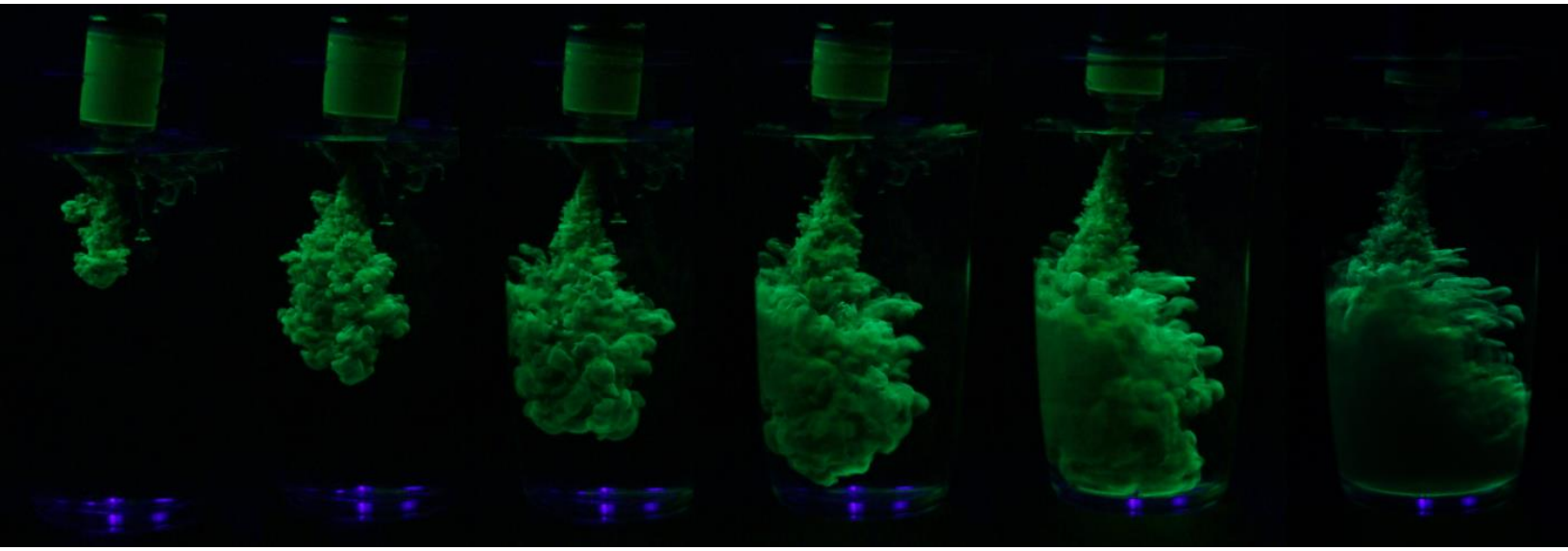

Fluorescent Dye injected into Water

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For Team First 2016

Introduction

The image, or the image set, captured shows a turbulent jet of fluorescent dye injected into a stagnant glass of water. This image was, however, not the planned image for Team 3. Team 3 consisted of Mark Noel, Jason Savath, Jeremiah Chen and me (Daniel Bateman). Team 3 planned on capturing a Von Karman vortex street behind a PVC cylinder in a water tank. Due to flow limitations in the current configuration of the tank, a high level of incoming turbulence in the flow, and a non-uniform velocity profile, a clear vortex shedding behavior was not achieved. With a limited amount of time, the team got creative in setting up other flows using the available fluorescein. Mark spotted a very interesting instability forming after the fish tank flume was turned off and the dye dripped slowly out of the feed line. Jeremiah and Jason captured images of Worthington jets as fluorescein was dripped into a glass of water. All images turned out well, despite their improvised nature. Modifications are being made to the fish tank flume setup for future attempts to create a clear vortex street.

Flow Apparatus

The apparatus for this flow was fairly simple consisting simply of a syringe filled with fluorescein and a glass of water. The Syringe was a food product, intended to inject broth into meats. No needle or attachments were used in this flow. The glass was clear, and contained about 16 fluid ounces of water. Jason, who is just out of frame, held the syringe and rapidly depressed the plunger, injecting about 10 ccs of watered down fluorescein in about 1.5 seconds.

Visualization Technique

Fluorescein is a highly fluorescent water soluble chemical, which fluoresces under black light. Two desk lamps with 60 watt black-light bulbs were used to illuminate the flow. The lights were both above the glass, and off to either side. This provided top-lighting, and illuminated both sides of the flow. Black plates were used to create even higher contrast. One black sheet was under the glass, one behind.

The fluorescein for this photograph was extracted from highlighter markers. Highlighter ink consists of fluorescein and a water soluble binder. To extract the fluorescein, 70% isopropyl alcohol was fed through the highlighter ink tube. This extracted the fluorescein, which is alcohol soluble, while leaving behind the water soluble parts of the ink. Using a hot plate, the alcohol was evaporated, leaving behind a concentrated fluorescein solution, which could be added to water and used as an injected dye.

Photographic Setup

This photo was taken with a single camera and no flashes. A Canon 70D was used with a 50mm f/1.8 prime lens. This was mounted on a tripod. One of the main issues of capturing this image was the lack of light available. The 50mm prime lens was used because of its wide f/1.8

aperture. This allowed higher shutter speeds to counteract motion blur. However this had the adverse effect of creating a shallow depth of field. An ISO of 3200 was selected, this was chosen as it provides good sensitivity, and on the 70D, still has an acceptably low amount of noise. The decision was made to shoot in jpeg, to allow the camera to shoot in its highest possible speed mode and not risk filling the buffer. With this, upwards of 8 frames per second is possible. As seen, many compromises were taken to capture this flow. In a perfect world, raw images at ISO 800, f/8 and 1/1000 of a second would have clearly defined the flow with low noise, low motion blur and wide enough depth of field for the whole flow to be in razor sharp focus. However this was just not possible with the available resources.

The flow was adequately captured over a set of 35 images. However, due to the aforementioned compromises in photographic settings, the images did not contain the clarity I felt would allow any of the images to be a standalone image. The shutter speed, and the wide aperture, introduced some blurriness into the image. To overcome the shortcomings of a single image, the idea of using multiple images was used. Six images showing the start through the end of the injection were chosen. The six images were chosen at an even interval, every other picture taken. Using Gimp, the images were placed side by side in a large panorama type picture. The curves tool was used to apply same color correction profile was used on each image. The green and blue channel were lightened t bring out the details of the fluorescent jet, while the red channel was crushed to zero, as it had little contribution other than noise.

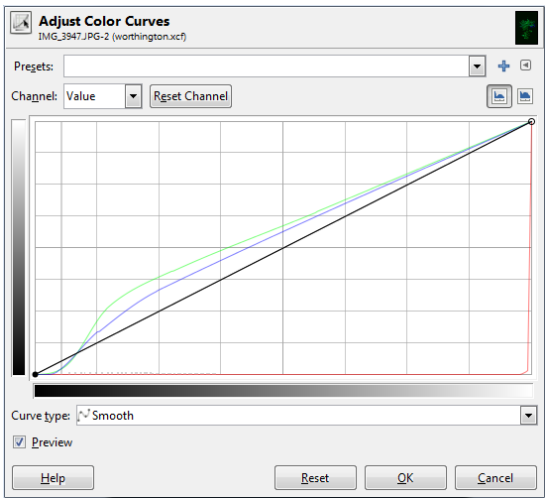

Figure 1
The curves color correction used to all images in Gimp

Discussion of Flow Phenomena

The flow here is a contained, impulsively started turbulent jet, and many of the defining characteristics of this can be seen clearly throughout the set of images. The flowrate, about 10 cm^3/s were ejected from a nozzle with a 1.5mm diameter in 1.5 seconds. This gives a mean exit velocity of 3.8 meters per second. The Reynolds number based on the nozzle exit diameter and velocity is as follows,

$$Re = \frac{\rho V d}{\mu} = 7.2E3$$

Reynolds number is a ratio of viscous to inertial forces. With a Reynolds number of 7.2E3, though it is somewhat low, still suggests turbulence, which is clearly observed.

The first noticeable feature is the expansion of the jet. Boundary layer theory shows that when developed, the flow expands linearly in a self-similar manner. This is apparent especially in the middle three images, especially near the injection point, where the boundaries of the glass have little effect on the flow. The jet of dye expands in a cone like shape with nearly straight edges (minus the individual turbulent structures.)

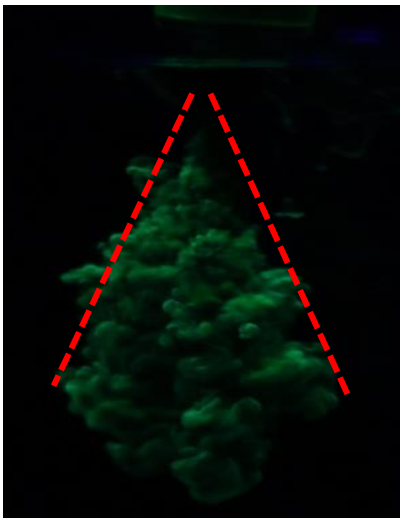

Figure 2
The approximately linear expansion of the jet is outlined with red dashed lines

The flow also, and especially with this set of multiple images, is a great visual example of one of the mathematical techniques used to define turbulence; defining a mean flow profile, and fluctuations from the mean. With the images side by side, the viewer can easily see the similarity between the images (the mean flow) as well as the turbulent structures which are unique to each image (the fluctuations from the mean). One can also observe the many length scales of turbulence given the variety of vortices and structures seen in the jet itself.

Discussion of Image

Ultimately, the image conveyed the intended phenomenon and vision of the photographer. The method of combining multiple images, while initially used as a crutch for the lack of sharpness in the individual images, in the end actually conveyed a sense of time which really added to the image. Peer review of the image was generally positive, agreeing that the sense of time from the multiple frames added to the photo. Future improvements can include the use of more lighting; this would allow a smaller aperture and faster shutter speeds, resulting in a much clearer image.

Works Cited

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