Sheet to Mist: A Study of Fluids Responding to Rapid Energy Change

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Context and Purpose

I took this image while attempting to get an entirely different photograph. I was originally attempting to capture how a fluid in a glass is drawn up and out by a high velocity stream directly above (The Bernoulli effect). Instead of capturing this phenomenon, the glass I was using shattered, and I ended up with an entirely different image. To highlight the different fluids in the experiment, I used red fluid in the stationary container, and blue fluid as the high velocity fluid. This photo was extremely dramatic, so I decided to use it as my final photo. I ended up using post-processing to make the photo as striking and provoking as possible.

Visualization Technique

To obtain this image, I used a high-pressure air cannon, a wine glass, and dyed water. The water in both the cannon and the wine glass was dyed at a dilution of 32 drops per cup for a dark solution. Blue water filled the barrel of the air cannon, which was pressurized to 100 psi. The air cannon pressure chamber has an approximate volume of 82 in^3 , and the barrel has an approximate volume of 32 in^3. The air cannon's valve is a modified irrigation sprinkler valve. The wine glass was filled with the red dyed water, and was taped down to a large wooden board to prevent movement of the glass during the shot. A white translucent backdrop was placed behind the scene, and a strobe was aligned to flash through the backdrop, backlighting the scene. The air cannon was on the left of the scene, shooting from left to right, and a flash trigger was placed on the right of the scene.

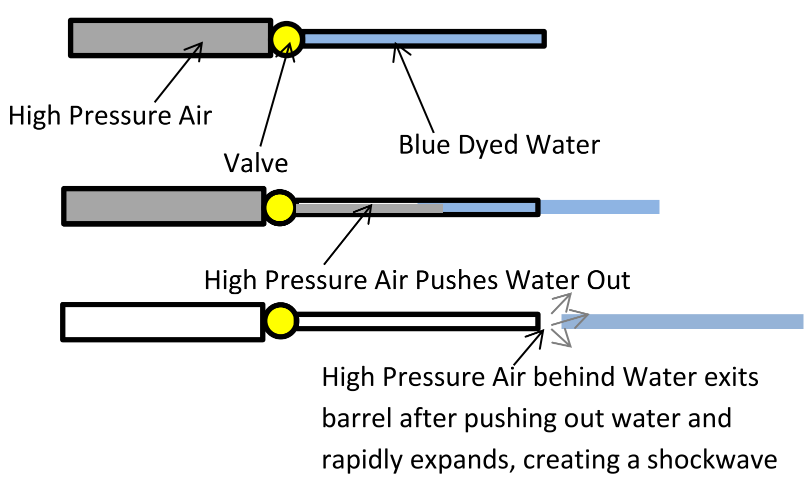
Flash Trigger Construction and Implementation

The flash trigger is a composite film of aluminum foil and wax paper. To construct the trigger, two pieces of similar sized aluminum foil are cut. Next, a piece of wax paper that is larger than both of the aluminum foil pieces is cut out. Next, the wax paper is sandwiched between the two pieces of aluminum foil so that the two pieces of aluminum foil do not touch. The whole trigger is then ironed together on high heat so that the composite layup binds together.

The flash trigger is then placed normal to the projectile vector of the air cannon. Leads are connected from each foil layer to the ground and trigger contacts on the strobe. When a projectile pierces the trigger, the foil pieces contact, and the strobe trigger circuit is completed, firing the strobe. In this photo, the strobe was triggered twice. The first flash occurred when the first stream of water ruptured the trigger, and the second flash occurred when the expanding air shockwave pushed water between the two leads, connecting the circuit a second time.

Further Explanation of Air Cannon Shockwave

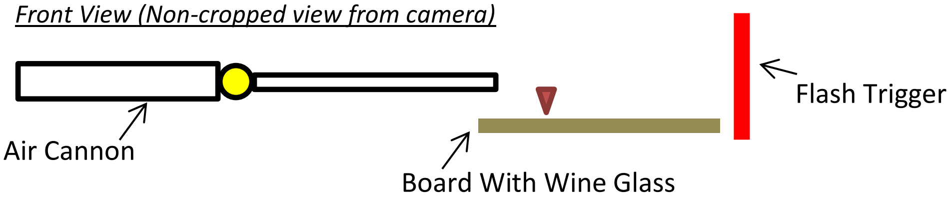
The air cannon shockwave was formed as shown below:



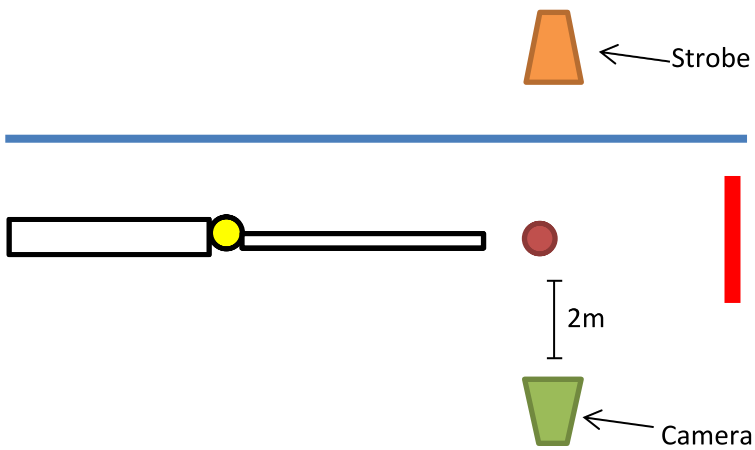
I believe this is what caused the glass to shatter, as the cannon made a loud explosion noise once the water was expelled completely, and the glass shattered directly after that event.

Explanation of Full Setup

Front View (Non-cropped view from camera)



Top-Down View



Approach and Flow Explanation

This image was a double exposure, so it displays fluid sheeting as well as the breakup of the sheet due to turbulence. Using a simple hand chronograph, I have measured projectiles travelling at 300 feet per second at the muzzle. Since the Barrel was full of water, I estimate the column of water was travelling at half that speed, and the shockwave propagated at roughly the speed of sound. First, it is known that a fluid sheet will finger out and eventually break up due to turbulence and instability. [1] The first (lightly-exposed) image shows the fluid sheeting out on the lower left had corner of the image, and the second (darker-exposed) image shows the sheet breaking up shortly thereafter. The wavelength of the fingering can be calculated using an equation from Bruyn, Habdas, and Kim:

$$l = \frac{H}{(3 * Ca)^{\frac{1}{3}}}$$

$$Ca = \frac{nU}{\gamma}$$

H = Depth of film = .001m
Ca = Capillary Number
n = viscosity of fluid = 1 N s/m^2
U = Fluid velocity = 300 m/s
γ = Surface Tension = approximate at .001 J/m^2

$$Ca = \frac{1 * 150}{.001}$$

$$l = \frac{.001}{(3 * Ca)^{\frac{1}{3}}}$$

$$l = .00001\ m$$

$$l = .01\ mm$$

This answer makes sense, as the fluid sheet is travelling extremely fast, and will subsequently essentially vaporize itself. This can be seen in the second exposed image as a light fine red mist.

Photographic Technique

To take this photo, I used an 18 MP Canon T2i DSLR. The lens I used was a 50mm 1.8. To get the drops in focus, I used manual focus to get the wine glass in focus. To hit the sweet spot for sharpness of the lens, I set my aperture to 6.3. To minimize noise, I set the ISO to 100. I used a longer shutter speed so that I could depress the shutter and then fire the air cannon. Since the environment was dark, the image was only exposed when the strobe fired. The original image was 3456 x 5184 px. I cropped the image slightly to 3336 x 5072 px to highlight the flow. I kept post-processing to a minimum. Mainly, contrast was increased to make the slightly overexposed first image stand out, and the image was color-corrected to make image as close to real-life as possible. The raw unedited image is shown as image 1 in the appendix.

Conclusion

Overall, I like this final image. While this image was not what I was aiming for at all initially, I really like the dramatic outcome. I hope to re-create this image in the daytime and film it with my high speed camera to get more accurate speeds on the fluid as it propagates from left to right and to observe the fingering instability into mist.

Works Cited

[1] de Bruyn, John R., Piotr Habdas, and Stella Kim. "Fingering instability of a sheet of yield-stress fluid." *Physical Review E* 66.3 (2002): 031504.

Appendix

(Image 1)