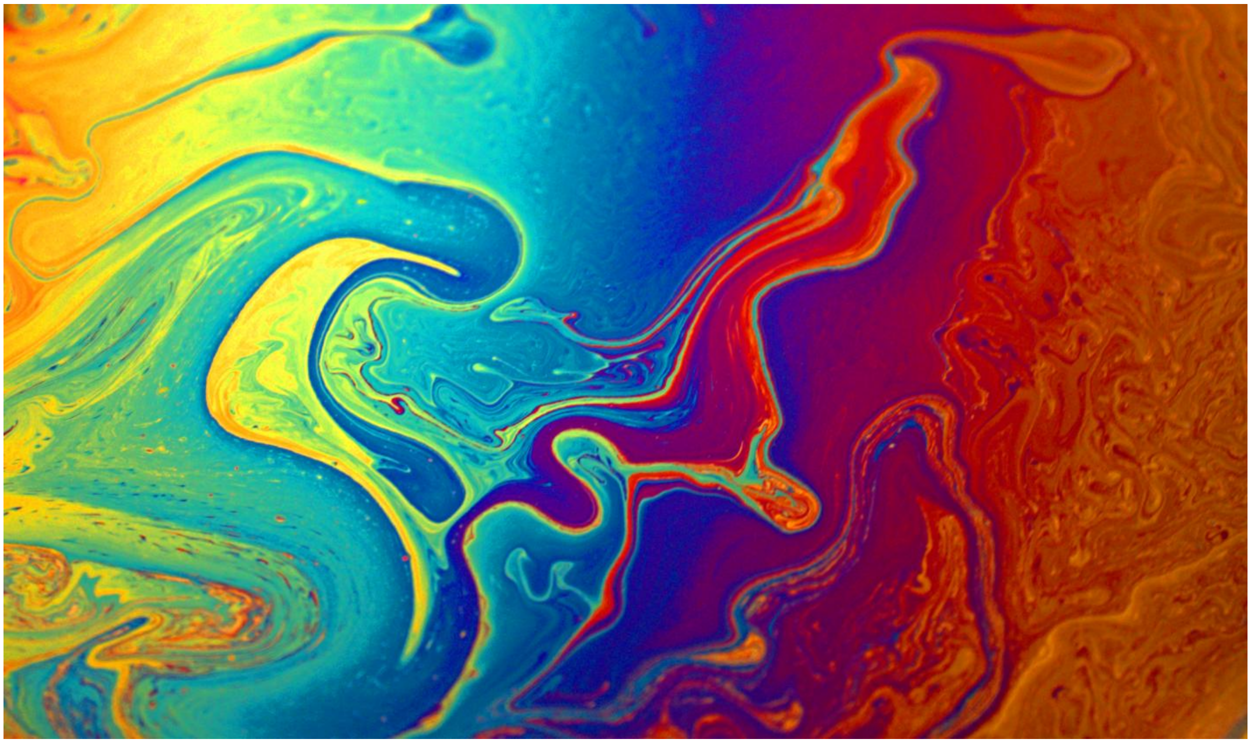
Group Project #1 – Soap Film Interference



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MCEN 4151
Professor Hertzberg
3/20/2012

Purpose

The purpose for this visualization was for the “Group Project #1” assignment assigned in the Flow Visualization course given at the University of Colorado – Boulder, led by Professor Hertzberg. The goal of the “Group Project #1” assignment was to display the physics of fluid flow in both an experimental and artistic way. It was my intent to display the interference patterns within a thinning soap film in a focused and appealing way.

Team

For this assignment, I was assigned to Group Delta, consisting of the following members

1. Ryan Kelly
2. Andrew Fish
3. Doug Schwichtenberg
4. Nicholas Travers
5. George Seese

Materials

For this representation, the team chose to use several materials that can be easily found at a local hardware store. This was done to allow the reader an easier way of replicating the team’s results for future endeavors. The materials were as follows:

1. Water
2. Ajax Triple Action Orange soap
3. Glycerin
4. 40 W light bulb
5. 1/8” white plastic
6. 4” diameter bubble ring
7. 2x 6”length x 1”width x 1”depth aluminum supports
8. 2’length x 1’height black paper background
9. 1’length x 1’height black velvet background
10. Canon EOS REBEL T2i DSLR Camera

Procedure

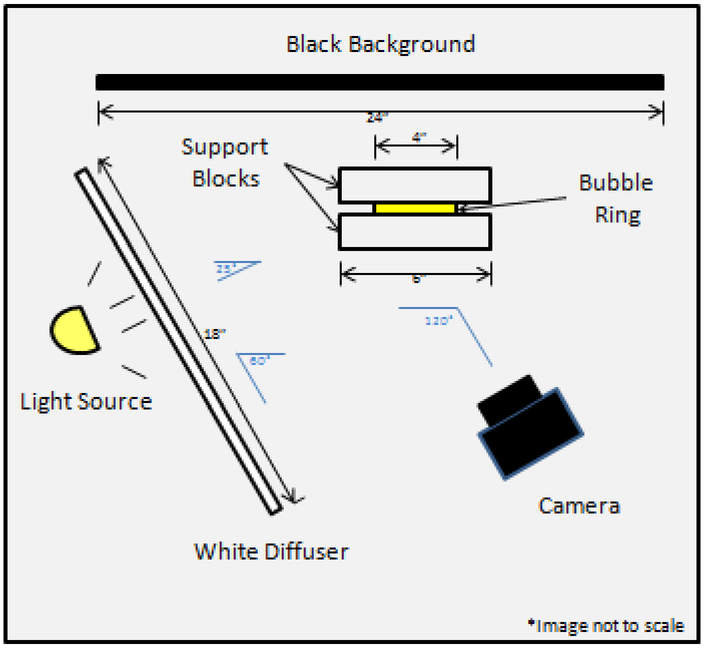

Figure 1: Experiment Setup

The full experiment setup can be seen in Figure 1 above. To setup this experiment, the team setup the two aluminum block supports on a table, and placed the black velvet background on them to eliminate the blocks from the image. A black paper background was then placed 3” behind the supports. A light source was placed 1’ away from the supports at an angle of 25°. The white plastic diffuser was placed 1” away from the light source at approximately a 60° angle from horizontal. The camera was then placed on a tripod 6” away from the support blocks at roughly a 120° angle from horizontal (angle varied due to finding the correct lighting).

The bubble solution was then made by mixing 1 cup of water with 2 tsp of Ajax and 9 tsp of glycerin. The team then placed the bubble ring within the solution, forming a large bubble.

To start the experiment, I initially held the ring upside down. The team allowed 15 seconds to pass. At this time it was evident that the bubble film was thinning out at the top of the film, showing a gray/silver color/horizon. When this color spread to half of the film, I slowly rotated the bubble ring to its upright position, and placed it in between the two aluminum supports, compressing the supports to ensure that the bubble ring would remain still. The team then waited briefly for the differently colored horizons of the film to merge with the silver horizon just above them. As this happened, the mixture of the horizons created a turbulent-like flow, creating intricate mixing, colors, and motions.

Fluid Dynamics

The physics theme displayed in this image is interference within the soap film. The interference physics are created when the soap film is spread over a large area and generates flow within the film that leads to thickness variations. When diffuse light is shined upon the vertical soap film at the proper angle, in our case 25°, these thickness variations can be viewed, revealing the interference phenomena in all its glory. Approximately 4% of the incoming light will reflect off of the outer surface of the film, while the remainder of the diffuse light will be refracted through the surface, with 4% of the remainder reflecting off of the inner surface of the soap film[1]. The air in which the light travels has a refractive index of 1 ($n_{air} = 1$) and the film has an index of refraction that is larger than 1 ($n_{film} > 1$)[2]. The reflection that occurs at the upper air-film boundary will show a 180° phase shift in the reflected wave because the refractive index of air is less than the index of the film. The light that is transmitted at the upper air-film boundary will continue towards the lower air-film boundary where it can also be reflected. Because the refractive index of the film is greater than the refractive index of air, the reflection that occurs at the lower air-film boundary will not change the phase of the reflected wave. When these light rays encounter the interference within the soap film, the wavelength of the rays either lessen or intensify creating constructive interference[2]:

$$2n_{film}d\cos(\theta_2) = (m - \frac{1}{2})\lambda$$

and deconstructive interference[2]:

$$2n_{film}d\cos(\theta_2) = m\lambda$$

Figure 2 below displays how air and light reflect upon a soap films surface.

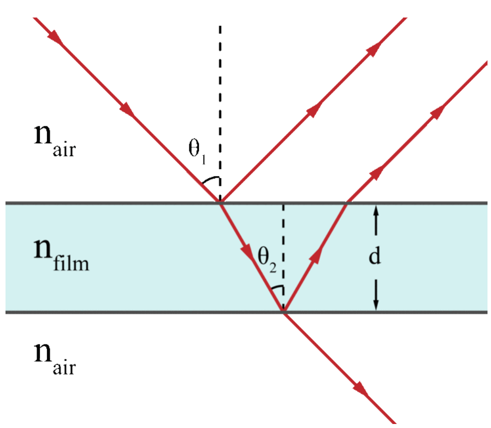

Figure 2: Light Incident on a Soap Film[2]

The film thins as it expands outward, and most of the wavelengths can be seen as deconstructive wavelength. The image that the team shot shows the phenomena of the interaction between the two distinguished wavelengths and thicknesses, with the yellows and reds displaying thicker sections of the film, and the blues and purples displaying thinner sections of the film.

The flow shown in the image shows a mixing of different thicknesses of soap film. This mixing is produced primarily from gravity convection as well as the added circular flip motion that the team chose to use as explained in the procedure section. The reason why these different thicknesses try to merge is to reach a state of equilibrium, granting equal thickness across the entire soap film. This can be seen as surface tension physics. The team chose to use the circular flip motion to produce the very thin silver horizon at the top (approximately 100 nm thick)[3], that when flipped, accelerated the gravity convection and displayed even greater mixing.

It is also important when analyzing the effects of surface tension to calculate what is known as the Eötvös Number aka the Bond Number, which represents the ratio of gravitational force to surface tension force[4]. The equation can be seen below[5]:

$$B_o = \frac{\Delta \rho a L^2}{\gamma}$$

where $\Delta\rho$ = density difference between soap and water, a = gravity, L = characteristic length (bubble wand radius), and γ = surface tension of solution. To solve this equation we must first find the surface tension of the solution. This equation can be seen below[6]:

$$\gamma = \frac{\gamma_w}{3}$$

where γ_w = surface tension of water.

Soap decreases the pull of surface tension when soap and water are combined to form a solution, typically to about a third of plain water[6]. After research, γ_w = 72 dyne/cm = 0.072 kg/s^2 [7]. When applying this value to the equation, we get a value of γ = 0.024 kg/s^2.

The next step in calculating the Bond Number is finding the density difference between the soap and the water in the solution. After research, ρ_{water} = 998.2 kg/m^3 [8], and ρ_{soap} = 932 kg/m^3 [9]. The difference between the two densities is calculated as $\Delta\rho$ = 66.2 kg/m^3.

With all variables calculated, they can now be applied to the Bond Number equation:

$$B_o = \frac{\left(66.2\ \frac{kg}{m^3}\right)\left(9.8\ \frac{m}{s^2}\right)(0.0508\ m)^2}{0.024\ \frac{kg}{s^2}} = 69.759$$

With a value of 69.759 for the Bond Number, the team can conclude that the system is relatively unaffected by surface tension forces.

Photo Technique

For this experiment, the team chose to use Doug Schwichtenberg's Canon EOS REBEL T2i with 18-55 mm kit lens DSLR camera as it proved to be the best camera for capturing the intricate physics. The field of view for the original photograph is 7 inches in height by 10 inches in width, and for the finished photograph is 3 inches in height by 3.5 inches in width (final image displays a 90° rotation). The distance from the soap film to the camera was 6 inches. The dimensions for the original photo are 5202 pixels in width by 3465 pixels in height, and for the finished photo are 2120 pixels in width by 1248 pixels in height. The horizontal and vertical resolution was 96 dpi. The f-stop was f/4, with an exposure time of 1/50 of a second, ISO of 640, a focal length of 27 mm. I used the GIMP 2 software to perform editing on the image. There's a tutorial on YouTube explaining how to make your images appear as if they were shot as a HDR image[10]. This tutorial had me download a patch for GIMP 2 known as Dodge and Burn[11]. I found that this process made the image more vivid and pleasing to the eye. Once this editing was complete, I cropped the image.

Conclusion

It was Team Delta's objective of the "Group Project #1" assignment to display interference physics themes in an artistic yet scientific way. I believe the team effectively shows the concepts of interference physics, and its relation with soap films. The team created images that are appealing to the eye, creating interest and intent to know more on the reader's part. In the future, I would like to perform this experiment with intent of displaying the critical fall phenomena within the soap film. I would also like to take a digital video of the phenomena to display its unique active mixing and motions

Original Image

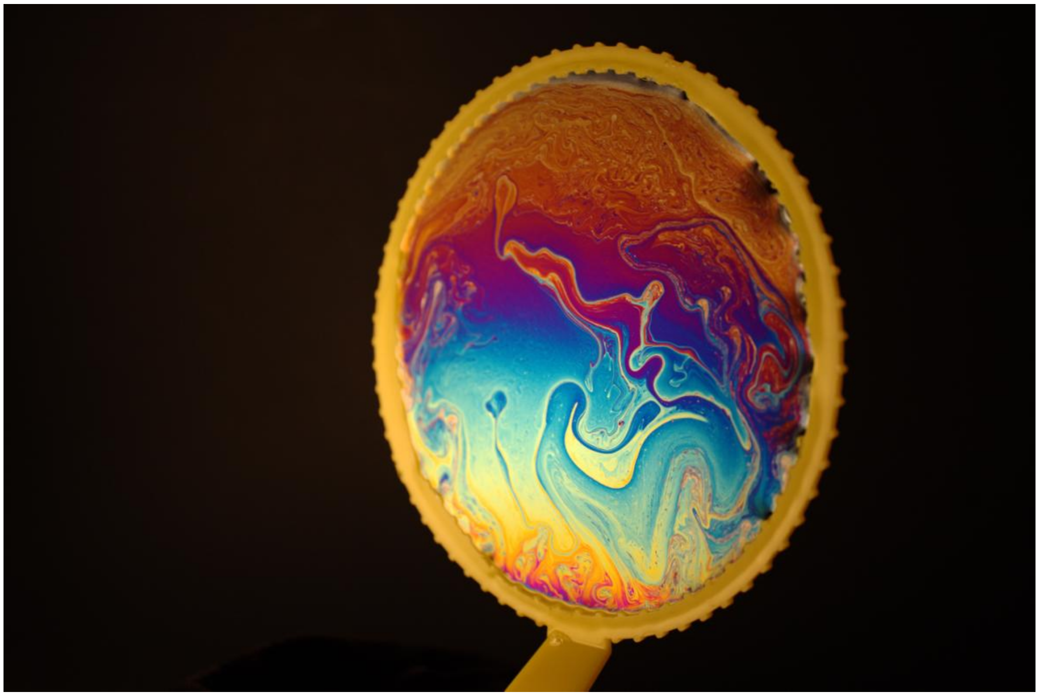

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Image Assessment Form

Flow Visualization

Spring 2010

Name(s): Ryan Kelly

Assignment: Group 1 Date: 3/20/2012

Scale: +, ! = excellent √ = meets expectations; good. ~ = Ok, could be better. X = needs work. NA = not applicable

Art	Your assessment	Comments
Intent was realized	!	
Effective	!	
Impact	!	
Interesting	!	
Beautiful	!	
Dramatic	!	
Feel/texture	!	
No distracting elements	!	
Framing/cropping enhances image	!	

Flow	Your assessment	Comments
Clearly illustrates phenomena	!	
Flow is understandable	!	
Physics revealed	!	
Details visible	!	
Flow is reproducible	!	
Flow is controlled	!	
Creative flow or technique	!	
Publishable quality	!	

Photographic technique	Your assessment	Comments
Exposure: highlights detailed	!	
Exposure: shadows detailed	!	
Full contrast range	!	
Focus	!	
Depth of field	!	
Time resolved	!	
Spatially resolved	!	
Clean, no spots	!	

Report		Your assessment	Comments
Describes intent	Artistic	!	

	Scientific	!	
Describes fluid phenomena		!	
Estimates appropriate scales	Reynolds number etc.	!	
Calculation of time resolution etc.	How far did flow move during exposure?	!	
References:	Web level	!	
	Refereed journal level	!	
Clearly written		!	
Information is organized		!	
Good spelling and grammar		!	
Professional language (publishable)		√	
Provides information needed for reproducing flow	Fluid data, flow rates	!	
	geometry	!	
	timing	!	
Provides information needed for reproducing vis technique	Method	!	
	dilution	!	
	injection speed	!	
	settings	!	
lighting type	(strobe/tungsten, watts, number)	!	
	light position, distance	!	
Provides information for reproducing image	Camera type and model	!	
	Camera-subject distance	!	
	Field of view	!	
	Focal length	!	
	aperture	!	
	shutter speed	!	
	film type and speed or ISO setting	!	
	# pixels (width X ht)	!	
	Photoshop techniques	!	
	Print details		
	"before" Photoshop image	!	