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351-336
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Final Image Assignment: Team Project 3

As a result of our trials with a Schlieren setup during assignment 2, we approached this last project with experience and determination. A new experimental location provided us with a large, undisturbed staging area, as well as complete elimination of ambient light. A technique developed by one team member allowed greater precision in the experimental alignment. These two items allowed us to produce images of acceptable contrast while using relatively low light input. As with many Schlieren photography sessions we examined as many types of flow that we could produce (due to the time investment of properly preparing the experiment!). Figure 1 below, is a composite of two more bizarre images, depicting turbulent breath produced by a team member.

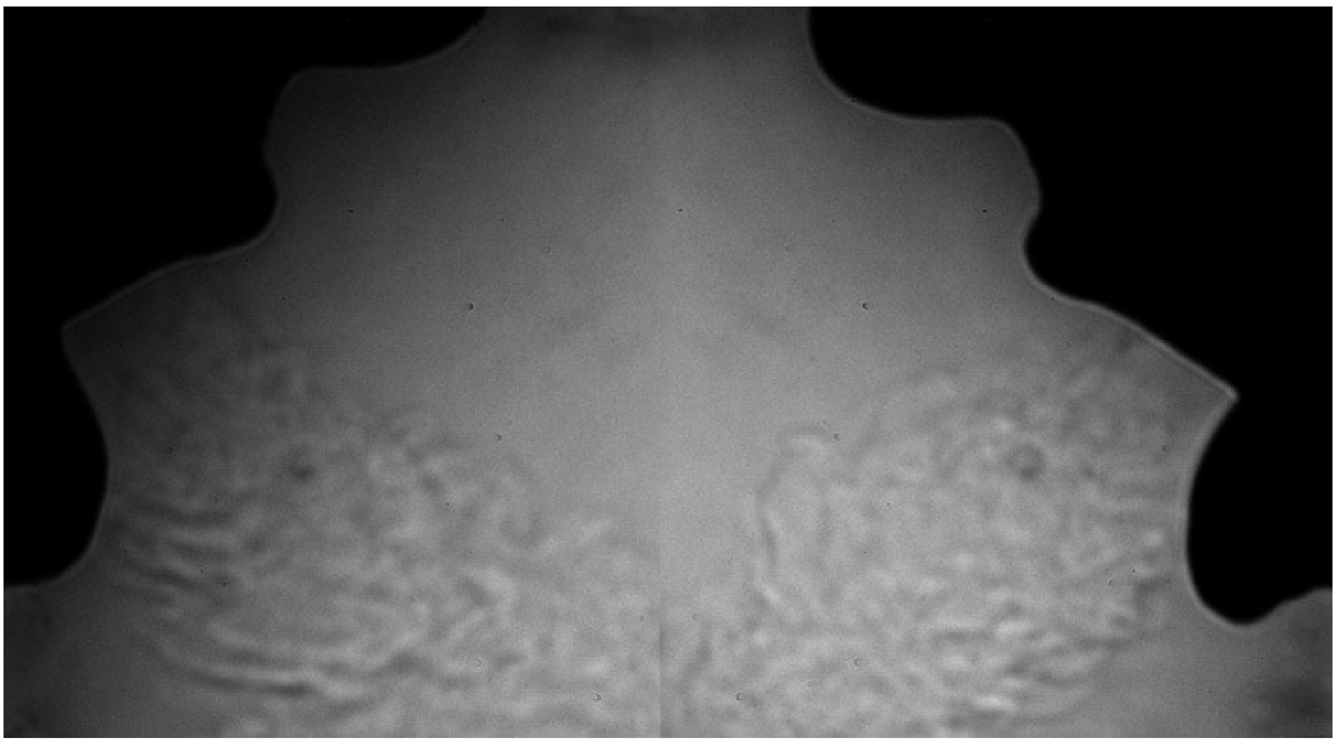


Figure 1. Composite Schlieren images of turbulent breath

As with our shadowgraph imageset, the salient principle behind Schlieren photography is light bending. The experimental setup is designed to amplify this natural phenomenon and control it for our benefit. We selected the popular 'z-type' setup for our experiment depicted in figure 2. The first step in this process is creating a column of parallel light rays between two parabolic mirrors. Parabolic mirrors have the unique characteristic of broadcasting any light generated at their focus as parallel rays[1]. Thus we started by locating our light source at the mirrors' focal length of 48". The angle of deviation of 6˚ was selected as the minimum that would fully remove the source from the column of light between mirrors 1&2. The source was also elevated to the center of the mirror (5.375" above the floor), and aligned with its long axis parallel to the floor. Most texts recommend a mirror separation greater than twice the focal length of the mirrors[2]. Note that some of the bent light may escape the light column if the mirror separation is large. This is acceptable for knife-edge techniques since that light would be discarded anyway, but for color-target images this effect is undesirable. Our choice of a >5f spread allowed us to see small angular misalignments better as they were magnified over the long distance (see appendix for description of alignment procedure). We elected not to use the color target, and instead placed a knife edge at the focus of mirror 2 to remove the light rays bent by the flow. This allowed for high contrast images without the need for powerful light sources (by design, the color targets filter out many wavelengths of light reducing the overall intensity). Finally, a digital CCD array was placed normal to the light leaving mirror 2. The image was projected directly onto the CCD array without the use of any lenses or filters. The CCD's distance from the knife edge was selected to maximize the size of the captured image. Our flow phenomena were centered in the column of light, roughly halfway between the mirrors.

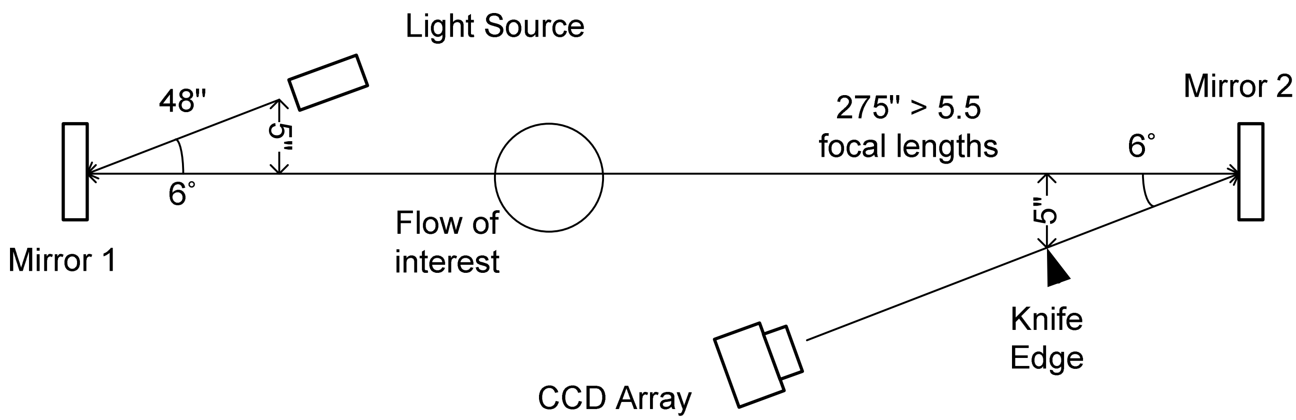


Figure 2. Schematic of experimental setup

The light source for this setup was an EG&G Electro-Optics Model PS302 strobe light, set to produce a single pulse of light. The charge voltage was set to 400V, delivered over ~1/100sec. The shutter of the camera was left open and the single pulse was used to expose the image.

The images I selected were produced by low velocity air currents, at ~90˚F, leaving a team member's mouth. The temperature differential between the breath and bulk room temperature (~65˚F) leads to a fliud density differential of .0028 lb/ft^3, as well as an index of refraction change of 1.3E-5 (based on Modified Edlén Equation[3]). Recall that the bending of light obeys Snell's law (equation 1 below) which relates the angles of incidence and departure to the ratio of refractive indices of the two fluids. The greater the difference, the greater the light rays are bent and the better contrast available for our image. Reynolds numbers in biological systems can be difficult to estimate, however numbers as high as 50,000 during heavy breathing have been found[4] and the visual characteristics of the images do indicate turbulent flow.

$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{v_1}{v_2} = \frac{n_2}{n_1}$$

Equation 1: Snell's Law

Vital statistics for this image:

Field of view:	4.5”x4”
Lens	None
Lens focal length:	0.0, F-Stop 0.0
Camera used:	digital, pixel dimensions 3872x2592, Nikon D80
Exposure:	shutter speed (exposure time) 1.30 sec (see proceeding paragraph

	for explanation of strobe exposure), exposure compensation 0.0
Photoshop processing:	Images cropped & rotated, composite was assembled, color curves adjusted, images were converted to grayscale, mirror clips were removed with clone stamp and burn tools.

As a culmination of the semester I feel this image is quite appropriate. Producing it required, by far, the most complex setup of our three team projects. The exacting requirements of the setup payed off, in an image that I think possesses striking aesthetic qualities as well as scientific merit. I feel that the flow is well resolved and easily identifiable despite its origin. The focus if the image could be improved, as could be the grain quality. Improving one would help the other as the grain resulted from attempts at increasing contrast lost due to mirror misalignment. If I was able to reproduce this setup I would be most interested is using the color target with a light source of greater intensity.

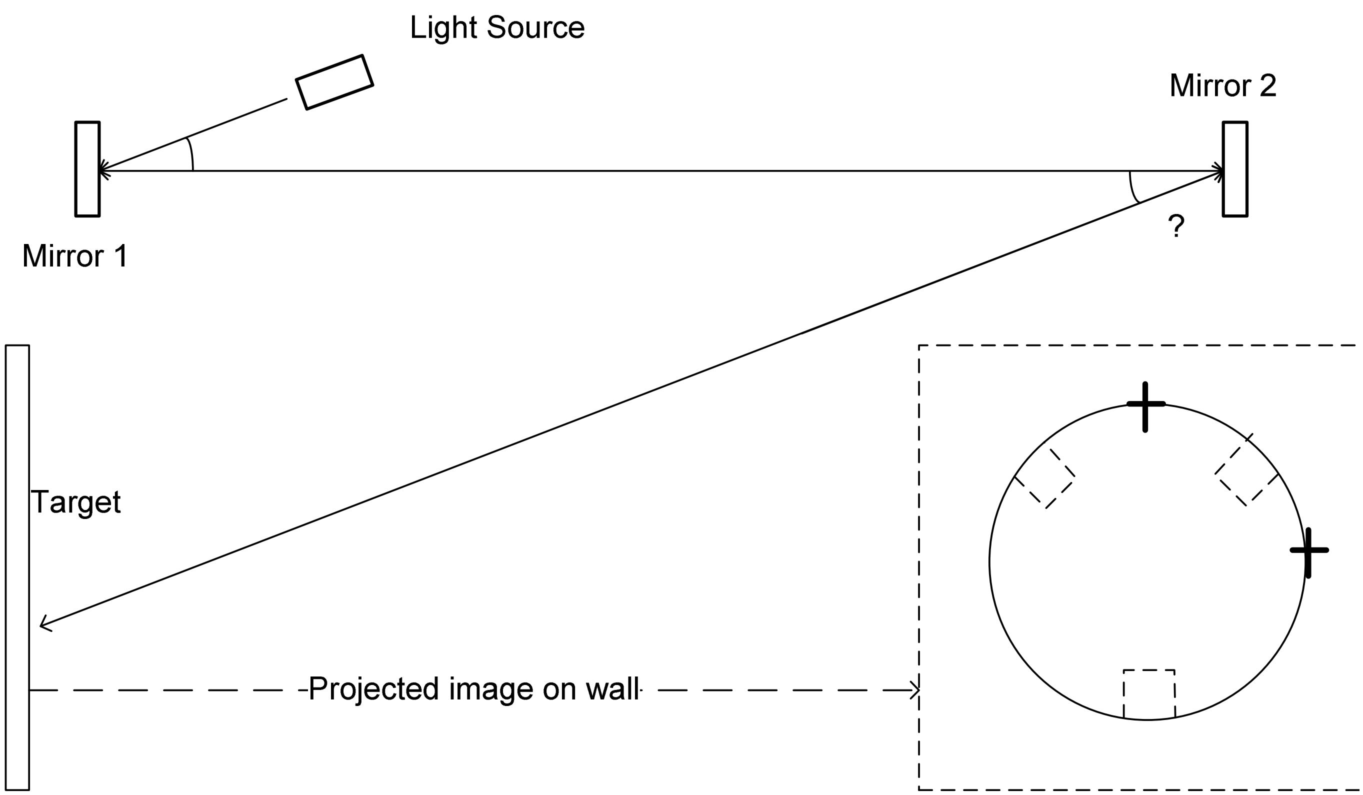
Appendix:

1. *Parabolic Mirror*
   http://www.cut-the-knot.org/Curriculum/Geometry/ParabolaMirror.shtml
2. Settle, Gary S. *Schlieren and Shadowgraph Techniques: Visualizing Phenomena in Transparent Media.* Springer, 2001

3. Stone , Jack A. and Zimmerman, Jay H. *Index of Refraction of Air* http://emtoolbox.nist.gov/Wavelength/Edlen.asp

4. Mazumdar , Jagan N. *Biofluid Mechanics.* World Scientific, 1992

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.