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Image Assignment 4: Team Project 2

For our second project as team alpha, we began with a desire to explore more elaborate visualization techniques. As a group we agreed to work without flow seeding. Opting instead, to use fluid interfaces with different indices of refraction. To that end, we began testing with interferometry using the Schlieren photography method. Unfortunately, lighting difficulties forced us to simplify to a shadowgraph method. Figure 1 below, is my submission from our shadowgraph work.

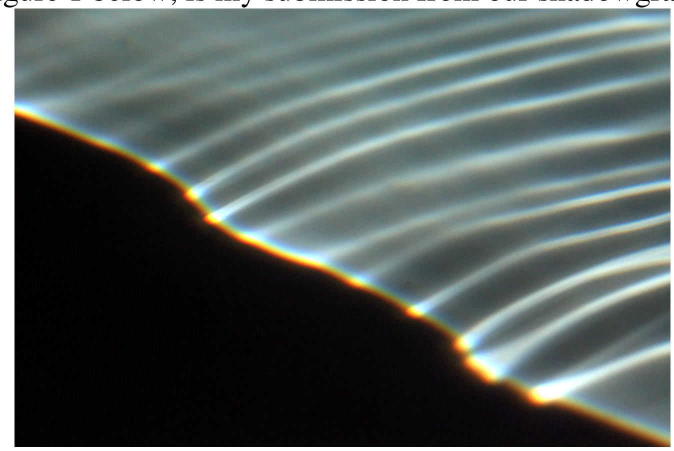

Figure 1. Water-Air boundary visualization

To produce our shadowgraph images, we placed unfiltered tap water in a glass, flat sided aquarium. The reservoir was inclined at an angle theta of 30 deg to the horizontal, with w=9.9" and h=8". The angle of inclination roughly corresponded to the solar angle of 33.7 deg on the day of shooting for 40 deg N latitude[1]. That angle placed the face of the tank normal to the incoming sunlight to minimize any bending of the sunlight by the glass. A dry erase board was placed directly below the tank as shown in figure 2 to project our images on. Though outside, filming was done in a courtyard below ground level to reduce any disturbance in the water surface by air movement. Instead, we generated waves with a flat paddle ~1/2 the tank width, placed in the water parallel to the sides. For the image in figure 1, the paddle was oscillated at ~.25ft/s generating waves of amplitude ~.125"; several waves are interacting in the image to produce the complex shape. At that speed, a single wave would traverse figure 1 in 1.17 sec, and shutter speed was 3 orders of magnitude faster than that allowing for good time resolution. The spatial resolution is acceptable as well, with ~288 pixels spanning the peak to peak wave height. Our choice to place the imaging surface on the horizontal was made to facilitate photography, but introduced distortion in the image proportional to the angle of inclination and the distance from the fluid surface.

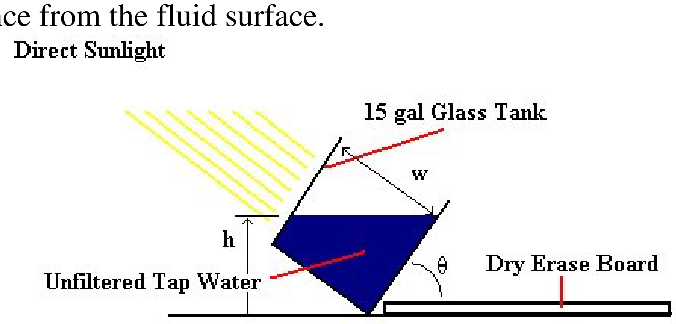

Figure 2. Schematic of system

The visualization method used for this image was a refraction technique. Specifically, we used the surface of water to bend light rays from the sun. This bending obeys Snell's law (equation 1 below) that relates the angles of incidence and departure (epsilon in figure 3) using the various indices of refraction. In our case of water at 20C n=1.333, and Air at STP n=1.0003[2].

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

Equation 1: Snell's Law

The basic optics of the shadowgram method are detailed in figure 3 below. Of particular interest to my submission is the parameter delta which describes a blurred region surrounding the projection. This region results from the fact that our sun is not a perfect point source and instead produces *nearly* parallel light that subtends an angle of ~.5 deg . This parameter delta can help explain the 'out-of-focus' appearance of figure 1. The blurred region is a function of the distance g from the fluid to the screen. We attempted to reduce the size of the blurred region by placing the imaging screen as close as possible to the fluid boundary. Interestingly, even with good temporal resolution and a short g, we experienced considerable haziness in many of our images.

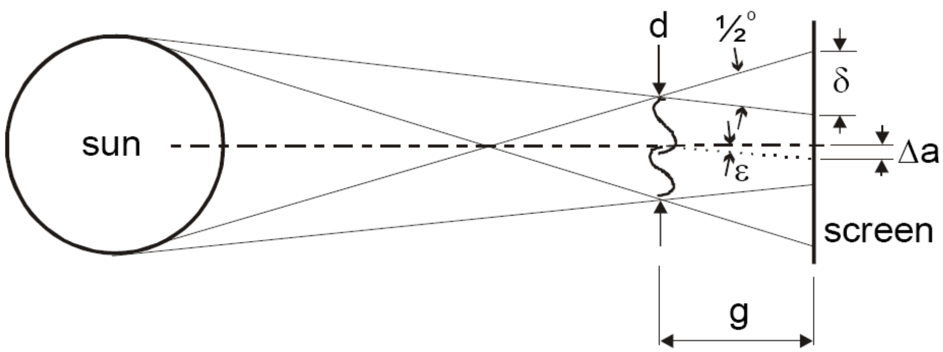

Figure 3. Diagram of sunlight shadowgram formation[3]

Consistent with the shadowgram method, our light source was the sun. In addition to addressing the solar angle, we rotated the tank about its long axis such that the ends of the tank were parallel with the incoming light. No flashes were used.

Vital statistics for this image:

Field of view:	~3.5” x 2.25”
Distance from object to lens:	~6”
Lens	28-135mm F/3.8-5.6 D
Lens focal length:	52mm, F-Stop 5.6
Camera used:	digital, pixel dimensions 3872x2592, Nikon D80
Exposure:	shutter speed (exposure time) 1/4000 sec, exposure compensation 0.0, ISO 800
Photoshop processing:	color curves were adjusted to increase contrast.

To me, this image is a poor representation of periodic wave action. There are reflected waves combining constructively and destructively generating a very chaotic surface that, is reminiscent of a staircase. Because of the number of waves interactions in the image I would argue that it can tell us little about the mechanics of the flow. Other images with standing waves were produced, which showed flow physics well, but offered less interesting composition. This project was a good introduction to refraction techniques, and armed with this experience we are all excited to attempt the Schlieren method again. For me, further investigation of the shadowgraph method would be most interesting using heated air, and would include quantitative determination of the effects of the blurring region.

Appendix:

1. *Earth-Sun Geometry Applet.*
http://cwx.prenhall.com/bookbind/pubbooks/lutgens3/medialib/earthsun/earthsun.html

2. *List of Refractive indices.* Wikipedia. October 2007
http://en.wikipedia.org/wiki/List_of_refractive_indices

3. Settles, Gary S. *Schlieren and Shadowgraph Inaging in the Great Outdoors.* Schlieren and Shadowgraph Techniques, Springer 2001.
http://www.mne.psu.edu/psgdl/psfvip2.pap.copyrightedimages.pdf