MCEN 5151 Image 1 Report

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September 27^{th}, 2021
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I. Purpose and Methodology

This was the first image taken of a series of images that will be taken and processed which visualize different simple flow phenomena. The purpose of this particular experiment was to capture relatively small scale vortices that occur when one liquid of higher density is slowly added to a liquid of lower density. In this case those two liquids were milk and water, respectively. Unlike a Rayleigh-Taylor instability that mixes two different fluids, the point here was to instead slowly have the milk enter the water along a wall, and use the wall to spur vortex interactions that could then be captured.

II. Scientific Principals

To begin, a few of the flow properties must be estimated to get a better understanding of the behavior. Most importantly, the Reynolds Number must be found as that is of utmost importance in any turbulent flow. In general, the Reynolds number is calculated as:

$$Re = \frac{u * D}{\nu}$$

Here, u is the velocity of the fluid, D is a characteristic length associated with the flow, and ν is the kinematic viscosity. The easiest parameter to get here is the kinematic viscosity of milk, simply taken from a table of standards, listed as $\nu = 1.13 * 10^{-6} \frac{m^2}{s}$. Then from an estimate of the velocity of the flow, based on the size of the glass and the time from start to end, its an estimate of $u = 0.1 \frac{m}{s}$. Next, using a control image of a ruler next to the glass, a characteristic diameter of the vortex ring is estimated to be $D = 0.03m$. This diameter was chosen as this section will investigate the behavior of a vortex ring which is exemplified in the photo of a ring located just south of the center of the photo. With all of this information, the Reynolds number comes out to be:

$$Re = \frac{0.1 * 0.03}{1.13 * 10^{-6}} = 2654.87$$

This is not an especially high Reynolds number for a flow, but it is high enough to indicate turbulence in the situation, so it is expected that vortices are being created as the flow develops and confirms the suspicion that the image and particular phenomena being looked at is in fact a vortex ring.

There are a few core principals that should be discussed here, and how they relate to the image taken. The first is a basic overview of vortices and how they interact with other vortices as well as boundaries of the fluid. At the most basic level, a vortex is defined in fluid mechanics as the motion of a particle in a circular streamline, and a vortex ring is defined as a slice of a vortex tube, where vortex lines create a fully enclosed cylindrical space. Next, in ideal scenarios and very generally as well, it has been shown that as a vortex ring such as the one in the photo approaches a wall, it behaves in two ways, by slowing down and by expanding in size [2]. This can be seen in the photo if the dye the vortex ring left in its wake is examined. It becomes clear that this was the case here as the tube leading up to the ring is relatively smaller in diameter, and then as it approached the side of the glass (towards the camera), the diameter began to rapidly increase. This is precisely the behavior implied by the dynamics of the situation. Intuitively, the slowing of velocity near a wall is a result of an increase in shear stress of the fluid as it nears the edge of the wall since the velocity at a bounded surface must always be zero.

Some interesting continuations of this investigation can be followed though. The first is to realize that since this is a turbulent scenario, there will be an unsteady forcing on the vortex wall interaction. That is to say that the shear stress between the wall and the fluid will be oscillating in some way naturally due to turbulence. This particular phenomena has been investigated with a pair of vortex rings approaching a wall [1]. As it applies to this photo, this phenomena could very well be happening as right below the vortex ring in question there appears to be another vortex ring approaching the wall, and it is certainly close enough to the current ring to be interacting. This interaction could signal the appearance of Crow instabilities in the system [1], but unfortunately due to the non-standard quality of the experiment and photo, it would be impossible to determine if that were the case here.

III. Visualization Technique

As stated in the introduction, the image was created by using blue dye in milk to make a sufficiently dark color, and then pouring that milk down the edge of a glass full of clear, transparent water and quickly taking pictures as the milk was still settling. The background was a white sheet, and there were three lamps set up around the glass shining on it to illuminate the dye as much as possible. For the actual procedure, in order to replicate the experiment, the camera was first focused until the top left corner of the glass containing the water's edge was sharp. Then, with one hand, the glass of water was tilted about 30 degrees, and with another hand the dyed milk was rolled down the side of glass. Once about a third of a cup of milk was poured, the glass was returned to upright and pictures were quickly taken as the milk was settling. This took a few tries to get the timing correct, but once the procedure was muscle memory it became relatively simple.

IV. Image Details

For the details of the actual image and the techniques used, the main focus was to get as sharp of an image on a relatively small portion of view. Because of this the field of view was pretty small, about 5 inches across in total. Since the lens being used was a standard 18 - 55mm lens, and since the image was intended to be as close up as possible, the lens rested about 20cm away from the region of interest. With the lens this close and the zoom all the way in, it was able to capture a relatively small area. This was mainly possible through the use of a Canon EOS Rebel T6i DSLR camera, and being able to manually lock the focus as none of the automatic setting were up to the level of detail necessary.

When manipulating the exposure settings, things were complicated because the lighting in the room was not ideal. There was generally not a lot of light coming through to the camera so a few things needed to be done. The first was to make the aperture as high as possible, setting it to the limit of f/5.6 on the camera, thus letting in the most light. In addition, this sharpened the focus of the picture as much as possible which was a positive byproduct of the solution. This alone wasn't letting enough light in, so the sensitivity was bumped up to an ISO of 800. Then with how rapidly the flow develops, the shutter speed was set to 1/800, which also limited the light coming into the camera, furthering the need for a higher ISO setting than usual.

Finally in post-processing, a couple important changes were made. First, there was automatic exposure balancing and white-balancing that is done by Darktable on startup that tweaks the image slightly. Since the dye used in the milk was mostly blue, a couple RGB color curve changes were made. The first change was to take a lot of the red out of the photo and lower that curve, and then take the blue curve and steepen it to highlight the blue contrast with the background. Lastly, the overall tone curve was adjusted to cool off the whole image and take some of the warm colors out. The before and after images are shown below.

Figure 1. Initial image from the RAW file

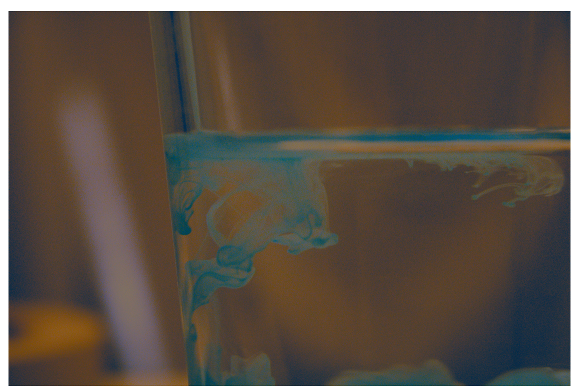

Figure 2. After post processing

V. Results

The results of this photo are actually rather pleasing. The biggest takeaway from the photo is the vortex ring in the forefront of the image just south of center. The fact that this ring was at the forefront of the image and that the path that it took is outlined by the dye trail behind it is incredible. It perfectly exemplifies the vortex travel interaction that the photo was going for which is remarkable. With all of this being said, having that result is somewhat a stroke of luck in terms of capturing the phenomena. In a largely uncontrolled environment, finding the chaotic phenomena of the flow and having it happen directly in the focus of the image was such a pleasant surprise. If anything was to be improved for the future, on the photography side it would mostly be changing up the lighting. Instead of lighting the glass directly one or two of the lamps would be directed toward the white sheet in the background to get a white background that the blue dye could stand out against. On the scientific side, liquids may not have been the best fluid to try and visualize vortex rings on. A more traditional and controllable method would have been smoke perhaps, as the creation of the vortex ring would be less up to chance.

References

[1] S. I. Benton and J. P. Bons. Response of a streamwise vortex–wall interaction to unsteady forcing. *AIAA Journal*, 55(10):3243–3254, 2017.

[2] J. D. A. Walker, C. R. Smith, A. W. Cerra, and T. L. Doligalski. The impact of a vortex ring on a wall. *Journal of Fluid Mechanics*, 181:99–140, 1987.