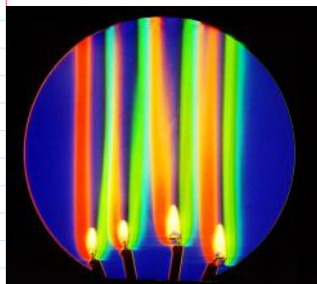


## 22.SCHLIEREN

Wednesday, April 21, 2010  
8:50 AM

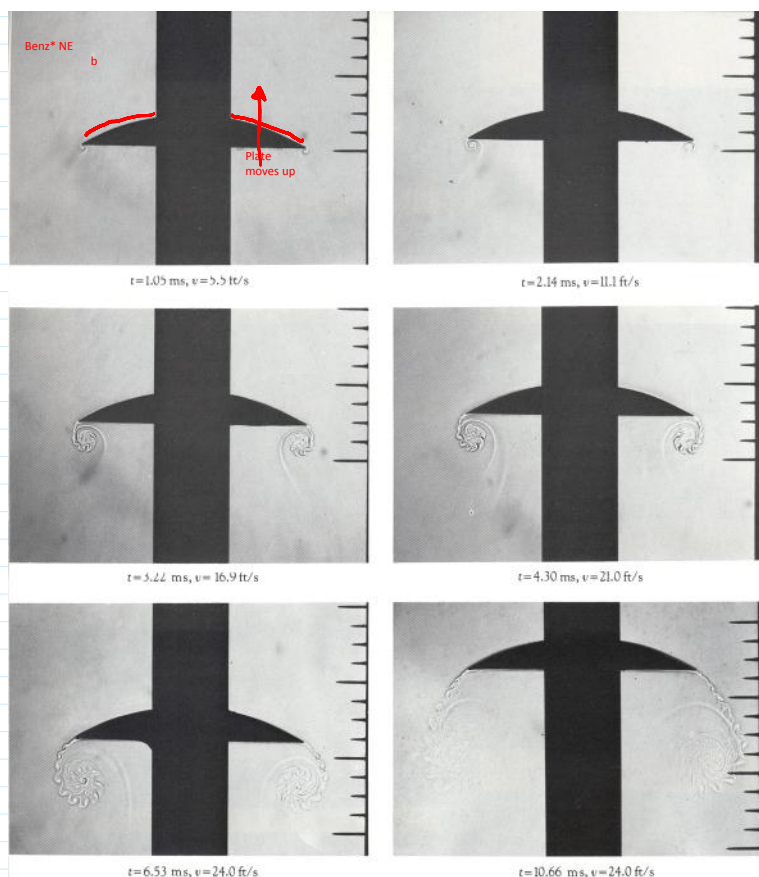


color SCHLIEREN

Pasted from <<http://www.compads.org/informal/images/features/schlierenlarge11-29-06.jpg>>

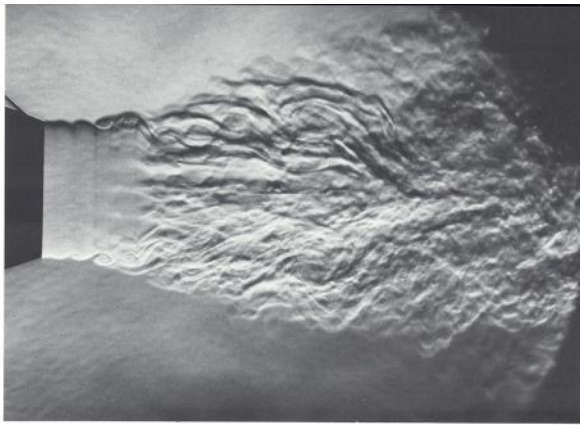
A. DAVIDHAZY,  
RIT = Rochester Institute of Technology,  
offers engineering and BS through PhD in  
Imaging Science.

## SHADOWGRAPH



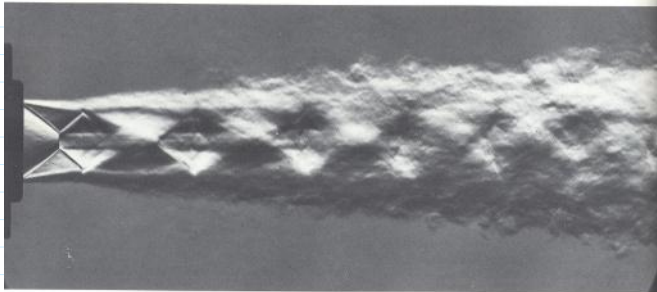
81. Growth of vortices on an accelerated plate. Spark shadowgraphs show the history of a 3-inch-square plate in air, accelerated from rest to 24 ft/s. The sharp edge of the plate is initially opposite the first of a series of pins spaced 1/4 inch apart. The motion is actually vertical, and the flow is 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

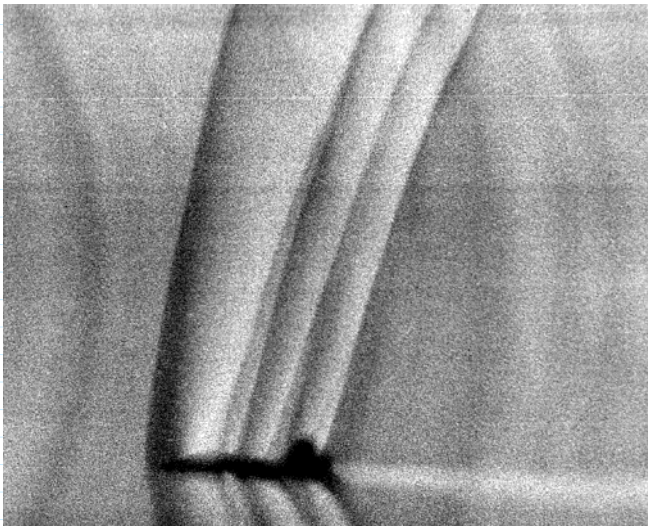
figure 102, and the entire jet eventually becomes turbulent. Bradshaw, Ferris & Johnson 1964



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

98



Pasted from <[http://commons.wikimedia.org/wiki/File:Schlieren\\_photograph\\_of\\_T-38\\_shock\\_waves.jpg](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

How it works:

$$n = \frac{c_{\text{VACUUM}}}{c_{\text{MEDIUM}}}$$

n = index of refraction

Light is deflected towards more dense medium

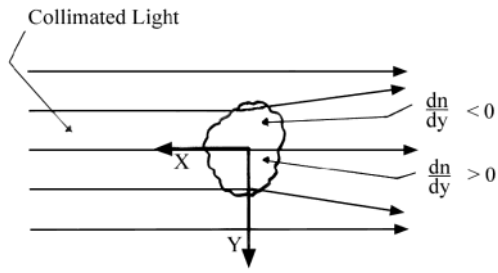
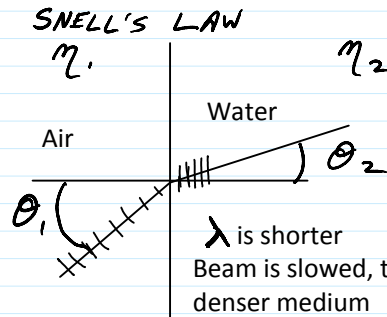


Figure 1. Disturbance in Collimated Beam

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$$\frac{1}{r} \frac{\partial^2 y}{\partial x^2} = \frac{\partial^2 y}{\partial z^2}$$

curve of disturbed line



like a caustic

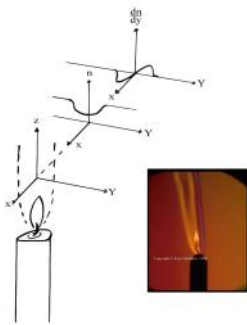


Figure 2. The Refractive Index Gradient Above a Candle

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

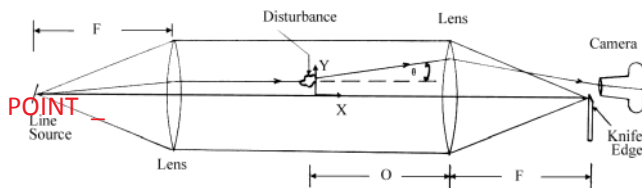
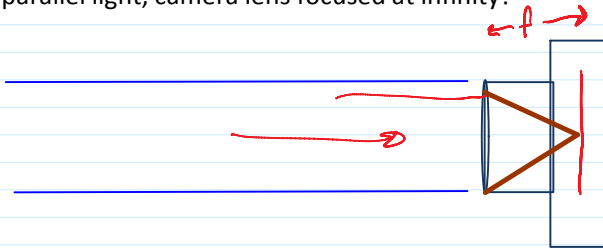


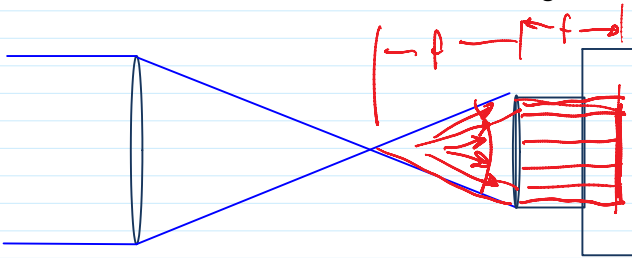
Figure 3. Schlieren System with a Small Disturbance

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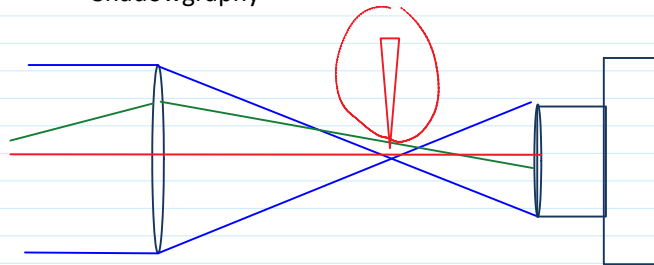
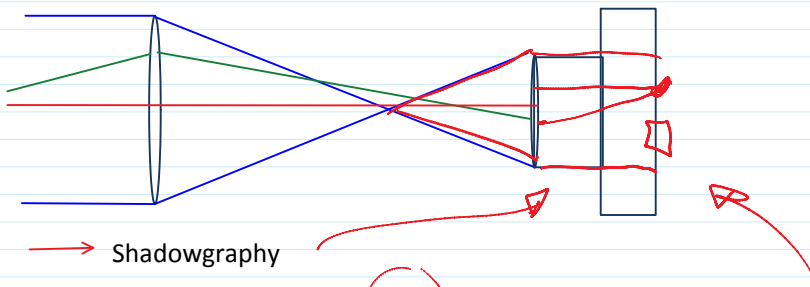
Minute paper: What would camera see looking at parallel light, camera lens focused at infinity?



And in this case? No disturbance, no knife edge



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



Cut the deflected light with a knife edge (razor blade)

→ schlieren

By Foucault, 1859

schlieren: German noun, Not a name

**SHADOWGRAPH EQUATION**

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

Shadowgraph, sensitive to 2nd derivative of  $\eta$

Ref: 1. Wolfgang Merzkirch, *Flow Visualization, Second Edition*, 2nd ed.

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

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

Relative light intensity at exit. Light propagates in Z direction

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

Similar math for schlieren, is sensitive to first derivative; to gradients in temperature.

Variants:

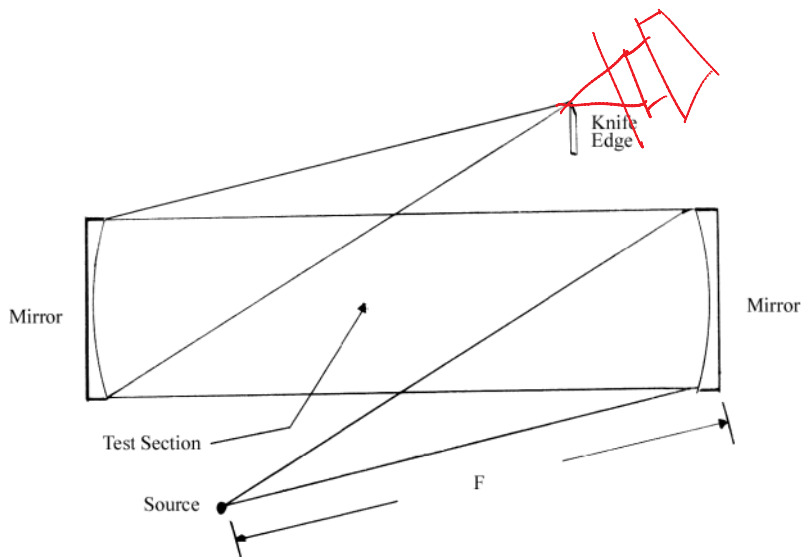
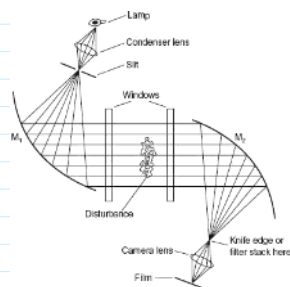


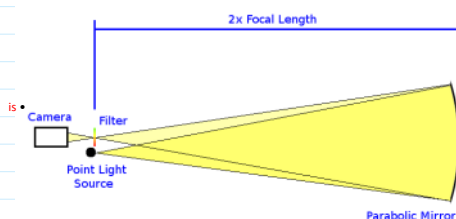
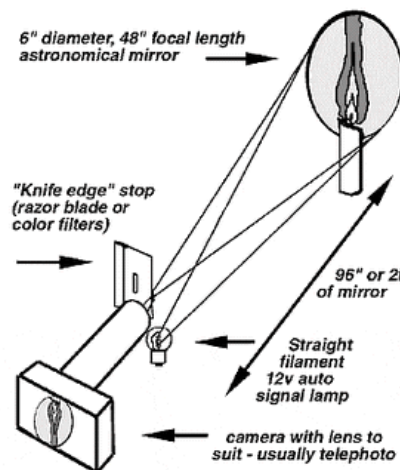
Figure 7. Mirror System

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Z fold with mirrors; saves space. Want space between mirrors to be 3 x f



Posted from  
-http://7.bp.blogspot.  
2UJESv8R0uK0/SQZ01d  
AU/AAAAAAAAABN/COGv  
2UJESv8R0uK0/schlieren.pdf





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](file:///C:/Users/hertzber/Documents/01CLASSES/FlowVis/MiscImages/Settles/SchlierenVisit/DSC_0324.AVI)> My visit in  
 March

BOS = Background Oriented Schlieren

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

Focusing Schliemann

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

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