Shades

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I. Introduction

This report documents the techniques used to create a suspended soap film, as well as the physics and fluid principles that are involved. It will also describe the photographic techniques used to capture the image.

This project was the first of three team projects for the Flow Visualization Course at the University of Colorado at Boulder in the spring of 2012. The purpose of the assignment was to group engineers and art students and combine their disciplines, in order to visually produce a fluid phenomenon and capture it using the photographic technique of their choice.

II. Flow Apparatus

A soap film can be created using a bulk soap solution and suspending it across a framed apparatus, such as a hollow tube or glass. This is usually achieved by dipping the frame in the soap solution creating a layer or film of solution inside the frame. For this experiment a pair of disguise glasses were used and dipped into the solution. The vibrant and varying colors can be achieved using an angled light source and an angled line of sight. The original image was captured using the experiment set up in **Figure 1**.

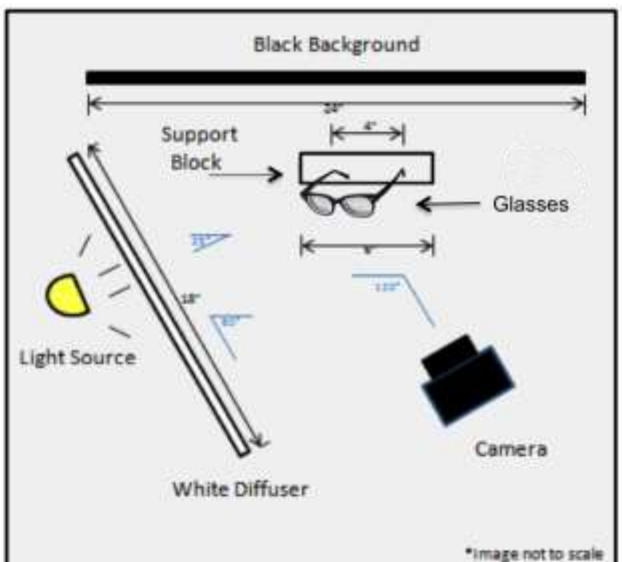

Figure 1: Experiment setup

The physics in the image are caused by interference and thickness variations of the soap film. Gravity creates flow due to its affects on anion molecules in the soap solution. Anion molecules are made of a hydrocarbon chain that is both hydrophobic and hydrophilic [1]. The colors in the image are a result of angled light reflected off of the surface of the film. According to Isenberg, 4% of the light will be reflect off the surface of the film and 4% through the inner surface, the rest simply passes through and is not visible [1]. A graphical explanation of the reflection and refraction phenomenon can be found in **Figure 2.**

The phase difference d is related to the thickness of the film T for a given wavelength λ at a constant angle of refraction θ for a fluid with a refraction index μ by:

$$d = 2\mu T\cos(\theta) + \frac{1}{2}\lambda$$

The film has an index of refraction that is greater than 1 ($\mu_{\text{film}} > 1$), while air has an index refraction equal to 1 ($\mu_{\text{air}} = 1$). There will be a 180° phase shift in the reflected wavelength due to the refractive index of air being less than the film's index of refraction ($\mu_{\text{air}} < \mu_{\text{film}}$). The interference of reflected light on the soap film can be either constructive or destructive [2]. Most of the destructive interference is what is actually visible in the image. The interference can be found by:

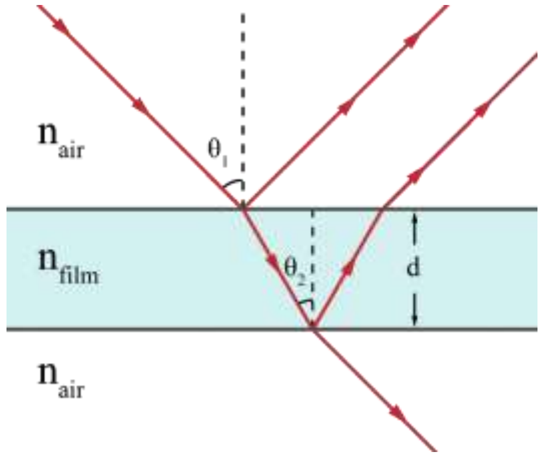

Figure 2: Light reflection and refraction through a soap film. (Wikipedia)

Constructive interference:

$$2n_{\text{film}}\,T\cos(\theta_2) = (m - \tfrac{1}{2})\lambda$$

Destructive interference:

$$2n_{\text{film}}\,T\cos(\theta_2) = m\lambda$$

Where T is the thickness of the film, n_{film} is the refractive index of the film, θ_2 is the angle of incidence of the wave on the lower boundary, m is an integer, and λ is the wavelength of light.

In this image the soap film thins as gravity convection takes effect. The thin black and silver layer at the top of the image is where the film is at its thinnest [3]. As you move down the colors represent varying thickness as they flow to create a uniform thickness across the frame. The thickness of the film in this image is estimated to be from 300nm down to 100nm.

A bond number, or buoyancy force divided by surface tension force, is expressed as:

$$E_o = \frac{\Delta\rho g L^2}{\sigma}$$

Where E_o is the bond number, Δp is the difference in density or the two phases, g is the gravitational acceleration, L is the characteristic length, and σ is the surface tension. Calculating a bond number can be used to characterize the shape of bubbles moving in a fluid [4].

III. Visualization Technique

The suspended soap film was created using a solution including parts of Ajax dish soap, glycerin, and water, the amounts are described in **Table 1**. This solution can create a film when spread across a framed apparatus, such as a hollow tube, a glass, or in this case eye glasses with no lenses. The colors seen in the image are created using a combination of effective angles of a light source and the viewer's line of sight.

Component	Amount
Ajax® dish soap	5 ml
Glycerin	44 ml
Water (H_2O)	120 ml

Table 1: Soap film solution

In order to achieve the desired lighting, a flexible neck desk lamp, fitted with a 40W light bulb, was placed and diffused across a 3mm thick white plastic 15cm away. This gave the photo a smooth even light source and minimized glare. The diffuse light was placed at approximately 60° from horizontal against a black poster board background. An aluminum block was used to support and level the glasses in a stationary position. The block was then covered with a piece of black velvet and placed 7.5cm directly in front of the poster board. The camera was placed on a tripod, 20cm away from the block, at an angle of approximately 120° from horizontal.

The disguise glasses were then placed in the soap film solution created earlier, creating a soap film lens for the disguise. The glasses were then placed approximately level using the aluminum block as a support. An animation of the complete experiment setup can be found in **Figure 1** earlier in this report.

IV. Photographic Technique

An 18.1-mega pixel DSLR camera was used and captured a RAW image of 5184 x 3456 pixels. The camera was a Canon EOS Rebel T2i body, housing the high resolution CMOS sensor, with a Canon EFS 18-55mm f/3.5-5.6 IS II lens [5]. The camera was focused manually and custom exposure settings were used including shutter speed, aperture, and ISO. A relatively fast shutter speed of 1/60s and an aperture value of f/4.5 were chosen to quickly capture the moving flow, minimizing distortion that maybe caused when photographing moving objects. A high ISO of 3200 was used to compliment the shutter and aperture values and also due to the low light level that was provided. The camera's focal length was 37.0mm. The final image was 54.86 x 36.58cm, giving a resolution of 94.48 pixels/cm. The RAW image is seen in **Figure 3**.

Figure 5: Raw image. Size: 5184 x 3456 pixels

Post processing was then done using Adobe Photoshop CS5 and adjustments were performed to enhance subtle qualities and produce the final image. First, a copy layer was made of the image and the original was turned black and white. Now, imagine a color picture placed directly on top of a black and white copy. Layer masking, a technique used to remove part of an image to reveal the bottom layer, was then applied. In this case, parts of the top (full color) image were erased, surrounding the colorful soap lenses, revealing the black and white the image below. Next the tonal curves of the image were adjusted (**Figure 6**) to bring out shading and color qualities by brightening light colors and deepening the darks. The brightness of the image was brought down to -8, to minimize background noise from the velvet as well as the glare in the left soap film lens. These adjustments produced the very pleasing image and focused the viewer's attention to the soap film. The canvas size was adjusted on the left and top side to position the image to the bottom right of the frame.

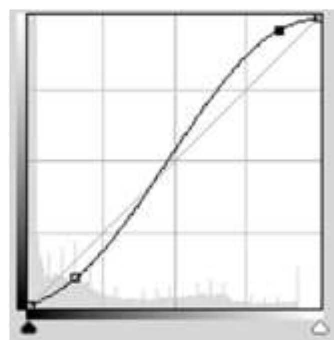

Figure 6: Tonal Curves

V. Image Analysis

The final image is seen below in **Figure 7**. The image effectively reveals the fascinating soap film interference physics involved in a unique and intriguing way. Intent was achieved and I feel this image would make a great piece of art, if it was printed and framed. The vibrant and colorful soap film is complimented by the black and white surroundings. I really enjoy the colors and the shape of the flows, they are very vibrant and seem to pop out right out of the photo. I would like to make some more adjustments in post processing to remove some glare in the left lens, this would require further developed Photoshop skills.

Figure 7: Final edited image

References:

[1] Icenberg, C. (1992). The science of Soap Films and Soap Bubbles. Toronto, Ontario, Canada: General Publishing Company, Ltd.

[2] Yang, T.S., Wen, C.Y., & Lin, C.Y. (2001). Interpretation of Color Fringes in Flowing Soap Films. *Experimental Thermal Fluid Sciences* (25), 141-149

[3] Couder, Y., Chomaz, J.M., & Rabaud, M. (1989). On the Hydrodynamics of Soap Films. *Physica D* (37), 384-405

[4] Wikipedia: The Free encyclopedia. “Thin-Film_Interference”. Web. <http://en.wikipedia.org/wiki/Thin-film_interference>.

[5] Canon U.S.A. “Consumer & Home Office.” EOS Rebel T2i EF-S 18-55IS II Kit. Web. <http://usa.canon.com/cusa/consumer/products/cameras/slr_cameras/eos_rebel_t2i_ef_s_18_55is_ii_kit>.