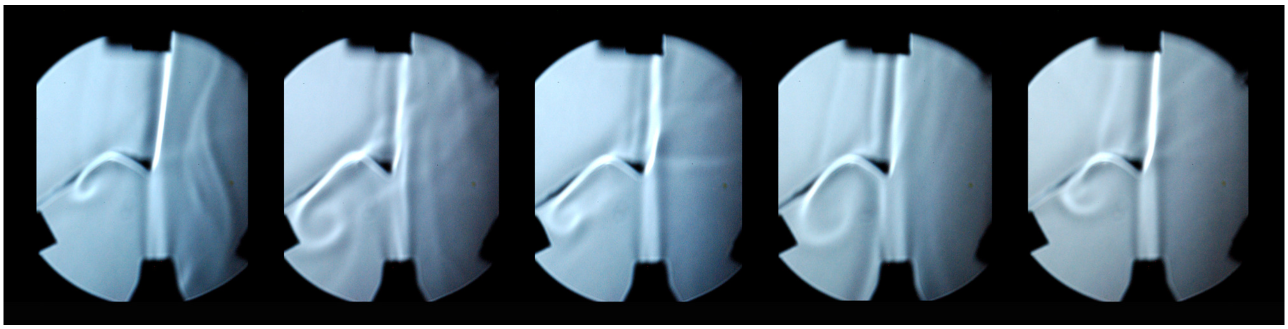


Tracy Eliasson
Flow Visualization
Fall 2007
Group Project 3: Schlieren

The final image, Vorticity Induced in a Buoyant Plume, was made as for the final group project in Flow Visualization at the University of Colorado. The visualization technique is Schlieren Imaging. The Schlieren technique enables the experimenter to visualize “invisible” fluids by utilizing their light bending characteristics. In this image a buoyant plume created by a tea-light candle is conditioned by a funnel. The resulting laminar flow is interrupted by a knife edge which results in shedding of vortices.

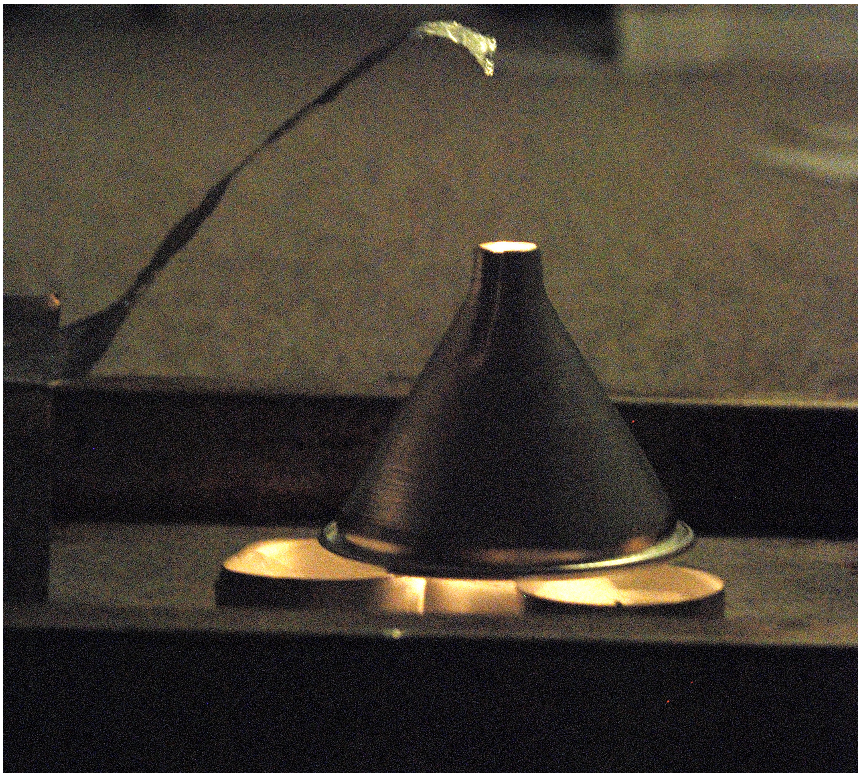


Figure 1

The flow apparatus is pictured in Figure 1. Heat rising from a tea light type candle is conditioned by a metal funnel. The small opening on the funnel is approximately .75 cm across. The funnel serves to condition the flow as well as to keep the candle light contained. An aluminum foil baking tin was modified in order to provide a barrier to place within the laminar flow. This foil barrier causes the laminar flow to split. The portion of the flow travels downward to the left until the buoyant force causes it to rise again. At this time the direction of flow changes and vorticity is present. The field of view for these images is equivalent to the size of the mirrors which is 4.25 inches in diameter. The full height of the mirrors is included in the final composite image. The width across each composite image is about 4”. The spatial resolution of the image is estimated to be about 3.3 mm, thus motion blur of the flow is clearly present. The five images chosen for the composite each exhibit vorticity, but the vorticity was not constant. There were many other images in which the vorticity was not apparent. The flow was periodic in nature such that the large vortex in the left of the image re-appeared several times. Several studies on the periodic nature of vorticity have been made including one titled “Periodic Motions of Vortices on Surfaces with Symmetry”.[1] The experimenter estimates that about 1/4 of the images made with the current apparatus displayed strong vorticity. As camera shutter release and vorticity presence are assumed to be independent we can conclude that this type of vorticity is present about 1/4 of the time.

The visualization technique is Schlieren imaging, the visualization apparatus is similar to that described

[1] Souliere, Anik & Tokieda, Takashi. Periodic Motions of Vortices on Surfaces with Symmetry. Journal of Fluid Mechanics. Vol. 460. pp. 83-92. 2002.

in Settles,[2] A drawing of the apparatus is included as Figure 2[3]. The apparatus employs two parabolic mirrors were placed at a distance of 275" from each other. This is approximately 5.5 times the focal length (48") of the mirrors, well better than the minimum of 2 times the focal distance recommended by Settles[4]. The first mirror was angled 6 degrees from the centerline toward a strobe light. The strobe light was placed in the focal point of this first mirror. After much adjustment, and use of an alignment tool, described in Appendix A, parallel light was reflected from the first mirror towards the second. Several alignment techniques were attempted for the second mirror. One technique, which proved very useful, is described in Appendix B. A threaded screw was employed to test focus. Screw threads were clearly visible in the image after alignment was complete. A knife edge (razor blade) was placed at the focal point for mirror 2. This provides good contrast as some of the bent light is eliminated from the image. Image capture was done directly onto the CCD of a Nikon D80 camera without any lens or filter. Earlier attempts to project the light onto paper or ground glass proved ineffective because of low light conditions. The light source for this setup was a EG&G Electro-Optics model PS302. This strobe light set to produce a single pulse of light with estimated duration of 1/100 of a second. The voltage was set to the lowest available setting, 400 V. The camera shutter was left open for 2 seconds, during which time the strobe was pulsed once in order to expose the image.

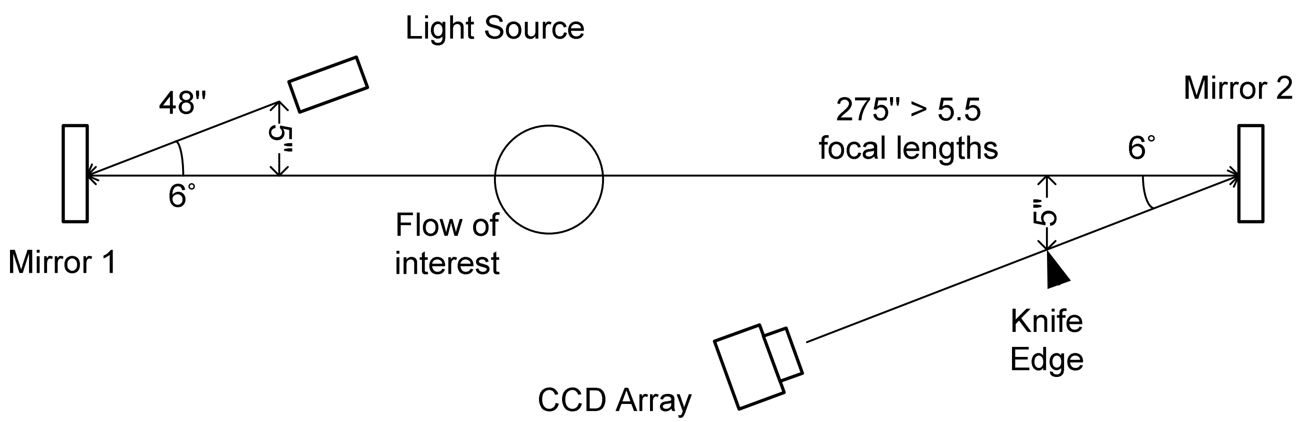


Figure 1. Schematic of experimental setup

Figure 2

The photographic technique for the images is unusual in that the camera body was employed without the use of a lens or filter. The image captured was projected directly onto the CCD of the camera. This technique allows for optimal image quality in very low light conditions and in fact caused an issue of too much light, rather than too little light. Reported camera settings for the image are included as Appendix D. Although the camera shutter speed was long the actual image collection time was much shorter as the light source was a strobe pulsed just one time. The strobe duration is estimated to be

[2] 2.***Settle, Gary S.*** Schlieren and Shadowgraph Techniques: Visualizing Phenomena in Transparent Media. ***Springer***, 2001

[3] Drawing courtesy of Owen Hnath.
[4] ***Settle, Gary S.*** Schlieren and Shadowgraph Techniques: Visualizing Phenomena in Transparent Media. ***Springer***, 2001

1/100 of a second. The strobe voltage was 400 V. the Photoshop Elements software package was used to crop the original images and join them into a composite image. After creating the composite the gray levels were adjusted slightly in order to increase the contrast in the image. Minimal image processing was needed as the knife-edge has already been adjusted to provide a good level of contrast.

The image reveals several things. First it reveals the laminar nature of heat rising from a candle. Second it reveals that vortices can be shed from a laminar flow with a barrier while the remaining laminar flow remains laminar, which was somewhat surprising to the experimenter. The composite image, made from 5 separate images, reveals that although fluid flow is not an exact science the results are repeatable over time. The technique allows the experimenter to view the flow, and to build up an understanding of similarities and differences at different times. The flow patterns are visually appealing and certainly fascinating. I like that the composite image gives the viewer a chance to compare and contrast different instants in time for the same fluid flow. Given another chance with the Schlieren apparatus it would be interesting to employ the high speed camera in order to make a video of the scene. If the no-lens photographic technique is available for that camera the results could be phenomenal.

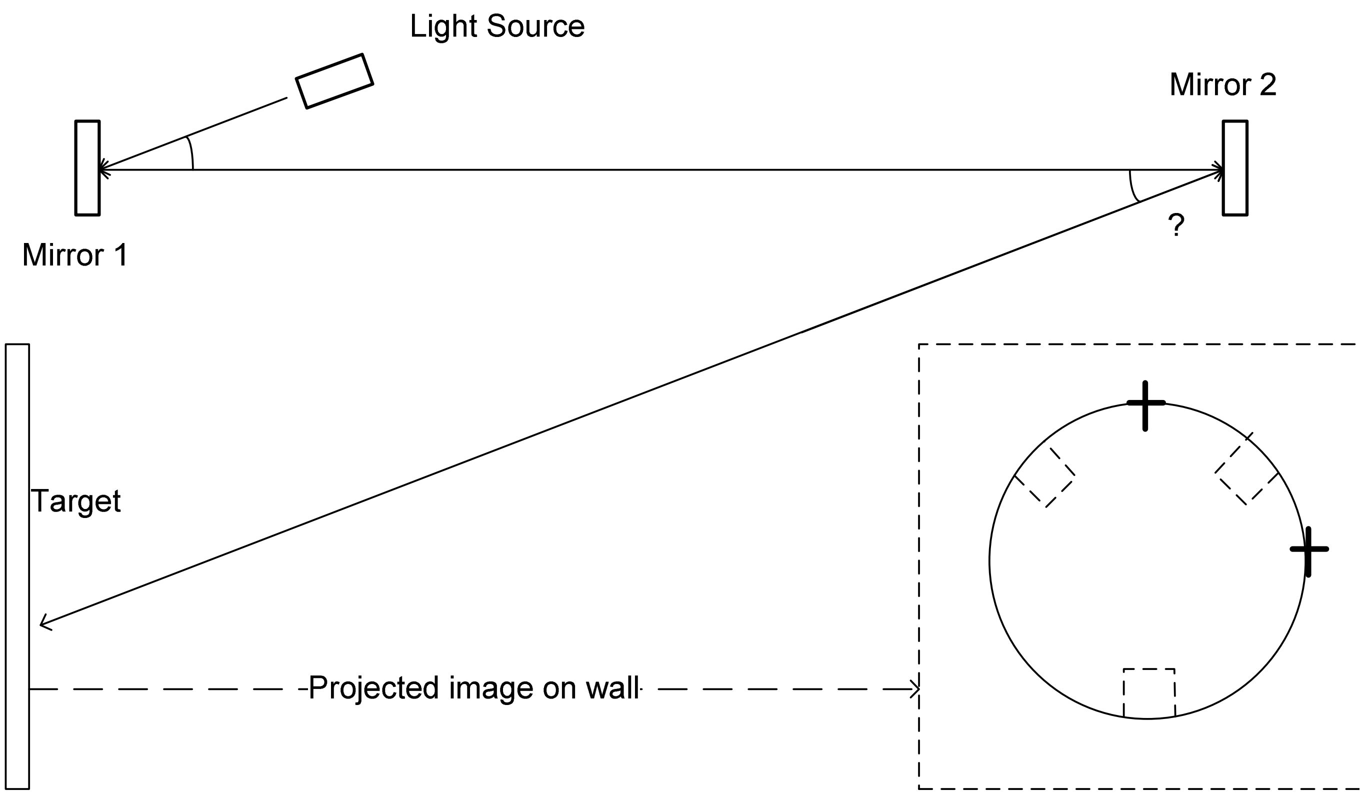
Appendix A: Parallel Light Tool:

Purpose: Help the experimenter to get the light source exactly in the focal point of Mirror 1.

Design: 2 manila folders or similar materials are needed.

1. On the first manila folder draw a circle with the same diameter as the mirrors. The circle should be at the same distance from the floor as the mirrors and should be in the approximate center of one half of the folder. Cut out this circle.
2. On the second manila folder draw a circle 3mm in diameter smaller than the mirrors. This circle should be concentric with the circle on the first folder (if the folders are held together the circles are concentric).
3. Use tape to attach the folders to one another. Put some distance (about 2") between the sides of the folders with It is possible to do this such that the manila folder so that the beam of light coming from the first mirror toward the second mirror can pass thru the holes without a person needing to hold the tool.
4. When correct light source alignment is achieved the light will pass thru the first (larger) circle and just skim the outside edge of the second (smaller) circle.

Appendix B: Alignment method for mirror 2:



Geometric calculations of the size and location of the mirror on a wall were produced, then translated into two target marks marking two tangent points on the projected circle. With the source and mirror 1 aligned, and mirrors 1&2 parallel. The angle of Mirror 2 was adjusted such that its projected image corresponded with the marks placed on the target. The long distance helped magnify errors such that even with an uncertainty of ~.125" at the target, our CCD recorded little focus variations.[5]

Appendix C: Reynolds number calculation

Descriptor	Value	Units
Dynamic (absolute) viscosity of Air @ 30 C[6]	1.1 x 10^-5	N*sec/M^2
Fluid Velocity	.3	m/s
Characteristic Distance	.75	Cm
Density of Air @ 30 C	1.165	Kg/m^3
Reynolds number	2.38 x 10^5	Dimensionless

Appendix D: Camera Settings

Nikon D80
2007/12/12 00:25:50
RAW (12-bit)
Image Size: Large (3872 x 2592)
Color
Lens:
Focal Length: 0mm
Exposure Mode: Manual
Metering Mode: Center-Weighted
1/8 sec - F/0
Exposure Comp.: 0 EV
Sensitivity: 1 Step Over 1600
Optimize Image: Normal
White Balance: Auto
AF Mode: Manual
Flash Sync Mode: Not Attached
Color Mode: Mode Ia (sRGB)
Tone Comp.: Auto
Hue Adjustment: 0°
Saturation: Auto
Sharpening: Auto
Image Comment:
Long Exposure NR: Off
High ISO NR: On (Normal)

[5] Drawing and description courtesy of Owen Hnath

[6] Fox, Robert W, McDonald, Alan T. Introduction to Fluid Mechanics.p. 763. John Wiley and Sons, Inc. New York. 1992.