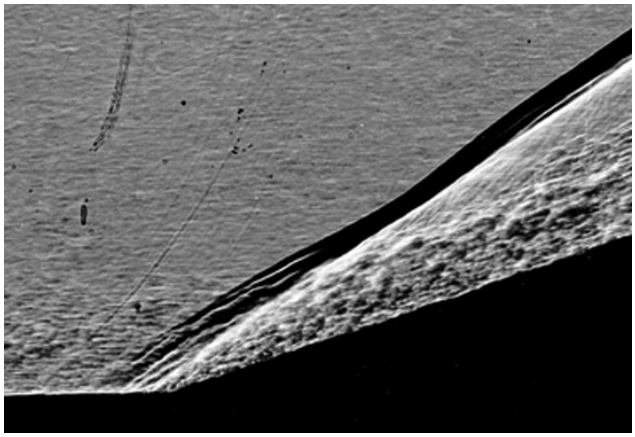
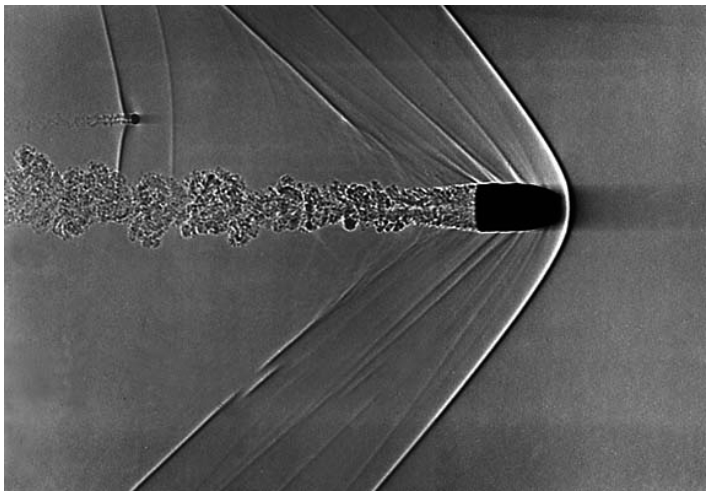
Visualization based on Refractive-Index Affects

Shadowgraph

The density of a fluid varies with temperature, salinity, and pressure. And, the index of refraction changes with fluid density. Variations in the refractive index deflect or phase shift light passing through the fluid. If a screen is placed opposite the light source, these effects create shadows one the screen creating an image called a *Shadowgraph*. For example, in the following image the deflection of light by the discontinuity in pressure across a shock wave creates a thin black shadow.



The above picture is a shadowgram of Mach 3 airflow over an 18 degree compression corner which shows the shock wave/turbulent boundary-layer interaction (from G. Settles PhD thesis, Princeton, 1975). Prof. Gary Settles of Gas Dynamics Lab, Penn State University http://www.efluids.com/efluids/gallery/18degramp.htm



Supersonic bullet flying between a small, short duration (1 microsecond) light source casts a shadow of its shockwave onto a sheet of photosensitive film forming the basis for a shadowgraph recording system. Contributor: Prof. Andrew Davidhazy, Rochester Institute of Technology (Copyright retained by the contributor). http://www.efluids.com/efluids/gallery/bullet_shadowgraph.htm.

Subtler density differences due to temperature or salinity can also be visualized.
http://www.city.ac.uk/mathematics/Fluids/DD_shadow.html

Traditional shadowgraph collapses a three-dimensional field into a planar image. The following study describes how multiple shadowgraphs of the same flow can be combined to recover three-dimensional information.
http://www.math.nyu.edu/AML/wetlab/projects/3d-convection.html

Schlieren Technique

Like the shadowgraph the Schlieren method visualizes the distribution of fluid density within a fluid, as fluid density controls the indes of refraction. Regions of density gradient deflect light beams, shifting their position on the image plane. The relative change in light intensity can be used to infer the original density and flow field.

http://www.eng.vt.edu/fluids/msc/gallery/misc/kimcb.htm
http://web.mit.edu/edgerton/people/vandiver/schlieren.html
http://www.efluids.com/efluids/gallery/6cylAmes8.htm
http://www.ae.gatech.edu/~jseitzma/classes/ae6050/schlieren.jpg

How to Build a Basic Focusing Schlieren System
http://www.spie.org/web/oer/february/feb99/edprogs.html