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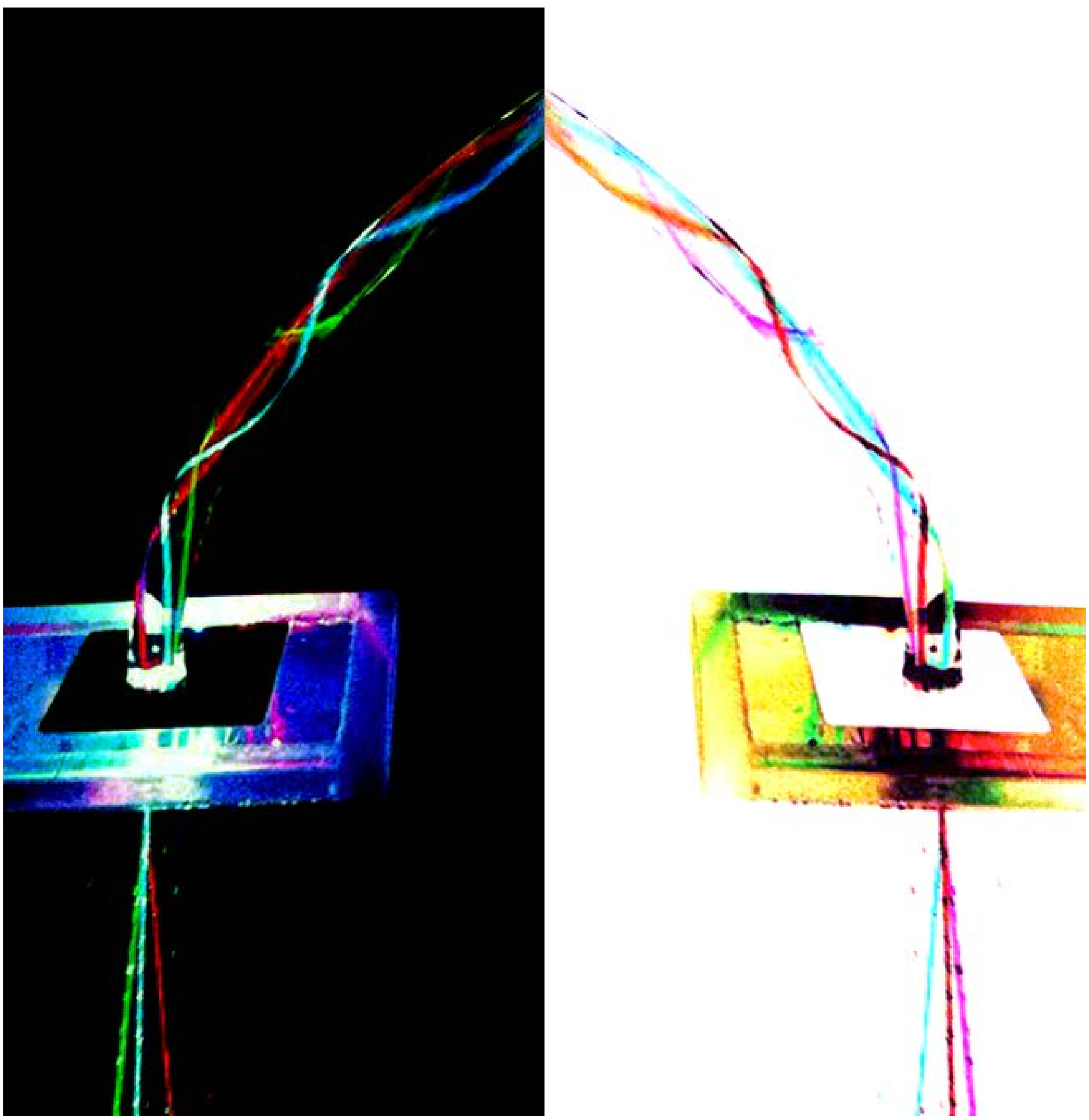
FLOW VISUALIZATION

MCEN 4151

"Total Internal Reflection"



The image was my submission for an initial team assignment in the course Flow Visualization MCEN 4151. Capturing and creating the image allowed us to practice our photography and photo editing skills, along with furthering our understanding of physics and dynamics. I worked with Chris Francklyn, Jiffer Harriman, Faith Batrack, and Lindsey Yarnell to create the image. Michael Thomason and the Physics Dept. at the University of Colorado, Boulder, provided equipment support. The intent of the image was to capture the phenomenon of the internal reflection of light in a laminar liquid flow, then present the image in a way that was interesting, while still capturing the physics that were occurring. It was also my intent to create an image that compelled the viewer to learn more about the physics involved.

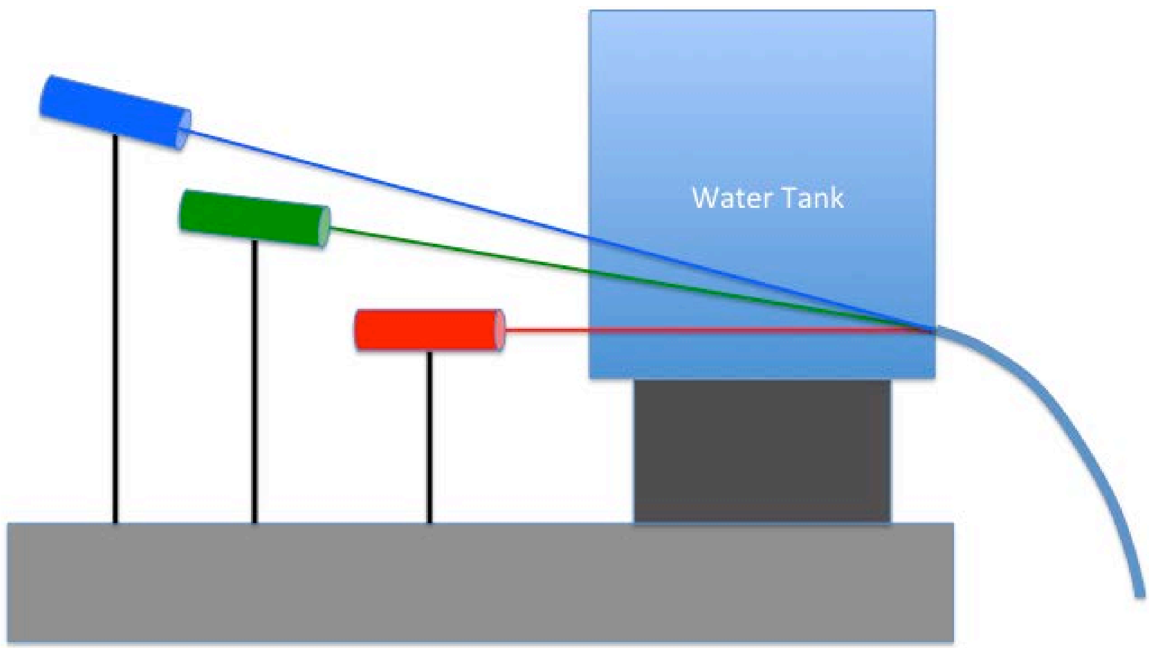
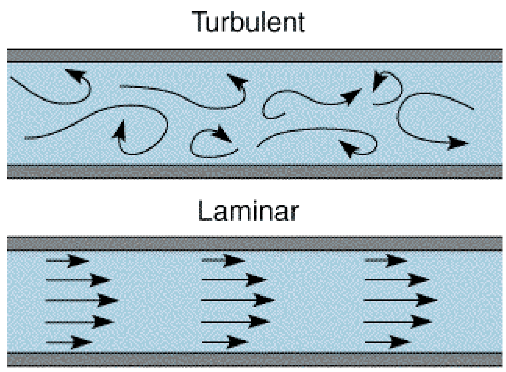



**Figure 1 SET UP**

To capture the image presented, we used a large clear acrylic tank (approx. dimensions 4” x 18” x 24” or 1 cubic foot), represented above as the blue rectangle on the right. Filled with water, the tank would drain slowly through a ½” hole in the side of the tank. The hole in the side of the tank had been made in a very thin (.030”) piece of aluminum, in order to achieve laminar flow as the water exited the tank. This is necessary, because if the hole had been made in the ½” thick acrylic, then there would boundary conditions at the hole that would prevent laminar flow from occurring. Laminar flow, or flow taking place along constant streamlines, is necessary to achieve the desired results. The alternative to laminar flow is turbulent, and with turbulent flow, the lights path would be disrupted and distorted and an image of the reflection phenomenon would not be able to be captured.




The next part of the set up involved the three different colored lasers, represented in the image as the blue, green, and red cylinders respectively. The lasers were all mounted to test stands to keep them stationary throughout the test, and then they were aimed through the tank and at the exit hole of the water, as shown. The water exited the tank, in a laminar stream, making a gentle arc that contained the laser "beams" and, as the image depicts quite clearly, the beams were reflected inside the stream. The length of the arc varied with time, as the pressure force "pushing" it out of the tank varied with time. The force was due to the amount of head in the tank, or the height of the water above the hole. We noted that at the beginning of the flow, there was almost too much pressure and the flow was less than laminar. But as the head and pressure decreased, there was an ideal range, which created almost perfectly laminar flow, and allowed us to see the reflection events clearly. Another important part of the set up was to add Pinesol to the water. We did this because it added particles to the water so that the lasers would have something to illuminate and reflect on as they passed through the water. With out them, it is likely that the lasers would have passed through the water without any visual reference.

To represent the flow with numbers to determine what kind of flow we are seeing, we will calculate the Reynolds number. Since the head height of the water is changing with time as water exits, we can assume the outlet pressure and the initial exit velocity also change in time respectively. For ease of reference, we will do our calculation not for the velocity with respect to time, but the velocity at the specific time the image was taken. The outlet flow speed can be calculated using the head height (at the time the image was taken, it was about 10cm), which allows us to determine the volume and weight of the water at this point. Knowing the volume and weight allows us to determine the pressure at the hole. Knowing the pressure and the hole size, where we will approximate the outlet hole as .01m (1cm) in diameter, we can calculate an initial exit velocity. We will use the initial exit velocity of approx. 2m/s to calculate the Reynolds number.

$$Re = \frac{VD}{v} = \frac{(2\ {}^{m}/_{s})(.01\ m)}{1.004\ \times\ 10^{-6}\,{}^{m^2}/_{s}} \approx 20000$$

This Reynolds number would usually indicate very turbulent flow, but in this case, it represents directional flow where inertial forces are dominant. Since we effectively laminarized the water by forcing it through a small hole, all its inertial forces are pointed in the same direction.

As stated previously, the water had a very small concentration of Pinesol in it. This concentration was so small though, that we can still treat the fluid as ideal water (*v* is the same). To complete the set up to capture the desired image, we had to work in a room of almost complete darkness in order to “see” the lasers most effectively. With no other light sources, there was also no risk of glare on the water or the tank. We also hung black fabric in the background to reduce glare, and make for an ideal blank black canvas behind the image. When we were taking the picture in low light we adjusted for a higher ISO. This was in order to capture the light emitted from the lasers with the fast shutter speed that was necessary to capture an image that was not blurry as the particles in the water being lit by the laser exposing its path were moving by at more than 2 m/s. When we took the picture we had the camera less than a meter away, with less than a meter in the field of view. For final editing of the image, I used Adobe Photoshop. I used the software to crop and turn the image, then invert the image and its colors, to place them adjacent. The experimental set up was used with permission from Michael Thomason and the Physics dept. here at CU.

The image reveals the phenomena of total internal reflection of light, and in this case is exemplified as the light is reflected up and down, side to side inside an arcing water stream. I was glad I was able to capture such a kinetic looking image, and hope that in invokes feelings of ease and harmony in the viewer. I also hope I provoke the viewer to learn more about the physics involved in the image. I filled the intent that I desired from the image, but next time I hope to work with an image with more clarity so it turns out with less obvious pixilation. To develop the idea further, I would consider shooting high speed video footage of the event, this would show the full experiment best, and it’s possible that more of the physics would be describe better in a movie rather than a picture.