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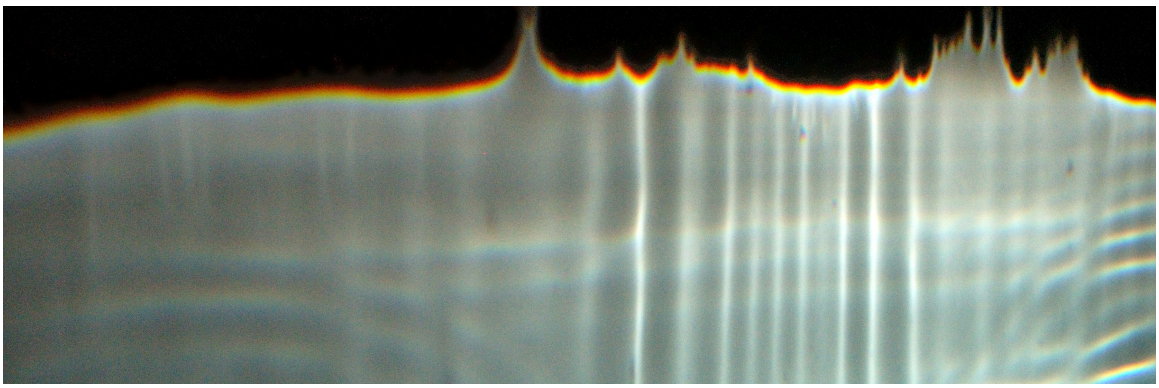
Flow Visualization
Group Project 2
Fall 2007



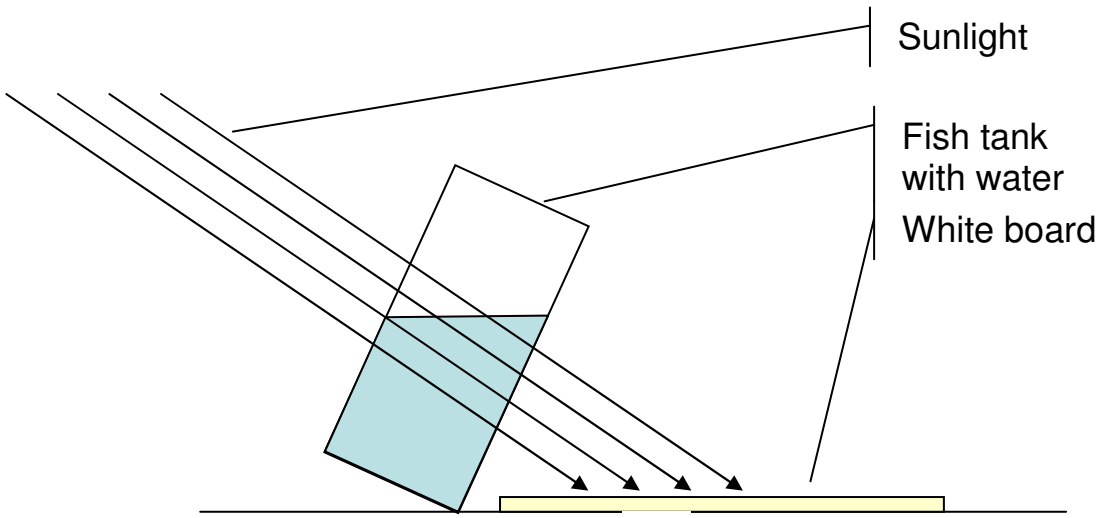
Context and Purpose

This image is a result of work by team alpha on the 2nd group project for the Flow Visualization course at the University of Colorado. The group has explored the shadowgraph flow visualization technique by use of water in a fish tank. Flow phenomena that were explored included both free surface physics of the water and the sheeting affect of water as it interacted with the side of the fish tank. This image demonstrates the second of these phenomena.

Flow Apparatus

Figure 1 shows the flow apparatus. A 15 gallon fish tank was filled about half full with water. This tank was placed in an outdoor area that had full sunlight. A clean white board was positioned upon the ground to serve as a canvas for the shadows to fall upon. The fish tank was tilted to an angle of about 30 degrees so that the shadows did fall upon the canvas and not under the fish tank. The fish tank was held in this tilted position by a person. This person tried various perturbation methods including dropping droplets of water onto the free surface, rocking the tank back and forth so that the total tilt varied by about +/- 5 degrees of the original 30 degree mark, and also tapping the sides of the fish tank in order to produce waves that propagated parallel to the sides of the tank. The water depth was about 9 inches, the shadows falling upon the white board covered a region of about 15 inches by about 24 inches. The flow in question is that of a thin film receding from tilted glass. The contact line between the glass and water takes on the shape of a wave form as the water is subject to both adhesion, or wetting forces, and the forces of surface tension and gravity that both attempt to pull the sheet of water back into the fish tank. The film is quite

Figure 1: Flow Apparatus



thin near the boundary, probably on the order of a few mils. The Reynolds number has been estimated to be about 3, the flow is believed to be laminar.

This phenomena is similar to those discussed in the literature. Specifically Neogi[1] discusses a phenomena known as tears of wine in which liquid wine is pulled up by surface tension, then beads, and falls back into the bulk liquid. In this case our fluid is water and there is not a large surface tension gradient to pull the liquid up the glass, instead our climbing mechanism was by way of forced waves in the tank that lapped up the side of the glass. The return mechanism, where the thin sheet of liquid pulls together due to surface tension and downward due to gravity is similar to the phenomena discussed by Neogi.

Visualization Technique

The technique employed for making images of free liquid water is shadowgraph. This technique enables the photographer to use a fixed focal length and focus setting in conjunction with a tripod to make images of shadows that have been projected upon some surface. In our case we utilized a plain whiteboard. This technique enables photography of thin, quickly moving fluids that would otherwise be difficult to focus and capture. Another benefit to shadowgraph is that the glare due to light reflection off of the surface of the water back into the camera is avoided. The white board can be chosen to be of low glare material. The lighting technique utilized was sunlight. The image was made in late fall in Boulder Colorado. The sun is low in the southern sky during this time of the year and provided a good angle for source light.

Photographic Technique

The image was made with a Nikon D80 digital camera. The camera was hand held at a distance of about 20" from the shadow that laid upon the ground. The angle from which the image was taken is somewhat oblique, such that the camera is pointed in a vector that intersects the ground at about a 45 degree angle. Shutter speed is 1/4000 second, focal length is 28mm. The field of view of the original image is approximately 2 feet by 1 foot. A non-oblique field of view at the same camera settings would be 1' 2" by 9.6", the oblique nature of the shot means that more field is contained in the image. The final image contains 2432x792 pixels that were cropped from 3872 x 2592 pixels. The estimated field of view for the final image is 8" x 4". The camera was set to an iso setting of 800. All detailed shooting data is included as Appendix 2. As mentioned earlier the final image has been cropped from the original. A rotation of 120 degrees clockwise (in order to make vertical flows vertical in the image) was also made. No color correction was made, but image levels were adjusted in order to stretch information over the range available. Some effort was also made to make the black region more black as it looked somewhat grainy in the original image. The magic wand was utilized to select this area. The area was subjected to a second image level correction. The area was then grown by 5 pixels and a median filter

[1] Neogi, P. (1985). Tears of Wine. Journal of Colloid and Interface Science, Vol 105, Number 1.

was run on the selection in order to soften the edge between the unmodified foreground and black background.

Image Impression

The image reveals both the power of shadowgraph techniques and some interesting fluid flow phenomena of water sheeting off of a glass surface. I like the colors and shapes in the image and find it artistically appealing. The image does an adequate job of showing the fluid physics, but not a fantastic job. This is the sort of image that makes you want to go back and investigate the situation more fully. It is an image that can spark interest and wonder. From a scientific point of view the image is somewhat confusing because the corners of the tank are not clearly marked and it is somewhat difficult to interpret the actual locations (on the tank) of some regions of the image. Further work could be done with the following improvements:

1) Camera angle optimized for image quality, not for number of photographers.
2) Utilize a tripod and an edge on the shadow canvas in order to fine tune focus once and for all. This technique would help the novice achieve optimal focus for every image.
3) Add some markers to the fish tank so that corners can be easily discerned in the image.
4) Try to control the forcing functions (droplet size and frequency, rocking tilt of the tank, frequency of tank tilt, etc.

Appendix 1: Reynolds Number Calculation

Property	Value
Water Viscosity[2]	8.90 x 10^-4 Pa*s
Density of water at 68 degrees Farenheit[3]	998 kg / m^3
Characteristic Length	50 microns
Mean Fluid Velocity	2 in/sec = .0508 m/s
Reynolds Number, Re	2.84

Appendix 2: Detailed Shooting Data

Nikon D80
2007/11/04 13:33:21
Compressed RAW (12-bit)
Image Size: Large (3872 x 2592)
Color
Lens: 28-135mm F/3.8-5.6 D
Focal Length: 28mm
Exposure Mode: Manual
Metering Mode: Multi-Pattern
1/4000 sec - F/5.6
Exposure Comp.: 0 EV
Sensitivity: ISO 800
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)

[2] Viscosity. (2007, November 5). In *Wikipedia, The Free Encyclopedia*. Retrieved 17:14, November 8, 2007, from http://en.wikipedia.org/w/index.php?title=Viscosity&oldid=169486818

[3] Density. (2007, November 8). In *Wikipedia, The Free Encyclopedia*. Retrieved 17:17, November 8, 2007, from http://en.wikipedia.org/w/index.php?title=Density&oldid=170120359