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Flow Visualization Video 1 – Laminar Flow from a Balloon

For my first project I decided to shoot a slow-motion video of laminar flow shooting out of a balloon filled with water. Being a mechanical engineering student with a sparse knowledge of cameras, I was intent on choosing a flow technique that was interesting and that I was familiar with from my fluid mechanics' course. I find laminar flow interesting and understand the math behind it fairly well, and so I was excited to try and capture this cool fluid phenomenon.

Laminar flow is fluid flow that travels in smooth paths where each streamline is parallel to the next. In other words, the fluid is not turbulent. When viewing perfect laminar flow, the fluid can look like glass, frozen in the air even though it is flowing. Laminar flow can be characterized by the Reynold's number which is shown below:

$$Re = \frac{\rho u L}{\mu}$$

Figure 1

ρ = density of the fluid

u = velocity of the fluid

L = characteristic length

μ = dynamic viscosity of the fluid

The figure below illustrates the difference between laminar and turbulent flow:

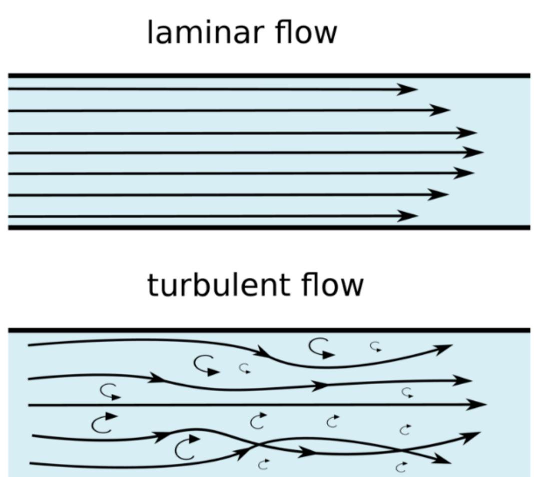

Figure 2

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In the case of fluid flowing through pipes (and my experiment), the characteristic length is equal to the diameter of the pipe. For laminar flow the Reynold's number must be less than 2300 (Re < 2300). Turbulent flow is described as Re > 4000 and anything in between 2300 and 4000 is in a transitionary zone. With this knowledge, it was crucial that I design my experiment so that I kept the Reynolds number below 2300. My inspiration for my experiment setup came from a Smarter Every Day YouTube video where the host, Destin, shows an experiment where he is able to create laminar flow out of a balloon. A sketch of my experimental setup is shown below:

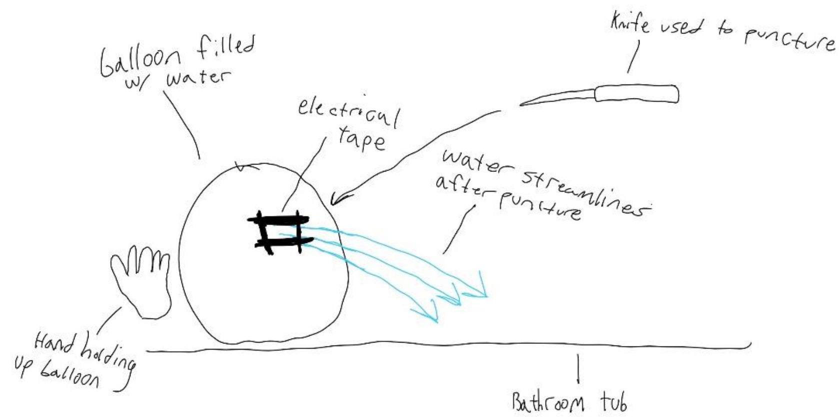

Figure 3

The setup steps are as follows: I first filled up a black 12" party balloon with room temperature water and glitter. I then tied up the balloon and used four strips of electrical tape to mark out a square on the balloon with a diameter of about an inch. I set up the balloon in my bathtub and had my roommate hold the balloon while I prepared to set up my camera for the shot. I used an iPhone 12 shooting in 240 fps for the shot. Once I was ready and recording, I had my roommate stab the area marked out by the electrical tape. The flow began, starting out as turbulent while it was making contact with the knife. Quickly, as the flow became fully developed, the water became laminar. The laminar flow lasted for a few seconds and then died down as the pressure within the balloon lowered enough to where the water was slowly sputtering out.

The purpose of the glitter within the balloon was so that I would be able to track a piece of glitter over enough frames that I could then calculate the velocity of the water. Knowing the density of water is 998 kg/m^3, the dynamic viscosity is 1.0016 mPa*S and the diameter of the puncture was 1'', I would be able to calculate the Reynold's number with the velocity. However, the glitter would not show up in the shot and so I could not track the velocity with this method. Since the flow was laminar I do know that the Reynolds number was equal to or less than 2300. With a simple analysis I can estimate the maximum velocity that the water could be for the flow to remain laminar.

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$$Re = \frac{\rho u L}{\mu}$$

$$Re \leq 2300 \qquad u \leq Re * \frac{\mu}{\rho L} \rightarrow u \leq 0.0909\ m/s$$

After converting my numbers into the proper units and solving for velocity, the velocity of the water could have a max velocity of 0.0909 m/s to remain laminar.

As for visualization techniques, I did not do anything crazy. As explained earlier, I placed glitter in the balloon in the hopes that I could capture the glitter flowing out. Not only would this be visually appealing, but I would have been able to calculate the velocity of the water. I also put glitter on the surface of the balloon to add more color to my shot and to draw the viewer in to the where the water was exiting the balloon. Without the glitter I think my setup would have been rather boring, so I am glad I added it. The lighting I used was the overhead light that is installed in my bathroom. I opted to not use camera flash, however in retrospect I wish I had. The overhead bathroom light operates at a much lower frequency than my camera was shooting at so you can see a lot of flickering in my video. I really wish I had foreseen this and provided lighting that mitigated the flickering. Perhaps the camera flash would have helped.

My shot includes about ¾ of the balloon on the left quarter of the frame with the rest of the space occupied by the flow of the water and the bathtub in the background. The size of the field of view is just a couple of square feet. The distance from the camera to the balloon is about six inches. I chose this way to shoot my video because I wanted most of the shot to be taken up by my subject, the laminar flow of the water. I only included ¾ of the balloon because I didn't want to capture my roommates' hand in the shot. I also wanted to be close enough to the water flow so the viewer could clearly see the laminar flow. The camera I used was an iPhone 12 shooting in 240 frames per second with automatic exposure and focus settings. I think this worked really well for a slow motion shot. In terms of editing, all I did was increase the color saturation a little bit in order to make the water more visible. I did this on my iPhone. Finally, I added some relaxing music that I felt worked well with the tempo of the shot.

My final product captures the fluid phenomena of laminar flow exiting a balloon in slow motion. I think the flow technique was experimentally executed well and captured fairly adequately. I don't like the contrast in my shot between the water and the background of the tub. The water would have been captured more clearly if I used a darker background to create separation in colors between the water and tub. I also do not like the flickering in my shot caused by my choice of lighting. If I could recreate the shot I would use a much higher frequency bulb and possibly camera flash to mitigate the flickering and really bring out the water flow. All that being said, I am happy with what I was able to capture for my first project.

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Citations:

Figure 2: https://www.cfdsupport.com/OpenFOAM-Training-by-CFD-Support/node334.html

Laminar flow and Reynolds number sources:

Munson, Bruce R. *Fundamentals of Fluid Mechanics*. Wiley, 2013.

https://www.simscale.com/docs/simwiki/numerics-background/what-is-the-reynolds-number/

https://en.wikipedia.org/wiki/Reynolds_number

Number for kinematic viscosity of water:

https://www.engineeringtoolbox.com/water-dynamic-kinematic-viscosity-d_596.html

Number for density of water:

https://www.sigmaaldrich.com/US/en/product/sial/denwat