Group Project 3

"Schlieren"

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Flow Visualization

Prof. Hertzberg and Prof. Sweetman

This project was inspired by images created by the technique of Schlieren which was described in lecture and observed in Colleen Stroud's laboratory. Schlieren is a flow visualization technique that allows the visualization of density gradients in a translucent medium, such as air. The images obtained for this project were specifically taken for the third group assignment of the Flow Visualization course. Below is an image that uses color Schlieren to capture a blow torch impinging on a metal fireplace shovel.

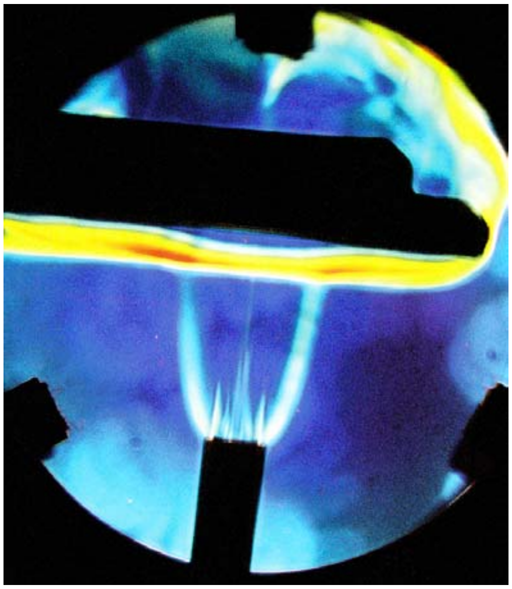


Figure 1: Color Schlieren image of a propane torch impinging on a metal fireplace shovel.

In color Schlieren the light passes through a color filter or stop before being captured by the camera. This method allows the image to be colored, as observed in Figure 1. A great deal of time went into setting up this flow visualization technique and it would have not been possible without the help of both Professor Jean Hertzberg and Colleen Stroud. Stroud was especially crucial to the capture of these images and aided tremendously in the focus and alignment of the camera. Several iterations of the project were completed in an effort to obtain the quality of pictures desired. The first images captured were black and white and used a knife-edge to block out and deflect some of the light rays in order to create the image. However, these images were not as striking and showed limited aspects of the flow because of an alignment error. Hence, the subject was pursued with differing techniques until images of a higher quality were produced. The intent of these images was to learn more about the visualization technique of Schlieren and produce both aesthetically pleasing images with scientific meaning.

The flow apparatus used in the image was rather simple and can be seen in the image (Figure 1). It was simply a blow torch impinging on a metal fireplace shovel. The blow torch was a Master Mechanic 14.1 ounce and contained propane. It was manufactured by TruServ and was equipped with the standard nozzle (labeled 403). The overall flow setup is shown below.

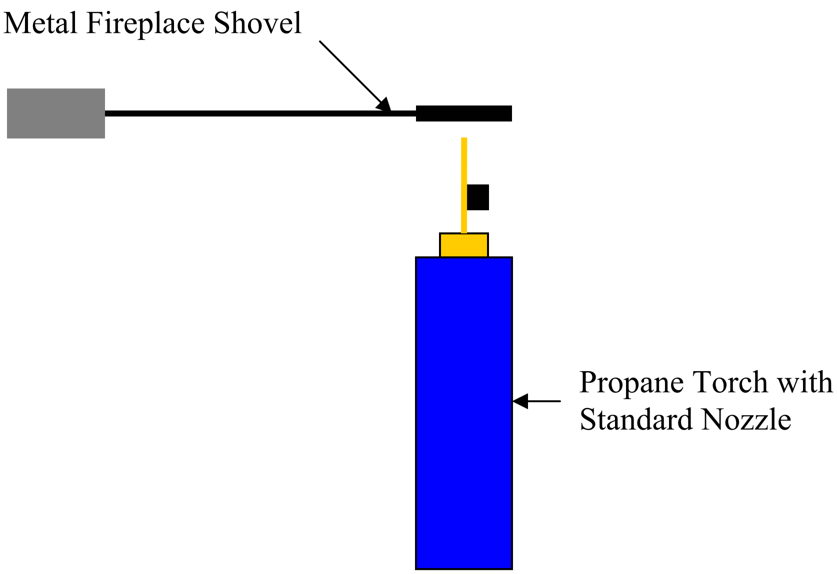


Figure 2: Flow Setup

Thus, the basic flow was a propane flame impinging on a metal fireplace shovel. The propane flame in the images is approximately ½ an inch wide and the metal fireplace shovel is approximately ¾ of an inch thick. As the propane emerged from the tank, it was ignited and was forced upward by the release of more propane from the tank. The flame then came in contact with the metal fireplace shovel and spread out on the surface. On the right edge of the image, the jet has wrapped around the shovel and has created an eddy current with a slight vortex seen in the upper right corner of the image. The material properties of propane were obtained from Engineering Equation Solver and the Reynolds number for the propane emerging from the tank before combustion was evaluated by assuming a velocity of one meter per second and an exit nozzle size of 5mm. The Reynold's number is given by

$$Re_D = \frac{\rho \cdot D_H \cdot V}{\mu}$$

and turned out to be 1108 for these parameters. This corresponds to laminar flow. Please see Appendix A for calculations. The spatial and time resolution for this image was also determined. Once again, the velocity of the flow was assumed to be one meter per second and the shutter speed was 1/500 of a second. Therefore, in the time it took the image to be captured the flow moved approximately .2 mm. However, what is seen in the image is the density gradient. If the conditions of a thermal equilibrium, a constant flow of propane, stationary flow setup and undisturbed environment are assumed then the density gradients should remain approximately constant. Next, the spatial resolution can be evaluated. The film has a print grain index (PGI) number of 39. According to http://www.kodak.com/global/en/professional/support/techPubs/e58/e58.pdf, the Kodak technical support website, "a PGI rating of 25 on the scale represents the approximate visual threshold for graininess, with higher numbers indicating an increase in the amount of graininess observed." Thus, a PGI vale of 39 indicates a relatively high level of graininess observable in the film. Unfortunately, there was no indication of how the print grain index corresponds to actual grain size or the RMS granularity rating, which typically determines the grain size, for this specific film. However, judging by the original image, the image is probably time resolved, but not well spatially resolved. This could possibly be improved with the use of a different film.

The physical principles behind Schlieren involve the deflection of light beams or rays as they pass through density gradients. For the image in Figure 1, the density gradients are caused by convective heat transfer from the propane flame to the metal fireplace shovel and the air surrounding air. In most Schlieren techniques, the deflected light rays are then directed past a knife edge or color stop. According to Andrew Davidhazy from the Department of Imaging and Photographic Technology Department at the Rochester Institute of Technology, the interaction between the light rays and the knife edge or color stop "gives rise to variations in the distribution of light at the image plane or a coloring of certain portions of the image depending on the degree to which the path of the rays was deflected. The knife edge or filter array in conjunction with the image of the light source acts as a discriminator which makes visible deflected light beams." (http://www.rit.edu/~andpph/text-schlieren.html) This is illustrated in an easy to understand manner in a diagram from a publication from the Von Karman Institute for Fluid Dynmaics entitled "Schlieren Technique – Lab Notes" by Jeronimo and Van Der Haegen (http://www.vki.ac.be/event/euroavia/slides/lab1exp.pdf). It describes a Schlieren setup similar to the one used to produce the image and details the light rays which are disturbed (dotted lines) and undisturbed (full lines).

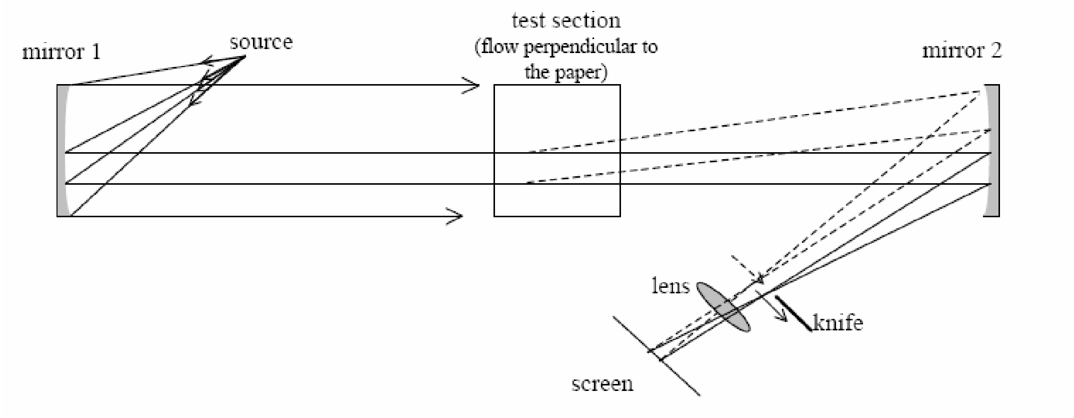


Figure 3: Schlieren setup describing light rays and distortion.

There are several differences between the setup in Figure 3 and the one used to create the image in Figure 1. For instance, a color target was used instead of a knife and the image was projected onto film instead of a screen. Thus, the flow visualization setup for the captured of the image in Figure 1 was created in the following fashion,

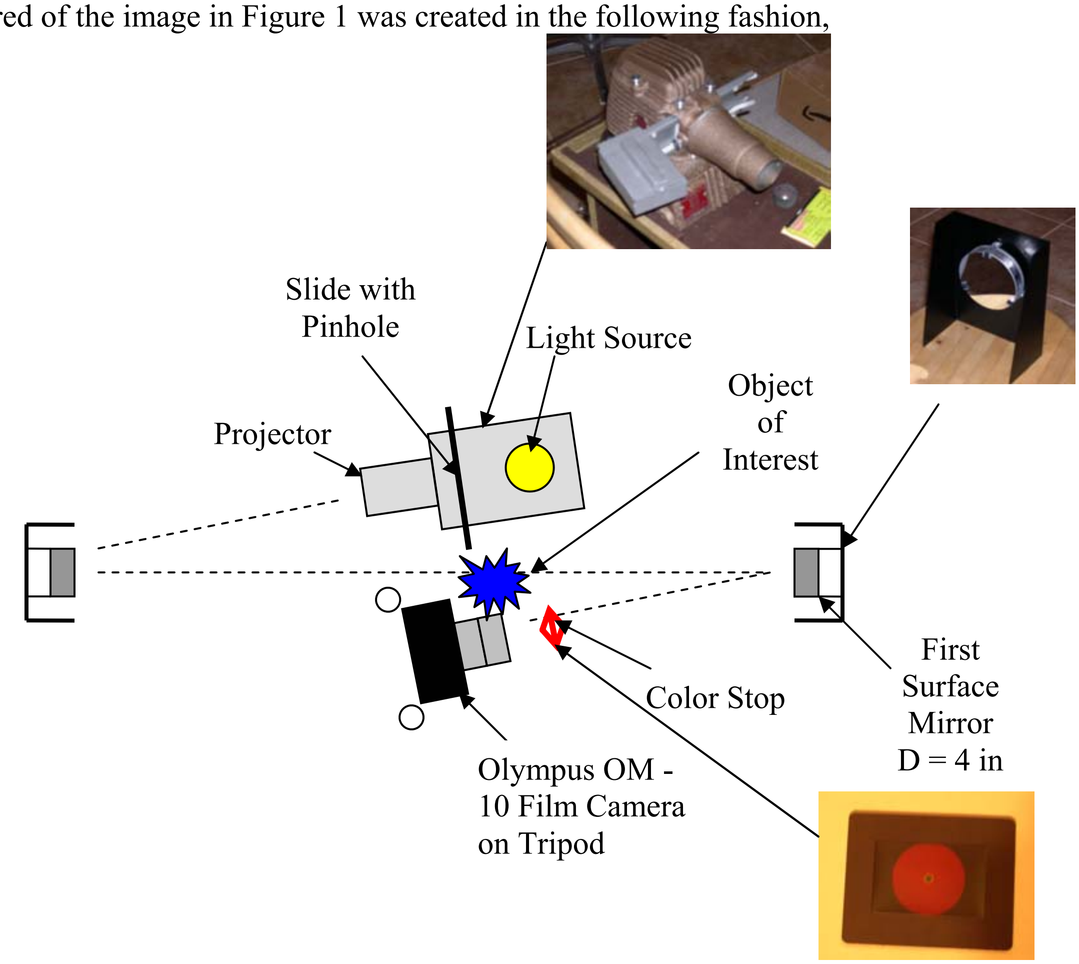


Figure 4: Flow Visualization Setup

As the light rays progressed through the air between the two mirrors, they encountered various density gradients due to the convection of air away from the lit blow torch. Each light ray was then bent appropriately depending on how much of a density gradient it had encountered. Thus, when these bent light rays passed through the color target, a color was given to each light beam depending on the location at which the light ray had passed through the color target. Then the appropriate color was imaged by the camera behind the color target. The color target was printed on 70 mm film and featured seven concentric circles ranging from a very small dark blue center to various shades of light blue, green, yellow, orange, and finally the outermost circle was red. The light rays that passed through the hottest part of the image, where the propane was undergoing combustion at the nozzle, were deflected the most and had the largest density gradients. In the image, the color white corresponds to these areas. Because there was no white ring on the color target, we can only presume that these light beams were bent so much that they didn't pass through the color filter. On the other hand, the background of the image is blue because these light rays were deflected the very little, if at all, and traveled through the center of the target.

The two mirrors in the system are first surface mirrors with a focal length of approximately four feet, which provide reflection of the collimated beam of light. According to Colleen Stroud, "the mirrors should sit 2 focal lengths apart and the light source should sit one focal length from the first mirror and the color stop should be 1 focal length from the second where the light is focused down to a point." This configuration resulted in a good quality of image. The exact measurements between the elements in Figure 4 are shown below,

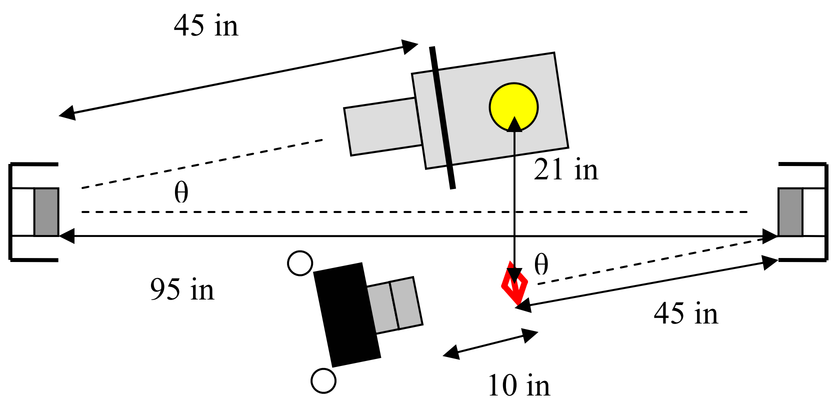


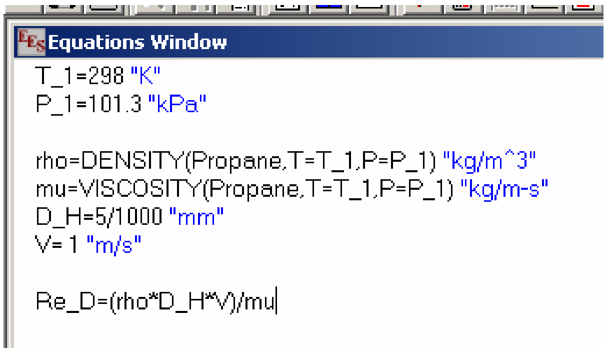
Figure 5: Measurements between elements in Schlieren system

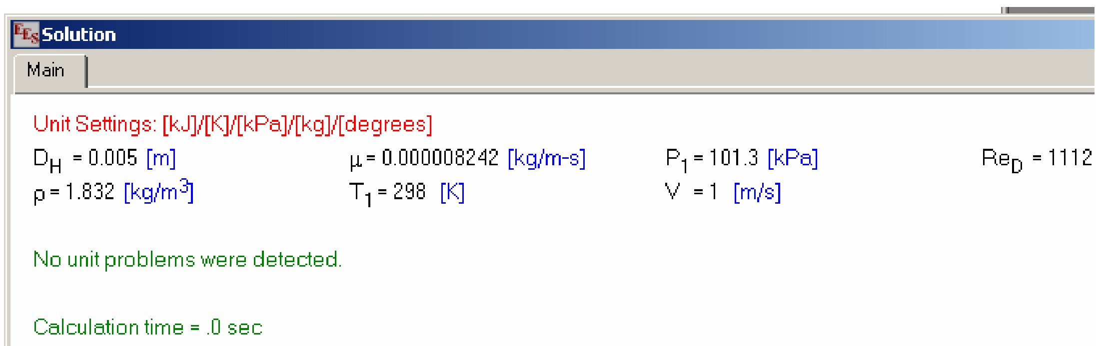
The lighting for the image was from a point source of light obtained by covering the output from a Gold E Blower Cooled Manmatic Slide Projector (Model #300-P-1042) with an index card with a pin hole in it. The projector contained a 300W bulb. The location of the light source is described in Figure 5. The light from the blowtorch was only used to create a density gradient to be imaged and did not contribute to the overall general lighting of the image.

The camera used to photograph this image was an Olympus OM-10 film camera loaded with 400 speed Kodak high definition film. For this image, the field of view was approximately two and a half inches wide by two inches tall. The aperture of the camera was set at an F stop of 4.5 and the shutter speed was 1/500 seconds. The lens of the camera was located approximately 60 to 75 inches away from subject when the image was captured. This measurement was obtained by noting the distance to the mirror from the camera lens and adding it to the distance of the object from the mirror. The lens used was a JC Penney Optic Lens Model 8514939 with a focal length of 190 mm. All images captured were modified in Adobe Photoshop to remove distracting elements such as the large black background. Unfortunately, when the images were developed, they were printed inappropriately and off center even though the negatives were correct. Photoshop was also used to remove some of the fuzziness due to the grain of the film from the images. This was done by applying and Auto Levels Filter followed by a Replace Color adjustment with a setting of +200 fuzziness and -100 lightness.

This image reveals the density gradients present in a propane torch impinging on a metal fireplace shovel. In the upper right hand corner, eddy flow is observed as the propane flame encounters the edge of the metal fireplace shovel. This eddy current creates a small vortex on the backside of the shovel. I am pleased with the final images obtained for this project, but I also feel that this is a very complex technique and that Clay and I barely had time to achieve a good configuration for obtaining images and a basic understanding of the technique. We have decided to leave the setup intact for a couple more days and experiment with different heat generating sources. Schlieren is one of the most interesting techniques I have ever used to capture images and I was amazed at the sheer number of innovations occurring in the field. For instance, NASA has created a Schlieren camera that is able to images of supersonic flows around airplanes. In the images we captured I feel that the focus could have been a bit better and the background could have been slightly less distracting. In addition, the grain of the film was present in the images before Photoshop filtering was applied. I believe all of these issues could have been resolved with more time to work on the technique. However, when comparing these images to our first attempts, these images are nearly perfect. The main burning question that I have about this technique is how the colors that indicate density gradients correspond to quantitative density measurements. I think this would be an interesting aspect about the technique to understand. I was also wondering why my digital camera was not able to capture any images even though the setup and camera position was the same as Clay's film camera. Overall, I believe the best way to improve this work is to contribute more time and resources to understanding the technique. In addition, there are limitless ways to develop this technique further.

Appendix A


Equations Window
T_1=298 "K"
P_1=101.3 "kPa"
rho=DENSITY(Propane,T=T_1,P=P_1) "kg/m^3"
mu=VISCOSITY(Propane,T=T_1,P=P_1) "kg/m-s"
D_H=5/1000 "mm"
V= 1 "m/s"
Re_D=(rho*D_H*V)/mu


Solution
Main
Unit Settings: [kJ]/[K]/[kPa]/[kg]/[degrees]
D_H = 0.005 [m]
μ = 0.000008242 [kg/m-s]
P_1 = 101.3 [kPa]
Re_D = 1112
ρ = 1.832 [kg/m^3]
T_1 = 298 [K]
V = 1 [m/s]
No unit problems were detected.
Calculation time = .0 sec