html (accessed 2026-11-02).

(2) Ting, D. Chapter 15 - Natural convection. *Thermofluids*; Academic Press, 2022; pp 295–319.

(3) Target Fire Protection. *What Is the Temperature of Fire?* Target Fire. https://www.target-fire.co.uk/resource-centre/what-is-the-temperature-of-fire/ (accessed 2026-11-02).

(4) Engineering Toolbox. *Air - Density, Specific Weight and Thermal Expansion Coefficient at Varying Temperature and Constant Pressures*. Engineeringtoolbox.com. https://www.engineeringtoolbox.com/air-density-specific-weight-d_600.html (accessed 2026-11-02).

(5) Engineering Toolbox. *Air - Dynamic and Kinematic Viscosity*. Engineeringtoolbox.com. https://www.engineeringtoolbox.com/air-absolute-kinematic-viscosity-d_601.html (accessed 2026-11-02).

(6) Editor Engineeringtoolbox. *Air - Thermal Diffusivity Vs. Temperature and Pressure*. Engineeringtoolbox.com. https://www.engineeringtoolbox.com/air-thermal-diffusivity-d_2011.html (accessed 2026-11-02).