28. Index Of Refraction

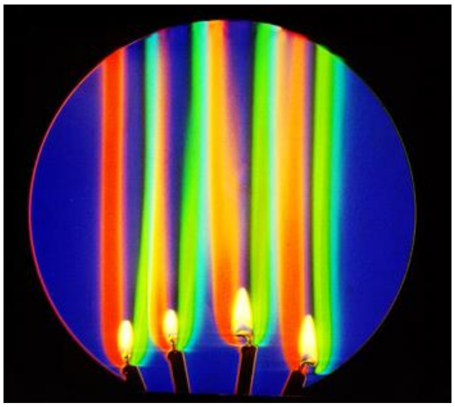
CLICKERS TODAY

Monday, December 2, 2024 7:50 AM

Index of refraction techniques

Requires no seed. Can visualize differences and gradients in temperature and chemical concentration,
as both change the index of refraction of the media.
Examples first, then techniques discussed in detail: schlieren and shadowgraphy

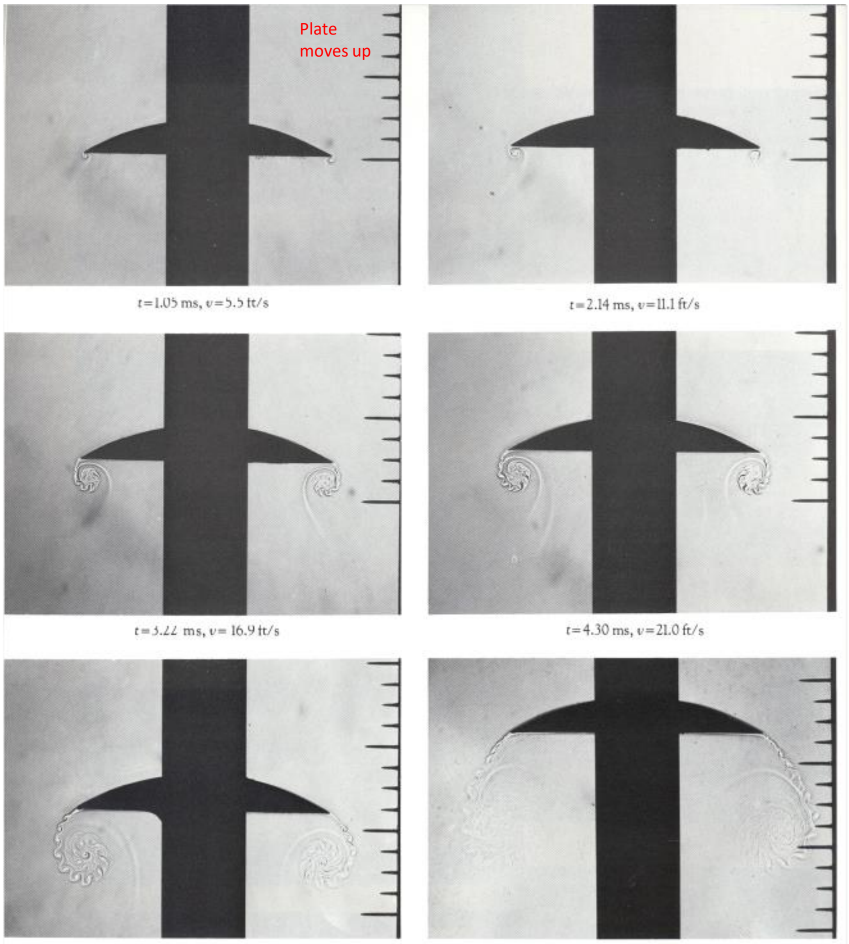
Color schlieren



Pasted from <http://www.compadre.org/informal/images/features/schlierenlarge-11-29-06.jpg>

Andrew DAVIDHAZY (retired now),
RIT = Rochester Institute of Technology, offers engineering and BS through PhD in Imaging Science.

SHADOWGRAPH

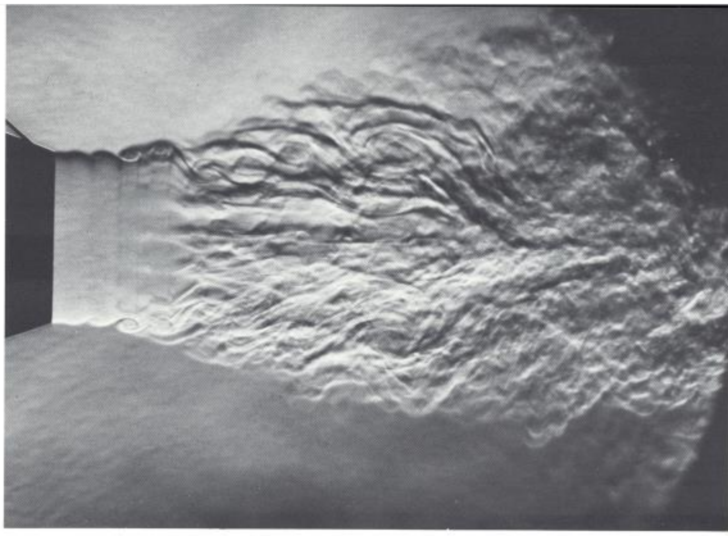


$t = 1.05$ ms, $v = 5.5$ ft/s | $t = 2.14$ ms, $v = 11.1$ ft/s

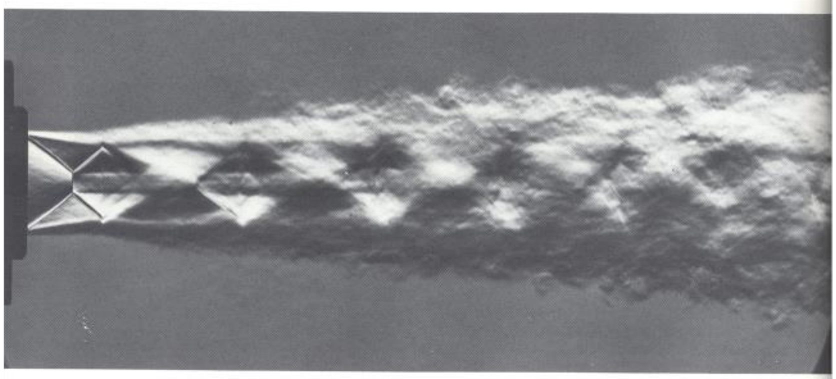
$t = 3.22$ ms, $v = 16.9$ ft/s | $t = 4.30$ ms, $v = 21.0$ ft/s

$t = 6.53$ ms, $v = 24.0$ ft/s | $t = 10.66$ ms, $v = 24.0$ ft/s

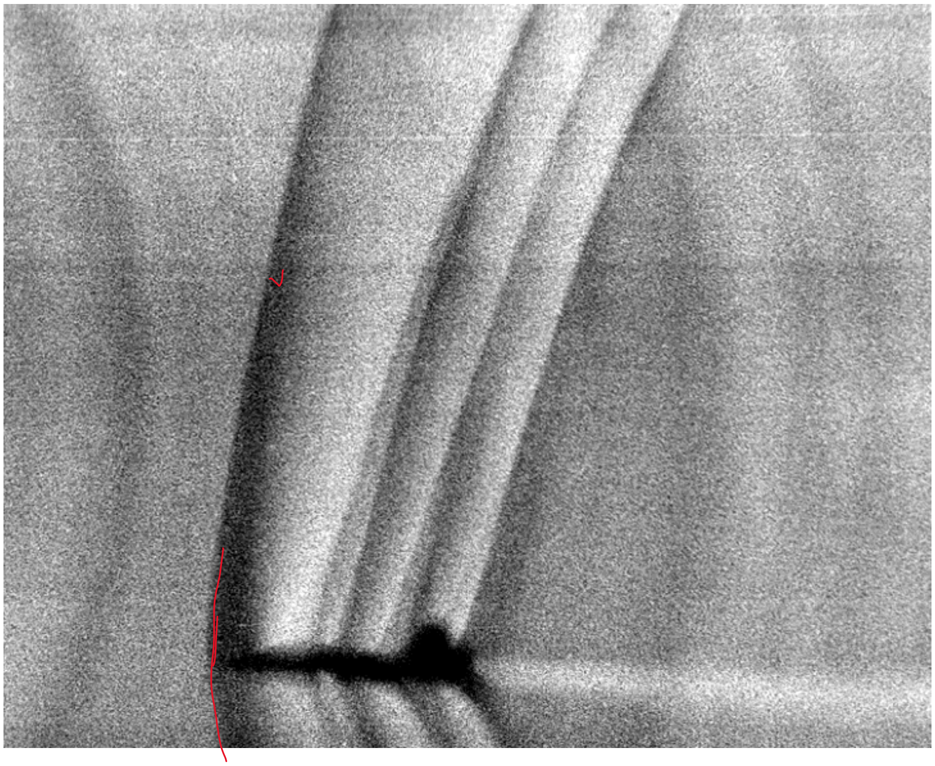
81. Growth of vortices on an accelerated plate. Spark shadowgraphs show the history of a 3-inch-square plate in air, accelerated from rest to 24 ft/s. The sharp edge of the plate is initially opposite the first of a series of pins spaced ¼ inch apart. The motion is actually vertical, and the flow is visualized by painting a narrow band of benzene across the center of the balsa-wood plate, so that when the plate accelerates benzene vapor is drawn into the vortex sheet. The difference in density between the vapor and the air makes the paths of their boundaries visible. Care was taken to ensure that the undulations observed in the vortex sheet were not caused by vibrations of the model. *Pierce 1961*



167. Subsonic jet becoming turbulent. A jet of air from a nozzle of 5-cm diameter flows into ambient air at a speed of 12 m/s. The laminar interface becomes unstable as in figure 102, and the entire jet eventually becomes turbulent. *Bradshaw, Ferriss & Johnson 1964*



168. Supersonic jet becoming turbulent. At a Mach number of 1.8 a slightly over-expanded round jet of air adjusts to the ambient air through a succession of oblique and normal shock waves. The diamond-shaped pattern persists after the jet is turbulent. *Oertel 1975*



Pasted from <http://commons.wikimedia.org/wiki/File:Schlieren_photograph_of_T-38_shock_waves.jpg>

Mach 1.1, full size T-38 in flight, 1993. L. Weinstein, NASA
example of Background Oriented Schlieren (BOS). Correlate patterned background from image to get schlieren

http://fuckyeahfluiddynamics.tumblr.com/post/47622561173/this-high-speed-video-shows-schlieren-photography

CO_2 bottle rocket video. Shows Mach diamonds and expansion fans.

How it works:

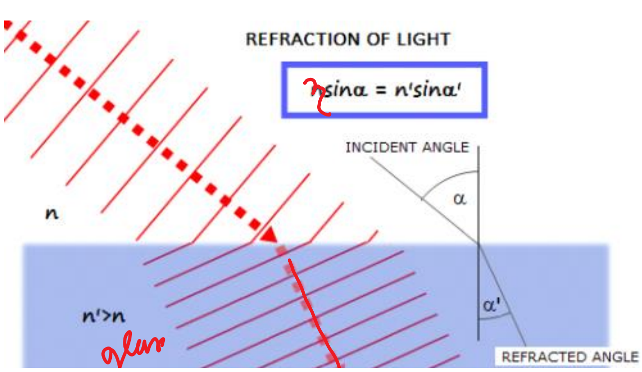
http://www.npr.org/2014/04/09/300563606/what-does-sound-look-like
Michael Hargather, New Mexico Tech

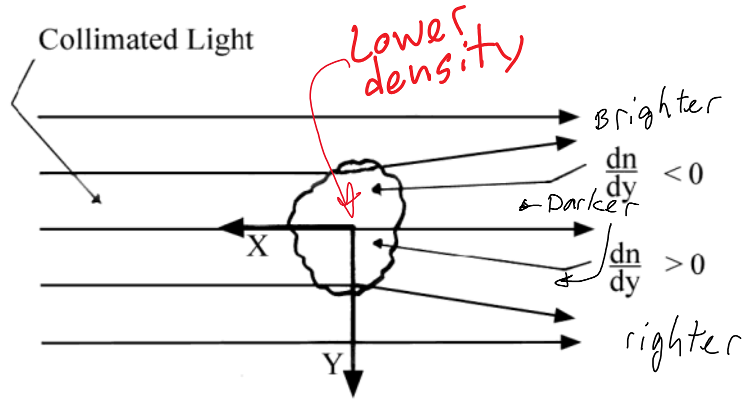
speed of light

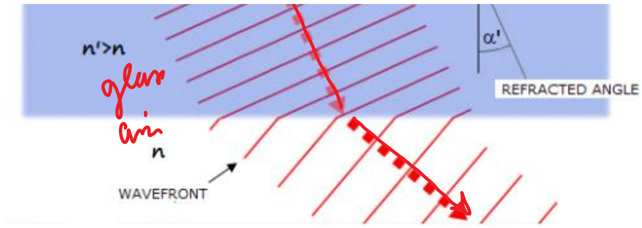
$$\eta = \frac{C_{VACUUM}}{C_{MEDIUM}} = \text{eetah} =$$

n = index of refraction

Light is deflected towards more dense medium







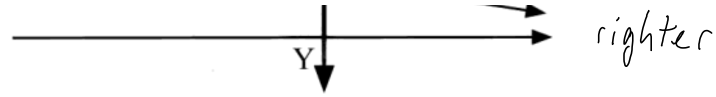
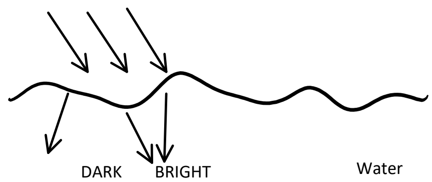


Figure 1. Disturbance in Collimated Beam

Shadowgraphy:

constructive and destructive interference from disturbed parallel light

like a caustic   sunlight



http://www.shutterstock.com/video/clip-3174052-stock-footage-dappled-pool-water-ripple-background-swimming-pool-water-abstract-background-with-seamless-loop.html

http://web.mit.edu/Edgerton/www/schlieren5.html

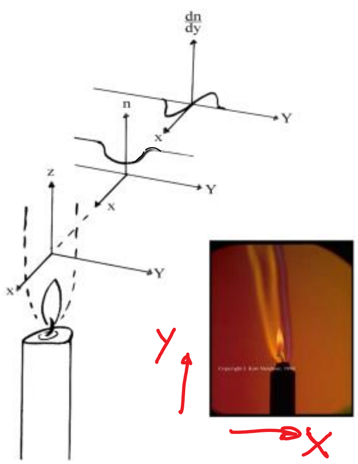


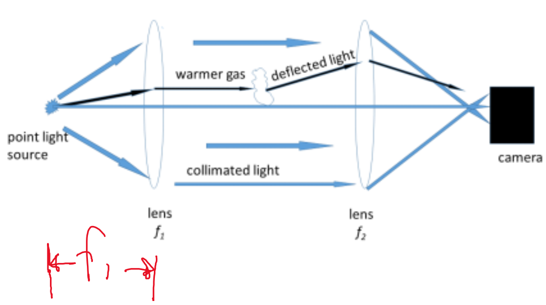
Figure 2. The Refractive Index Gradient Above a Candle

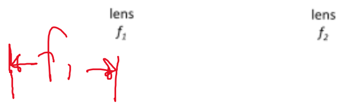
Shadowgraphy:

constructive and destructive interference from disturbed parallel light

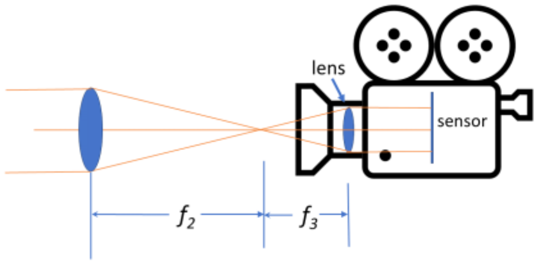
schlieren: schlieren is just a German noun, not somebody's name.

Selectively remove constructive or destructive interference from disturbed parallel light.
Higher contrast, controlled sensitivity to gradient directions





What does the camera see in this case? No disturbance, no knife edge



a. Uniform brightness
b. Point of light
c. Small dot
d. Something else

Hint: ray optics are reversible. Remember the Lens Laws.

	2022	2023	2024
a	86	71%	62
b	14	12	23
c		0	15
d		18	0

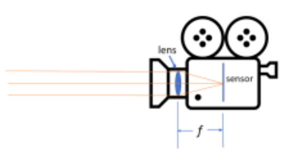
Clicker: What would camera or your eyes see looking straight at parallel light, with the camera lens focused at infinity?
Hint: what natural light sources do you know that emit parallel light? What do they look like?
Hint 2: what do the lens laws say about light entering parallel to the optical axis?

A) Uniform brightness
B) Point of light
C) Small dot
D) Something else

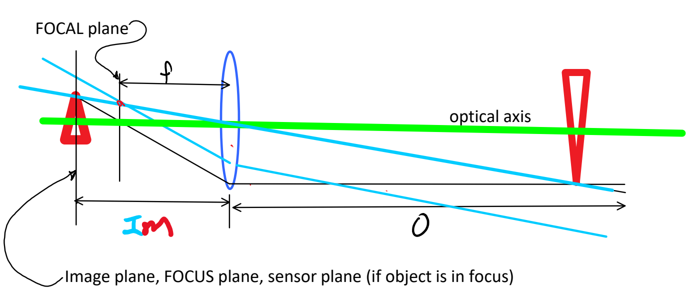
2022	2023	2024
14	13	7
64	63	86
23	19	7
	6	0

0	

Stars: the light is parallel, and they look like points of light in a dark field.



Let's review lens laws:



Lens Laws

1) light through center of lens is undeflected
2) light parallel to axis goes through focal *point*
3) all light entering lens at a given direction ends up at the same point in the *focal* plane (**not** *focus* plane)

≠ focus point

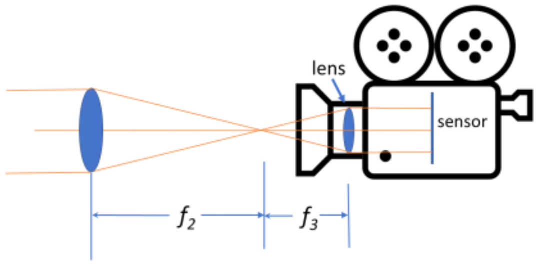
Focus equation

f = focal length
O = dist. Lens → object

f = O + I   I = dist. Lens → image (Sensor)

Think pair share: Where is lens relative to sensor when focus is at infinity?

Back to schlieren and shadowgraphy: What does the camera see in this case? No disturbance, no knife edge



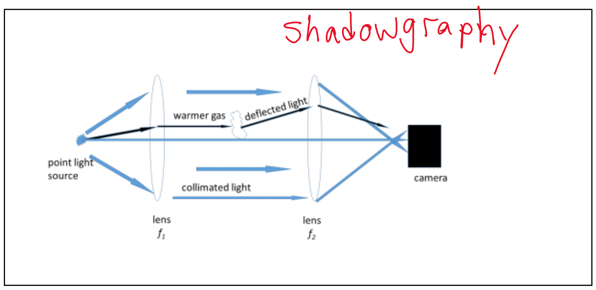
a. Uniform brightness
b. Point of light
c. Small dot
d. Something else

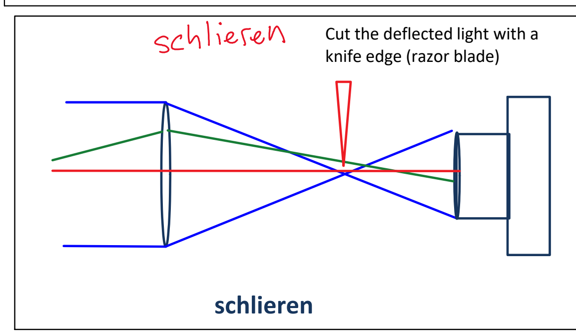
Skipped 2024

2022	2023
86	X
14	x

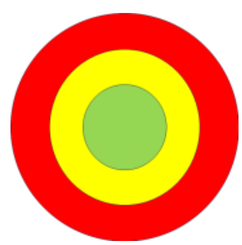
Hint: ray optics are reversible.

Now, deflect some of those light rays. Would add light in some areas, reduce it on others.

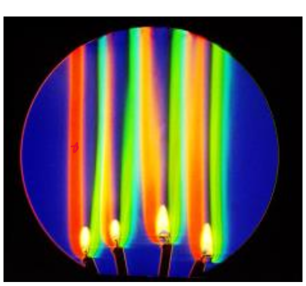




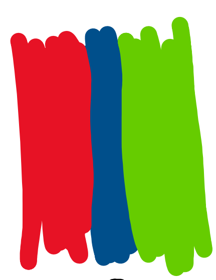
By Foucault, 1859

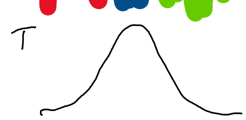


Color target for false color. Undeflected light is green, medium deflection is yellow, Highly deflected is red.



What do you think the color target looked like? Which way would light be deflected?





Shadowgraph Equation

Shadowgraph, sensitive to 2nd derivative of η

ΔI ... z_2 $(\partial^2$ ... ∂^2 ... $)dz$

Shadowgraph, sensitive to 2nd derivative of η

$$\frac{\Delta I}{I} = l \int_{z_1}^{z_2} \left(\frac{\partial^2}{\partial x^2}+\frac{\partial^2}{\partial y^2}\right)(\ln \eta)\, dz$$

- Relative light intensity at exit. Light propagates in Z direction

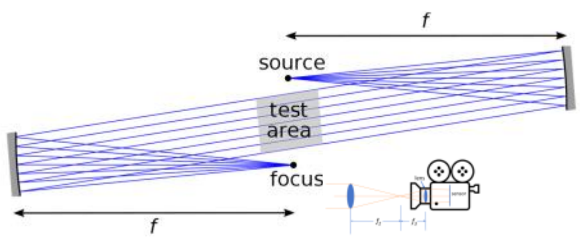
Integrated along line of sight. Drawback for looking at 3-d phenomena

Ref:

1. Wolgang Merzkirch, *Flow Visualization, Second Edition*, 2nd ed. (Academic Press, 1987).

Similar math for schlieren, is sensitive to first derivative; to gradients in temperature.
Has higher contrast, visibility; deflected light is not adding to or confusing light field.

Variants:



Z fold with mirrors; saves space, cost. Want space between mirrors to be 3 x f to give room to place the experiment.

Either spherical or parabolic mirrors work.

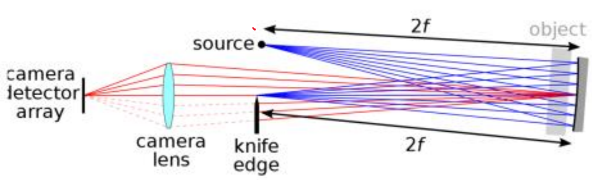
Settles, G. S. *Schlieren & Shadowgraph Techniques*. Corrected edition. Berlin *; New York: Springer, 2001.*
2nd edition coming out soon, with a Flow Vis student image in it!

Single mirror system

$$\frac{1}{f} \approx \frac{1}{O} + \frac{1}{I}$$

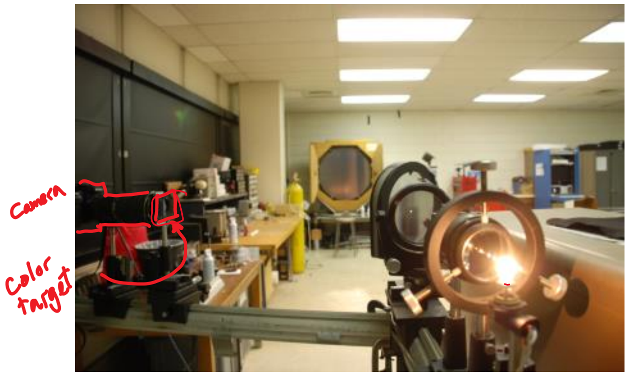
$$\frac{1}{f} = \frac{1}{2f} + \frac{1}{I}$$

$$I = 2f$$



Emissions from Musicians project uses this method.
https://vimeo.com/showcase/7707430

https://m.youtube.com/watch?v=BPwdlEgLn5Q Smarter Every Day; high speed video of shock waves from bullets



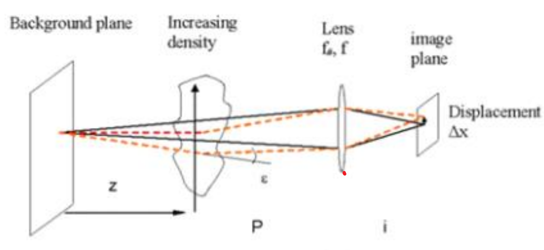
Gas Dynamics lab at Penn State University
Prof. Gary Settles, author of

Schlieren & Shadowgraph Techniques, Corrected. (Springer, 2001).

<file://C:\Users\hertzber\Documents\01CLASSES\FlowVis\MiscImages\Settles\SchlierenVisit\DSC_0324.AVI> My visit in March 2011

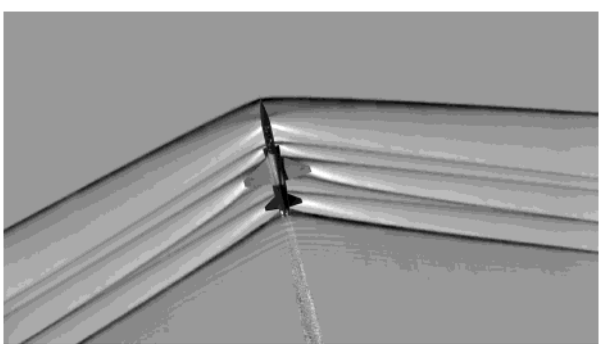
BOS = Background Oriented Schlieren

Uses patterned background instead of mirror, any random lighting. View of background will be distorted by η field. Take two images and do cross correlation, like PIV.



http://www.dlr.de/as/en/desktopdefault.aspx/tabid-183/251_read-2726/

Or open source: http://www.openpiv.net/bos/

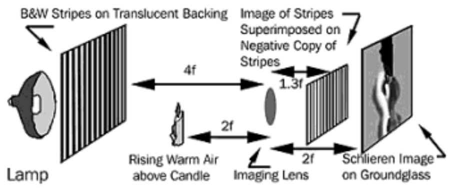


Taken looking DOWN. Photo 1 is just the ground, Photo 2 has the plane passing through. Subtract the background image.
2015 NASA & US Air Force: J.T. Heineck / Ed Schairer / Maj. Jonathan Orso / Maj. Jeremy Vanderhal, Public domain, via Wikimedia Commons.

From <https://www.flowvis.org/Flow%20Vis%20Guide/refractive-index-techniques-2-shadowgraphy-and-schlieren/>

Focusing schlieren

http://people.rit.edu/andpph/text-schlieren-focus.html



https://www.youtube.com/watch?v=DYx2xLLrUyg ice cube in a fishtank, by Spectabit:
http://www.spectabit.com/index.php/product-types

Now, an even simpler method, using an encoded light field:

**Light Field Back-
ground Oriented Schlieren Photography (LFBOS)**

http://www.cs.ubc.ca/nest/imager/tr/2011/LFBOS/

Klemkowsky, Jenna N., Timothy W. Fahringer, Christopher J. Clifford, Brett F. Bathel, and Brian S. Thurow. "Plenoptic Background Oriented Schlieren Imaging." *Measurement Science and Technology* 28, no. 9 (2017): 095404. https://doi.org/10.1088/1361-6501/aa7f3d.
In Zotero library.

We have two sets of 4" diameter mirrors; would love to see 3D stereoscopic schlieren.