The Effect of Spatial Cutoff Geometry on Schlieren Visualization of Thermal Plumes

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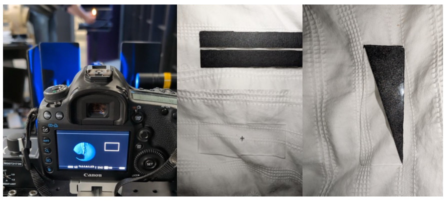
Introduction

- Schlieren imaging is a powerful optical technique used to visualize variations in refractive index within transparent media, such as air. These variations often arise from temperature or pressure gradients, such as those found in convective heat flow.
- Traditional schlieren systems use a knife-edge placed at the focal point of a light source image to block deflected light rays and produce contrast in the resulting image. However, the shape, size, and orientation of the cutoff can significantly affect what refractive features are visible.
- Single-mirror schlieren setups are increasingly used in educational and compact research environments due to their relative simplicity and reduced equipment requirements (Settles, 2001).
- While razor blades or straight knife-edges are commonly used, few studies have explored how nontraditional cutoff shapes, especially those made from easily accessible craft materials, affect schlieren image quality, sensitivity, and diffraction artifacts.
- Understanding how different shapes and materials interact with the focal plane cutoff allows researchers to optimize schlieren sensitivity or create custom visual filters for specific flow structures.
- This experiment investigates the impact of various cutoff geometries and materials (dots, stripes, wedges, etc.) placed on transparent microscope slides on the schlieren visualization of a heat plume rising from a heated heat sink.
- I hypothesize that cutoff shape and orientation will have a significant effect on the contrast and directionality of features observed in the schlieren image, that extreme or narrow cutoffs will introduce visible diffraction patterns, and that some of these filters could be more useful for various purposes than the traditional razor blade edge.

On the left, we have the camera's view of the schlieren setup. On the right, three different schlieren filters.



Methods

- A single-mirror schlieren setup was assembled using a 470 nm LED light source, a 400–700 nm beamsplitter, and a concave mirror. The LED beam was directed through the beamsplitter and reflected off the mirror, which was placed at twice its focal length (2f) from the LED and camera, creating a focused image of the light source.
- A video camera was positioned to receive the reflected beam after it passed back through the beamsplitter. A cutoff element—either a razor blade or a microscope slide containing a test shape—was placed just in front of the camera at the focal plane to act as a spatial filter.
- Test shapes included:
  - Horizontal and vertical half-blocks (black painter's tape)
  - Wedge-shaped edge (black painter's tape)
  - Crosshair and dot shapes (model airplane decals)
  - Traditional razor blade (baseline)
- For each cutoff shape, three tests were conducted:
  - Convection above a heated heat sink
  - Turbulent airflow from a heat gun
  - Thermal plume from a human hand
- Schlieren videos were recorded for each combination of test object and cutoff shape to analyze contrast, clarity, and directional sensitivity.
- Finally, each video was placed in a video editing software to perform a simple "motion extraction" for easier viewing of results.

References and Acknowledgements

Settles, G.S. (2013). *Schlieren and shadowgraph techniques : visualizing phenomena in transparent media*. Springer.

Very special thank you to my advisor Dr. Kevin Nolan and to Mohammed Heider for help during my experiments.

Materials

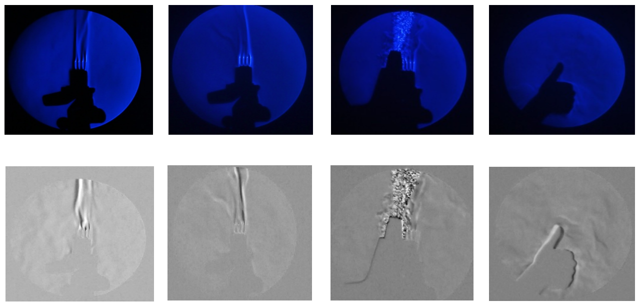
- Video camera
- 400-700nm beam splitter
- Heat sink
- 470nm LED
- Heat gun
- Mirror

Experiments (left to right)

First row: razor blade + heatsink, dot filter +heatsink, dot filter + heat gun, dot filter + hand.

Second row: each individual test after motion extraction.

After testing six filters, each video was put into a video editing software to hopefully enhance motion. From the "razor blade + heatsink" pictures, you can find the most easily visible plumes of heat. Compared to the dot filter in the pictures adjacent, it is much harder to visualize motion.



Results and Discussion

- In all three tests, the razor blade cutoff produced the highest image clarity and contrast, clearly visualizing thermal plumes, turbulence, and convective patterns. Its precise, sharp edge allowed for strong discrimination between refracted and unrefracted rays, minimizing light scatter and maximizing schlieren sensitivity.
- The horizontal and vertical half-blocks produced decent schlieren contrast but showed directional sensitivity, with gradients perpendicular to the edge appearing clearly and parallel ones often lost. These tape-based edges occasionally exhibited fuzziness or unevenness, which likely reduced sharpness and introduced unintended diffraction effects.
- The wedge cutoff provided a spatial gradient in sensitivity across the field of view, from low to high contrast. However, the wedge's imprecise hand-cut edge may have led to inconsistent results, especially where the tape taper wasn't clean.
- The crosshair and dot filters, taken from a decal sheet, added interesting visual effects but had limited contrast. Both were mounted on a thin transparent film, which was not optically pure. This film likely altered light paths unintentionally and introduced refraction or scattering artifacts around the shapes. These imperfections may have reduced overall image clarity and contributed to haloing or light haze near the center of the image.
- Overall, while all filters were able to produce visible schlieren effects to varying degrees, material properties and manufacturing precision played a significant role in performance. The razor blade, with its clean and sharply defined edge, set a clear benchmark.
- These findings support the theoretical understanding that cutoff geometry and edge quality critically affect schlieren image formation (Settles, 2001). Craft-based cutoffs offer flexibility and creative exploration but must be constructed with care to avoid compromising optical performance.
- In conclusion, although alternative cutoff shapes demonstrate how sensitivity, orientation, and diffraction artifacts can be manipulated, the razor blade remains the most effective and practical option for visualizing refractive flow features in a compact schlieren system.