Image II – Remnants of Vortices

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Figure 1: Final Image of rising smoke with remnants of vortices

Introduction

Continuing the investigation of visualizing flow physics, this second project in the course of MCEN 5151 Flow Visualization would focus on photographing smoke illuminated in a dark room. With the assistance of Ben Carnicelli, Nathan Gallagher, and David Milner, the fluid flow to be captured was to be vortex rings of traveling through air.

Flow Physics

The flow phenomenon of a vortex ring is formed when fluid is discharged from a container through a sharp-edged nozzle. The boundary layer of the fluid at the edge of the nozzle is separated and rolls into a spiral[1]. The spiral is known as a vortex. The vortex is wrapped around a central axis creating a circle, or a vortex ring. A ring vortex and a remnant of a vortex can be observed in two locations on the final image along with long plumes of smoke.

Breaking down the mathematical aspects of the observed smoke ring can be detailed using the Reynolds number. The Reynolds number is a ratio of inertial to viscous forces[2]. This

dimensionless number characterize the flow type into laminar or turbulent. Due to the smooth, long lines of smoke, an assumption can be made that the fluid flow visualized in the image is laminar. Proof of this can be derived using the physical properties of the flow and the Reynolds number. Laminar flow is often defined as a value of 2100 or less for a Reynolds number[3]. A Reynolds number above 2100 is transitional or turbulent flow.

$$R_e = \frac{VL}{\upsilon} = \frac{\rho VL}{\mu} \qquad \text{Eq. 01}\ ^{2}$$

Where R_e is the dimensionless Reynolds number, V is the velocity of the fluid $\left(0.15\frac{m}{s}\right)$, L is the characteristic length $(0.01m)$, ρ is the density of the fluid $\left(1.204\frac{kg}{m^3}\right)^4$, υ is the kinematic viscosity $\left(1.516 * 10^{-5}\frac{m^2}{s}\right)$, and μ is the dynamic viscosity $\left(1.825 * 10^{-5}\frac{m}{s}\right)$.

$$R_e = 98.96 = \frac{\rho VL}{\mu} = \frac{\left(1.204\frac{kg}{m^3}\right)\left(0.15\frac{m}{s}\right)(0.01m)}{\left(1.825*10^{-5}\frac{m}{s}\right)} \qquad \text{Eq. 02}$$

With a Reynolds number just below of 100, the flow is well below the considered cut off of turbulent flow. The values chosen for input were based on the atmospheric conditions of the day. The characteristic length is the radius of the vortex ring faintly seen in the large plume. The velocity is an approximation from observation from the day of photography. This was not explicitly measured.

Figure 2: The remnant vortex highlighted

Experimental Setup

To create and capture vortex rings, several pieces of equipment were used. The foremost being a smoke machine. The smoke machine was used to generate smoke on demand. This smoke was fed into a cardboard box. The box had one slot cut to match the vent in the smoke machine. This allowed the smoke to be fed only into the box, preventing smoke from filling the ambient air and subsequently being captured in the image. A circular hole, approximately 1.5 inches in diameter was cut in the top of the box. This was the sharp-edged nozzle in which the smoke would be directed through to create the vortex. To illuminate the smoke, a ring light was placed on top of the box concentric with the hole. This created the effect of the smoke being illuminated in a 360-degree fashion but only from the below. This also meant the

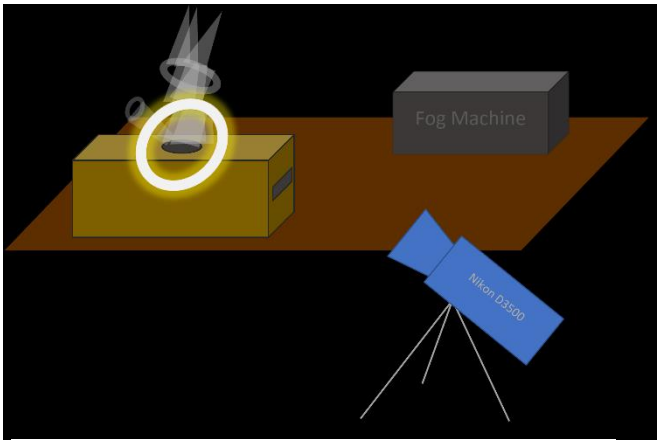

Figure 3: Schematic of experimental setup

background, a black tablecloth five feet behind the subject, was not illuminated and only the smoke in the foreground is visible.

Just prior to an image being captured, a team member would fill the box with smoke from the smoke machine. At the cameraman's command, the team member would compress the box slightly, driving the smoke-filled air from within the box out the nozzle. The cameraman would take many images of the quick plume of smoke to maximize the uniqueness and quality of the captured image.

Photographic Techniques

The camera used for this image was a Nikon D3500 DSLR with a Nikon lens with the specifications of AF-P 18-55mm f/3.5-5.6G VR. The focal length was set to 40mm, the exposure was 1/80, an aperture of f/4.8 and an ISO of 3200. The original size was 6016x4016 pixels. The edited image file is 5728x3635 pixels in size, with cropping along the bottom and sides. The camera was placed 18 inches from the subject mounted on a tripod.

Figure 4: The original, unedited photo

Focusing the image was done prior to each round of smoke using an object, such as a hand, at where the smoke would be. This allowed the camera's focus to be set without wasting time attempting to focus on the near-translucent smoke. This proved to be the most challenging aspect of capturing smoke rings. Because of the rapidly moving and hard to focus on smoke rings, there were many instances where a great potential image was captured out of focus. This limited images to just a few choices, even after six hours of shooting. The resulting final image adequately captured a brilliant plume of smoke with traces of vortices. The desired image would have more clearly accentuated the vortex, but the experiment drove itself in different paths due to this obstacle.

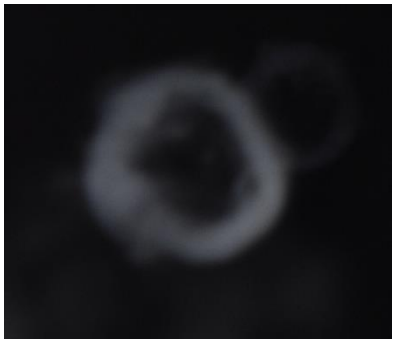

Figure 5: Example of blurry, out-of-focus vortex ring

Post-processing edits were made in the software Darktable. The image was cropped to remove excess black background and to remove the visible ring light at the bottom of the image. The image was sharpened to make the smoke look crisper. The RGB curve was altered to darken the background and brighten the smoke. The image was also denoised to remove distracting grainy features in the background that came as a result of photography. Two small puffs of smoke were removed from outside the main plume to make a clean, distraction free image.

Conclusion

This image presents smoke plumes with hints of vortex rings. Although this image was not what the original intended result was, it succeeds in capturing the beauty of fluid flow visualized with smoke. The vortex ring features can still be seen amidst other wonderful features. The unsuccessful capture of a pure vortex ring was not in vain as this image does uniquely visualize fluid flow in a challenging environment.

Bibliography

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