MCEN 5151-001 Team First Report

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Figure 1: Edited Submission Photo

Introduction

Vortices are flow phenomena that are present all around us in daily life, whether we realize it or not. Many behaviors that are just a part of normal life are a function of vortices: whether that be dug out pockets of snow around trees or the swirl of water going down a drain. Oftentimes, however, it is not directly obvious. My goal for this assignment was to capture the motion of a vortex ring, with the goal of showing how vortices interact. As a team, we got the idea for this visualization from a demonstration given by one of our former lab-mates, Dr. Robert Sasse. In his demonstration, he displayed a simple way to visualize vortex rings: using dry ice, water, and plastic cups. For our setup, Andrew Mord, Alyx Ellington, and I created similar vortex generators.

Methodology

The photo shows a vortex ring translating across a key light.The schematic in figure 2 shows the setup used to capture the image. During our session, at any point, one of us would be holding the vortex generator: a red solo cup with a hole cut in the base and a balloon over the mouth, and tapping the balloon to produce a vortex. Inside the cup-balloon container was a combination of dry ice and warm water, which when combined produces a translucent white mist as a function of the dry ice sublimating directly into gaseous carbon dioxide and combining with water vapor. With the cup pointed toward the light, we were able to directly illuminate the vortices.

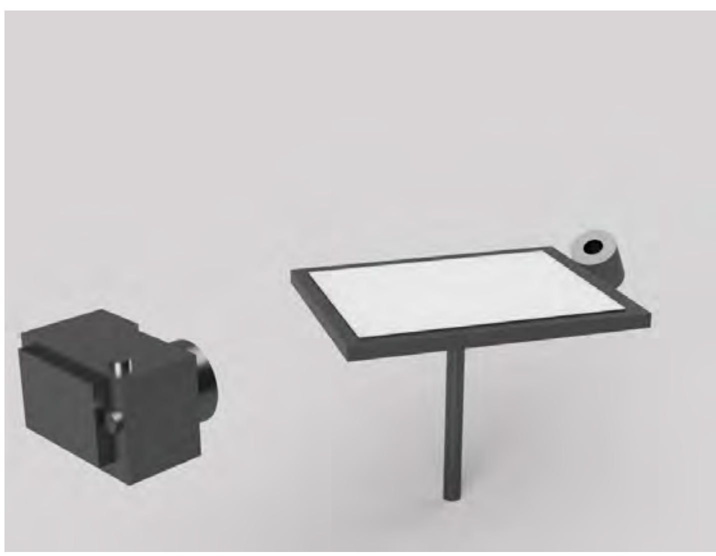

Figure 2: Experiment setup schematic (c. Alyx Ellington)

Mechanisms & Literature

Our setup was most similar to that of a synthetic jet: an injector style flow with zero net mass flux. This means that there is no 'new' fluid being injected into the flow, instead that the air expelled was previously pulled into the plenum (stilling chamber) of the container. Straccia & Farnsworth (2022) [3], in an experimental study on synthetic jets, demonstrated the progression of vortices generated through synthetic jet systems not-dissimilar to the one we used in our setup. Figure 3 shows a Particle Image Velocimetry (PIV) depiction of the vortices generated in their study, specifically showing the time-based decay of these vortices.

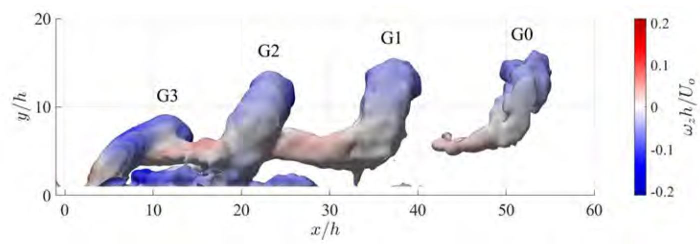

Figure 3: PIV Display of Streamwise Vortex Progression

An important mechanism to note, that clearly visible in the image, is that of vortex roll up. The roll up of a vortex, specifically of vortices generated using a nozzle-like system, is the mechanism that drives the motion. Didden et. al. (1979) [1], in their paper on the driving mechanisms of vortices, display a 2D representation of the ring vortex generation (Figure 4). This same mechanism is visible in the image captured for this assignment, where the tendrils of the vortex can be seen trailing behind the vortex as it propagates from left to right.

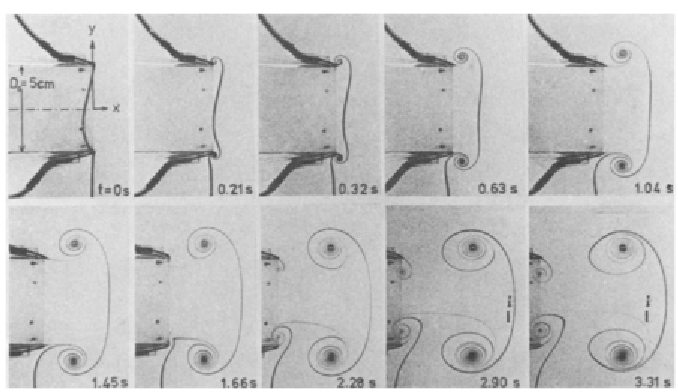

Figure 4: Vortex Roll Up from a Circular Nozzle

Instrumentation

The camera settings used to capture the image can be found in Table 1. Discussion of these choices can be found in the results section.

Camera Information	**Value**
Focal Length	70 mm
Aperture	f/5.6
Shutter Speed	1/3200
ISO	3200
Focus Distance	0.68 m
Original Image Width	6048 pixels
Original Image Height	4024 pixels
Camera Sensor Size	Full Frame 35mm
Camera Make & Model	Sony A7ii

Table 1: Camera Information

Results

The experimental set-up for this image was not in an entirely controlled environment. As such, there were fluctuations in the ambient pressure and fluid velocity as the room's HVAC system turned on and off. As such, the velocity of the vortices was inconsistent. The most accurate velocity estimation for this setup is then a range of 0.25 - 1 m/s. That can be plugged into the Reynold's number equation (Eq 1) to give a non-dimensional representation of the flow regime.

$$Re = \frac{\rho U L}{\mu} \tag{1}$$

Where ρ represents the ambient density the fluid, U is the fluid velocity, L is the characteristic length, and μ is the dynamic viscosity. It is important to note that Reynold's number is not necessarily an appropriate quantity for comparison in mixed-species non-uniform flows, however it does provide a baseline for the behavior. From the 1976 US Standard Atmosphere [2], given the altitude of 5145 ft and an ambient temperature of 72 degrees F, a density of 0.987 kg/m^3 can be calculated. Given a dynamic viscosity of 18.23E-6 Pa s, and the radius of the vortex, approximately 3 cm, used as the characteristic length, the Reynolds number range can be calculated as 400-1600. This would place the flow firmly within the laminar flow regime, which is consistent with the visual. The existence of large, distinct, and coherent vortex rings and the absence of smaller scales indicates that turbulent flow is not present. Further, it can be seen through the structures in the background of the image that the rolling motion of the vortex is still present, even if the more opaque mixture has begun dissipating due to concentration gradients.

Figure 5: Original Unedited Photo

By using a low ISO, a fast shutter, a relatively open aperture, and sufficient lighting, the image captured has very minimal noise and required very little manipulation. The final photo was cropped in and had a minor highlight increase. The original, unedited photos can be found in figure 5. The crop brought the final image size to 4576 x 3057 pix.

Conclusion

The photo does a brilliant job of capturing the motion of the vortex. Further, the detail in the wisps is striking, allowing for the photo to feel more physical and realistic. I'm very happy with the image that I was able to capture, I feel as though I was able to implement exactly what I wanted to. My next step in developing this image would most likely be using high speed cameras and a laser sheet. I would be interested in using PIV to quantify the fluid velocity, the vorticity, and the circulation of the fluid. There have been plenty of studies that have done so, I just believe it would be interesting to quantify myself.

References

[1] Norbert Didden. "On the formation of Vortex Rings: Rolling-up and production of circulation". In: *Zeitschrift für angewandte Mathematik und Physik ZAMP* 30.1 (Jan. 1979), pp. 101–116. DOI: `10.1007/bf01597484`.

[2] NOAA. *US Standard Atmosphere*. 1976.

[3] Joseph C. Straccia and John A. N. Farnsworth. *On the vortex dynamics of synthetic jet – turbulent boundary layer interactions*. 2022. arXiv: `2205.07370 [physics.flu-dyn]`. URL: `https://arxiv.org/abs/2205.07370`.