Within a Ring of Fog

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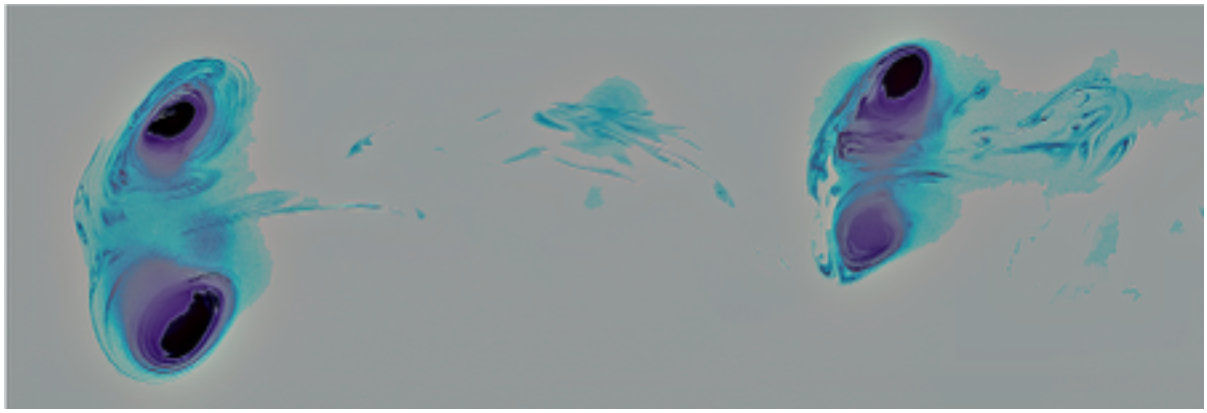
Dec 15th, 2015

Flow Visualization



The image seen above was taken in an attempt to reveal details of the beauty and complexity within a ring of fog. The intension of this image was to clearly show the internal shear layers forming vortex lines on a cross sectional field of view. The swirling motion shown is the direct result of how a fog ring manages to move consistently through space.

The fog was produced using vegetable glycerin in an electronic cigarette modified to produce a dense fog. The fog was then blown through a 1.5 inch diameter 14 inch long cardboard tube in bursts, producing vortices. The rings were blown through the focal point of the camera . 95 meters from the camera as a laser was passed through the rings. The duration of the laser sweep across the focal plane was about one second. The rings having developed for around three seconds are approximately two and a half inches in diameter. The direction of fog flow and laser movement is pictured in Figure 1. As inertia moves the vortex ring forwards the air surrounding

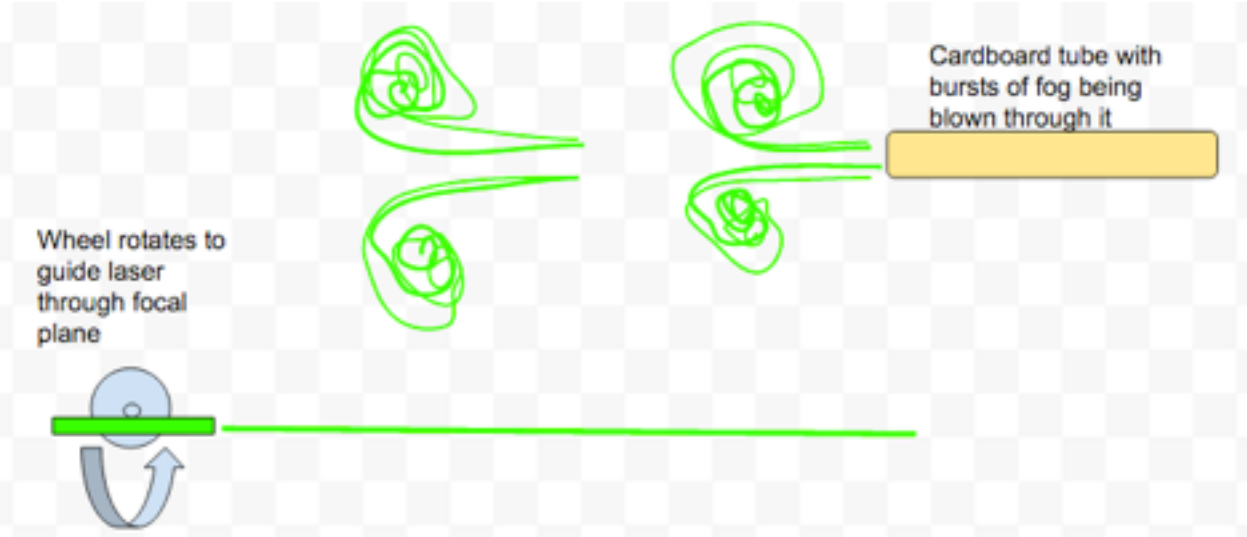


Figure 1: Depiction of experimental set up with camera 3.5 ft out of the page.

air is displaced around the vortex ring. Friction between the surrounding air and fog force the vortex to swirl forwards at the center and backwards on the outside.[1] As the vortex curls back towards its center it draws with it a thin layer of fresh air due to the no slip condition at a fluid

boundary. This layering of smoke and fog forms a continuous vortex line that spirals in towards the center of the ring. The no slip condition of the fog along the cardboard tube induces the spiraling motion, critical for allowing the vortex to move, stay together, and form the vortex lines seen in the final image. The formation and spiraling motion is depicted in Figure 2.

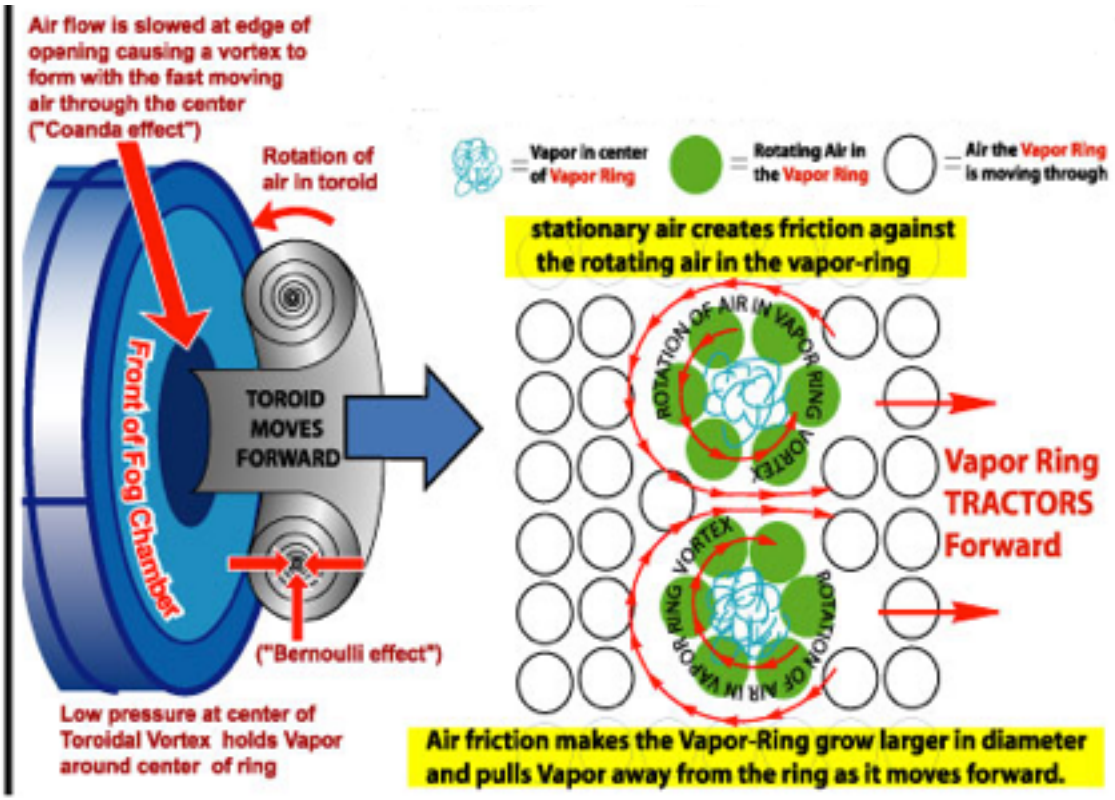


Figure 2: Depiction of spiraling motion and explanation of vortex formation.[1]

The fog and laser gives a great cross sectional view of the flow occurring within these vortices. In order to visualize this effect, a vegetable glycerin fog was generated in an electronic cigarette. This vegetable glycerin used in the electric cigarette is commonly used as stage fog and is not associated with serious health risks [Varughese]. A 500 mW green laser provided the only light in the dark room. This caused a single plane of light going through the cameras focal point. The plane of laser light was created with a half rotation of a wheel with the laser attached to it,

effectively sweeping the laser perfectly through the lens focal point. The laser was moved at a near constant speed to ensure equal exposure across the image. Since the laser only reveals a line of fog at a time it is impossible to use the motion blur to calculate the velocity of the fog ring. Finally, it was found that a single pass of the laser produced crisper images than multiple rapid passes which resulted in motion blur in the dynamic fog. Despite only exposing the vortices to a single plane of light, diffracted light illuminated surrounding fog which is why the post processing was so critical.

The necessary settings to take this image using a Nikon D5200 a Nikon DX AF-S Nikkor 18-55mm lens were a 10 second delay, allowing for set up time, and a two second shutter speed allowing time for the laser to pass through the focal plane. To allow for sufficient exposure across the fog rings, the exposure time was set to automatic and the ISO speed rating was 800. The camera was manually focused to the distance from the laser to the lens making leaving only one inconsistency, shooting a fog ring through the center of the focal plane at the right time. Seen in Figure 3, a significant portion of the original image was black space and non relevant fog exposure, so it was initially cropped from 4,000 X 6,000 pixels to 1,221 X 3,612 pixels. Post processing, done in Pixelamtor, consisted mostly of a color inversion, then an alteration to the color balance, changing the colors from the center to the outside of the vortex line. This made the physics within the vortex line much more apparent even though it exposed some residual fog around the rings.

This image shows very clearly the vortex lines resulting from non diffusive mixing taking place within the swirling of a fog ring. It is interesting to see the fog pushing through the center of the ring; a crucial part of how they stay together with the low pressure area (not discussed

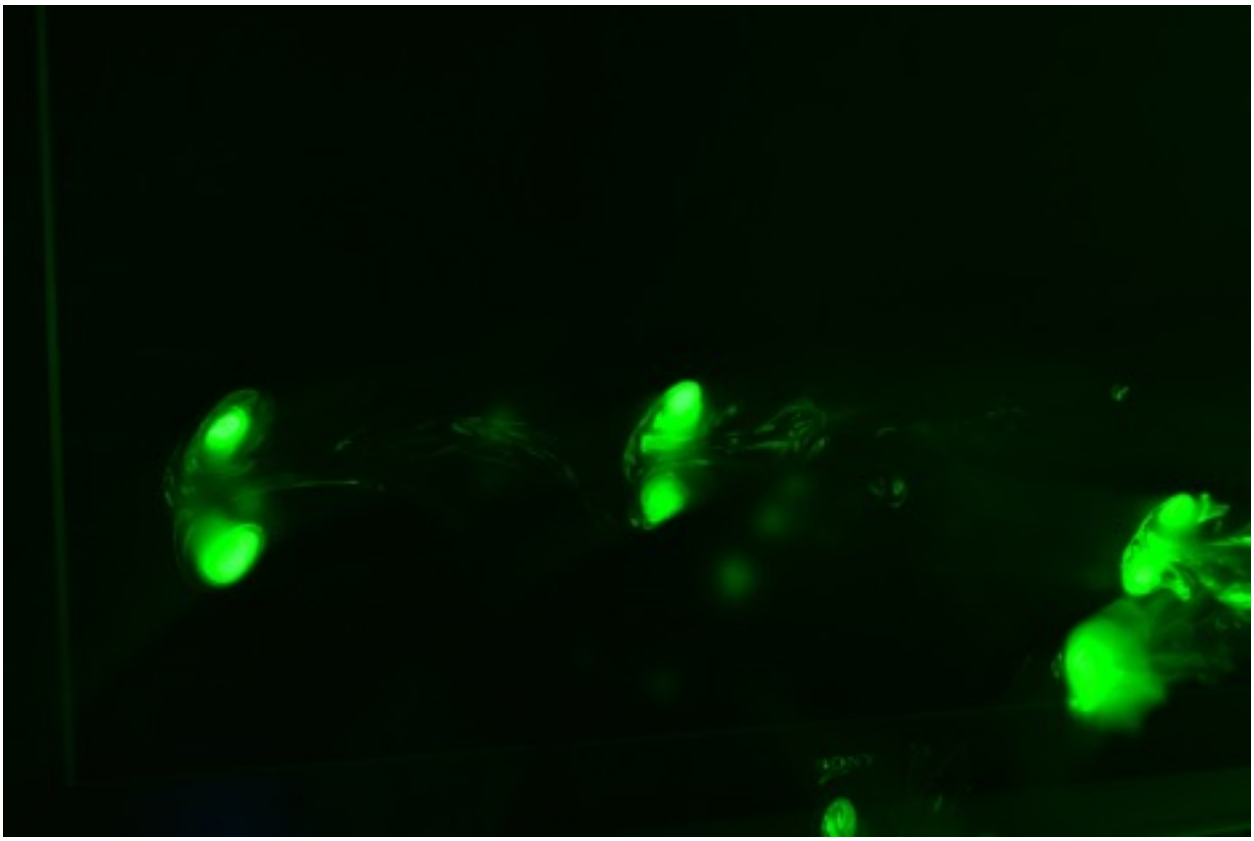


Figure 3: Original fog ring image.

here, but explained in "Bio-aerial Locomotion 2011.”). It also shows with astounding detail the vortex line spiraling inwards towards the vapor ring described in Figure 2. It is amazing how well this glycerin fog holds together and demonstrates non diffusive mixing, even in these very thin fluid layers. This imaging method shows incredible potential for visualizing cross sectional fluid flow patters, and is surprisingly simple to do. I encourage the use of this method for visualizing other forms of fluid flow which I may not even be aware of.

Work Cited

1. "Bio-aerial Locomotion 2011." Bioaerial Locomotion 2011 The Science of Smoke Rings Comments. 13 Dec. 2011. Web. 14 Dec. 2015.

2. Varughese, Sunil, Kay Teschke, Michael Brauer, Yat Chow, Chris van Netten, and Susan M. Kennedy. "Effects of Theatrical Smoke s and Fogs on
Respiratory Health in the Entertainment Industry." American Journal of Industrial Medicine 47, no. 5 (2005): 411–18. doi:10.1002/ajim.20151.