Schlieren Air Burst Against Object

Team Second Assignment - MCEN 4151
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Report By Hank Goodman
Team Members: Brian Terasaki and Juan Sanchez

Figure 1 - Final Schlieren visualization video showing a compressed-air jet striking a bottle cap and splitting into two symmetrical flows.

Purpose and Context

This project was completed as part of the second team assignment for Flow Visualization. The goal was to design an experiment that demonstrated the Schlieren imaging technique and revealed invisible density gradients in air caused by fluid motion. The intent was both scientific and aesthetic: to visualize the invisible structure of air flow and to capture it in a visually engaging form. The team used a compact single-mirror Schlieren system to produce a clean, symmetric image of a compressed-air jet interfacing with a solid surface. While the primary goal was to demonstrate the Schlieren method, achieving an appealing flow pattern and smooth, dynamic behavior was also a priority.

Flow Apparatus and Phenomenon

The Schlieren setup used a small 4-inch concave mirror positioned approximately 5 feet from a pinpoint lamp and a knife-edge assembly. The knife edge was placed at the mirror's focal point, which was determined by adjusting the lamp and observing focus. The light source was a pinpoint lamp aligned along the optical axis, without diffusion or collimation. This produced a bright, coherent beam suitable for detecting subtle refractive index gradients.

The flow source was a compressed air can, directed at the top of a hand sanitizer bottle positioned within the mirror's focal plane. The impinging jet struck the bottle cap, splitting into two symmetrical streams that formed a sideways "T" shape in the Schlieren video. Initially, the flow appeared laminar and stable, with well-defined wave fronts, but as the air expanded and mixed with the surrounding air, turbulence increased, and small ripples appeared in the background. This demonstrated the transition from laminar to turbulent flow and the Schlieren method's sensitivity to even small refractive gradients in air.

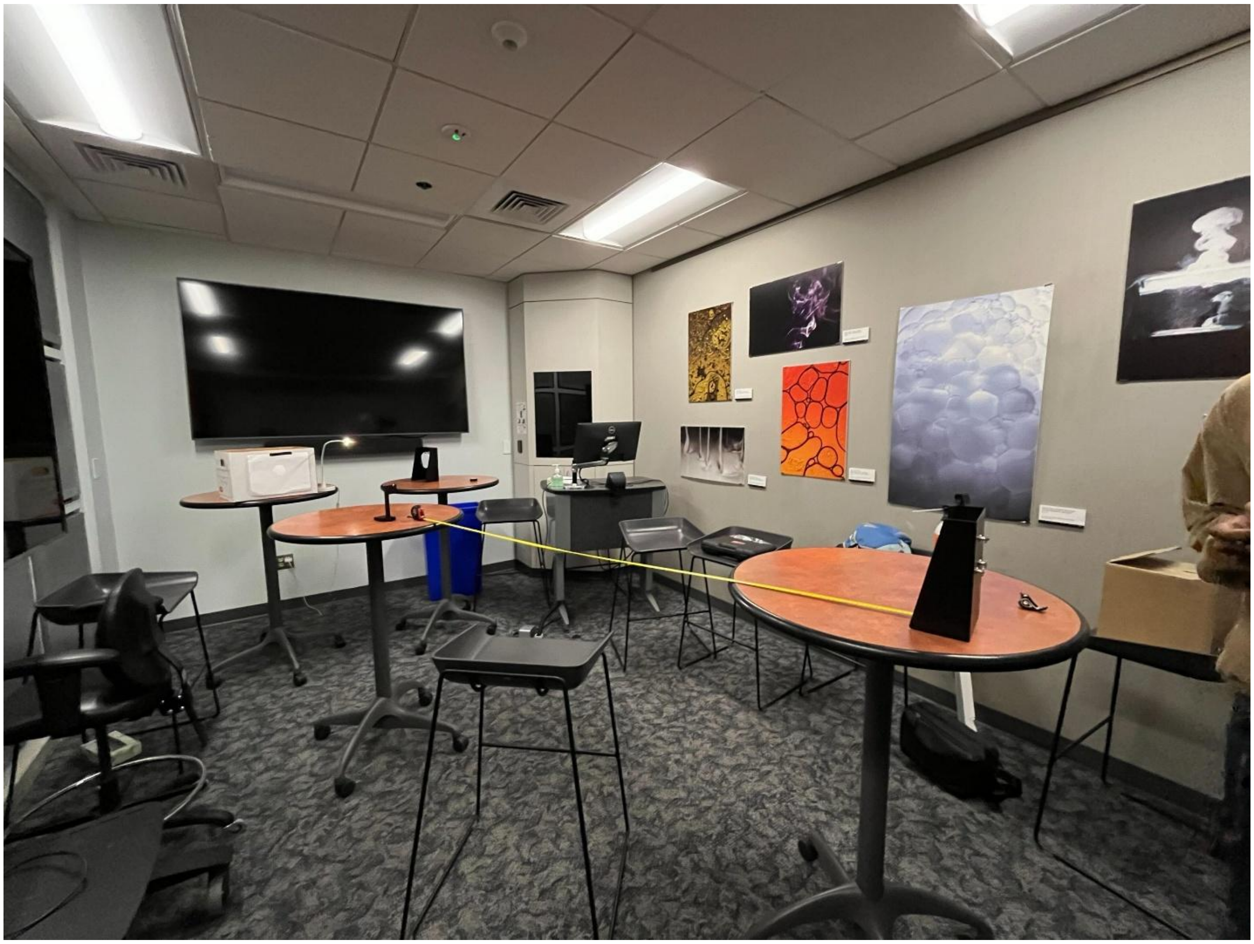

Figure 2 - Apparatus setup for the single-mirror Schlieren system showing mirror, knife edge, and lamp alignment.

Flow Analysis

The Schlieren video reveals compressible flow effects and turbulence development in air. When the compressed air jet exits the nozzle, it creates strong velocity gradients and small density changes. These refractive variations bend light slightly, producing bright and dark bands on the image. The split at the bottle cap forms two shear layers that evolve into increasingly irregular patterns as mixing increases.

Assuming an approximate jet velocity of 20 m/s and an effective nozzle diameter of 2 mm, the Reynolds number can be estimated as:

$$Re = \frac{UD}{\nu} = \frac{(20\frac{m}{s})(0.002\ m)}{1.5 \times 10^{-5}\frac{m^2}{s}} \approx 2700$$

This value is consistent with transitional to turbulent flow, matching the observed development of small-scale structures as the video progresses. The Schlieren method made these invisible variations visible through changes in optical density, providing both qualitative and aesthetic insight into air motion.

Visualization Technique

The single-mirror Schlieren system used in this project was part of the equipment provided by the course. This compact setup allowed for clear visualization of air density gradients without requiring a complex multi-mirror arrangement. Light from the pinpoint lamp reflected off the concave mirror and was focused near the knife edge. As the air jet passed through the optical path, local density variations deflected the light rays slightly, causing them to be partially blocked or transmitted by the knife edge. This converted refractive index gradients into brightness differences on the camera sensor.

No dye, smoke, or seeding particles were used; all features visible in the image were purely due to light refraction through the air. The alignment was carefully performed to minimize vibration and stray reflections, and the system remained stable throughout filming.

Photographic Technique

The visualization was recorded using a Canon EOS 7D Mark II paired with a Sigma AF 150-600 mm f/5-6.3 DG OS HSM Contemporary lens. The camera was placed directly behind the knife edge and the mirror axis. The following settings were used:

- Focal length: 546 mm
- Aperture: f/6.3
- Shutter Speed: 1/83 s
- ISO: 6400
- Focus: Manual
- Frame rate: 30 frames per second
- Original Resolution: 1920 x 1080 pixels
- Edited Resolution: 3840 x 2160 pixels

The original 8-second clip was processed in DaVinci Resolve. The only adjustments were slowing the playback to roughly 50% speed and removing the audio. No cropping, stabilization, or color enhancement was applied. The final result preserves the natural lighting and physical accuracy of the original experiment.

Interpretation and Reflection

The final video successfully demonstrates the sensitivity and beauty of Schlieren imaging using a minimal, single-mirror system. The flow structures were sharp and dynamic, clearly revealing the physical phenomena. The composition and symmetry of the flow created a clean, abstract appearance while maintaining physical accuracy.

If repeated, improvements could include refining focus and exposure, increasing illumination intensity to improve contrast, and experimenting with different knife-edge and mirror distances to capture a larger field of view. Increasing the ISO slightly might have improved brightness, but at the risk of noise. Overall, the visualization achieved its goals, effectively blending physics and aesthetics into a technically sound, visually engaging result.

References

Flow Visualization Course Guide – Schlieren and Shadowgraph Techniques, FlowVis.org, 2025.

Hirschberg, Avraham. (2002). Schlieren and Shadowgraph Techniques: Visualizing Phenomena in Transparent Media: G.S. Settles (Springer-Verlag, Berlin, Germany, 2001). European Journal of Mechanics - B/Fluids. 21. 493. 10.1016/S0997-7546(02)01191-3.