“Flaming Nemo”

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Introduction

This image was created to satisfy the second group assignment for the Flow Visualization course at the University of Colorado at Boulder. The purpose of the assignment was to capture a fluid flow in an artistic and physically revealing way. To satisfy said requirements, I set out to capture a still image of a fireball. When I first began the setup for this experiment, I was not sure what the final form of the image would be. As you can imagine, it is difficult to predict the exact shape of a fireball. In the end, however, I could not have been happier with the result. Due to what can only be described as luck, I was able to capture a fireball that bears a striking resemblance to a fish, specifically a famous clown fish, which inspired the name of this image – “Flaming Nemo.”

Setup

The setup utilized in creating this image was rather simple, but please note that extreme caution must be exercised in any such experiment involving combustibles. In the creation of this image, specific combustion experiment guidelines were followed (as described on the Flow Visualization website under the ‘Course Info’ tab). The specifics of this setup are highlighted in the figure to the right. The object on the left is a 6-inch grill lighting match. On the right is a 7.2 fluid ounce spray can of vegetable oil. The distance between the two objects is approximately six inches. The spray can was aimed such that the sprayed oil was centered about an inch above the flame. The nozzle was compressed for only a short burst (less than a quarter second) in order to achieve a singular fireball as opposed to a steady stream (like a flamethrower). This short-burst tactic was also used for safety’s sake, to minimize the size of the flame and to control the amount of combustible fluid exposed to the flame.

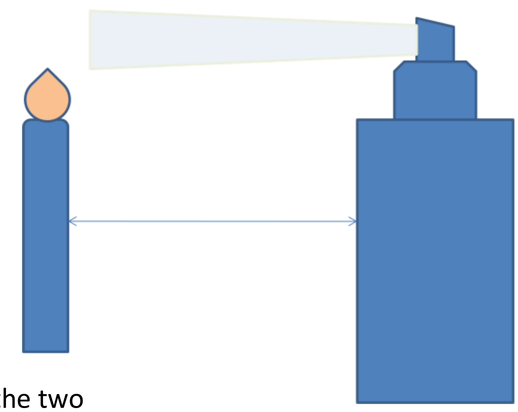

Figure 1: Experimental Setup

Flow Discussion

We will now examine two physical aspects of this fluid phenomenon in more detail. First, we will look at the combustibility of the substance used in this image and examine the properties of such a flame. Second, we will investigate the fluid properties of this flow, specifically looking at its estimated velocity and turbulent flow characteristics.

Vegetable Oil Spray Combustibility

The first topic of discussion when looking into the actual physics of this image is what flammable material we are actually dealing with here. Spray vegetable oil is essentially a mixture of liquid soy bean oil and a small amount of propellant, probably food-grade alcohol (ethanol). While vegetable oil itself is relatively combustible, this second ingredient is what gives it the extremely flammability we observe. In fact, the ignition of the propellant in this mixture is probably what is igniting the vegetable oil in the mixture since it is known as a IIIB class flammable liquid, meaning it has a relatively high flash point (or combustion temperature). The ethyl alcohol combustion reaction is very basic. We have ethanol and oxygen combining with a small amount of energy added (a spark or in this case heat from an open flame). Here is the basic chemical balance equation of the reaction:

$$C_2H_5OH + 3O_2 + \text{Energy (heat)} \rightarrow 2CO_2 + 3H_2O + \text{Energy (heat and light)}$$ [1]

This release of energy in the form of heat and light is what we have captured in this image. Much research has been done in the field of fluid combustion because it obviously has huge an effect on the day-to-day life of humans. The combustion of liquid fuels (i.e. gasoline, natural gas, ethanol) clearly has massive implications to the human race. In this specific case, we see an example of fluid combustion (oil sprays) that takes more energy than a regular gas mixture as we need more energy to evaporate the individual droplets of fluid.[3]

Velocity Characteristics

Now one thing to keep in mind when looking at the physical characteristics of this flow is that they change very rapidly. For example, the velocity of the sprayed fluid is much greater at nozzle exit then it is even one foot downstream. Frictional forces with the air and gravity have a relatively strong effect on the fluid immediately. That being said, I have estimated the average velocity of the sprayed vegetable oil to be about three meters per second over the first foot of travel. It then becomes quite difficult to estimate velocity and Reynolds number as the sprayed cloud of fluid becomes rather diffuse. Also, the chemical reactions involved in combustion have no viscous effects on the flow, but do introduce new time scales, thus making it difficult to model combustion flows[2]. The image itself shows the flow about 18 inches after ignition and about halfway through its life. I think this was an interesting point to capture the flow because it still appears turbulent, but has a smooth, less violent appearance than it would even a foot earlier in its travel, in other words, it is transitioning to a more laminar flow. I feel that a high speed video would allow for a much closer examination of this portion of the physics.

Visualization Technique

Since the object I was trying to visualize in this image was a fireball, I let the flame dictate the visualization techniques. Specifically, I was in a relatively well-lit garage at night time. In order to highlight the flame's extreme light, I simply altered the exposure time of the camera. By leaving the shutter open only for a very short amount of time, I let very little light reach the sensor. When the shutter was open, only the extremely bright light from the flame showed up in the image, leaving the background relatively dark, which is what I was striving for. I think this technique accounted for two desired aspects of this photo. First, the dark background. Second, by allowing less light from the flame to affect the sensor, we can see more of the detail in the fireball. Had the shutter stayed open for longer, the image may have become saturated in some sections, leaving sharpness and detail to be desired.

Photographic Technique

The photographic technique used to capture this image is of the utmost importance to its final form. I believe the combination of shutter speed and ISO setting was very important in capturing this image in the way I did. I have seen several photos of similar phenomena and, in my opinion, not many have had the effect that this image does. Below is a list of the photographic settings used to capture this image.

Field of View: approximately 24” (original image)
Distance from Object to Lens: around 5 feet
Focal Length: 44.0 mm
Type of Camera: Digital Still from Canon EOS 7D
Image Dimensions:
- Original – 5184 x 3456
- Final – 4924 x 1276

Exposure Specifications:
- Aperture: f/5.0
- Shutter Speed: 1/6400 second
- ISO setting: 1000

Photoshop Processing:

The original image itself came out in such a way that not much Photoshop work was needed for the image to achieve what I hoped for. The extremely quick shutter speed essentially blacked out the entire background by letting so little light in. In order to bring the flame’s presence up a bit I slightly altered the contrast. This gave the orange of the flame a bit more brightness against the black background. I did edit out a few droplets of spray that ignited at the bottom left of the frame in order to maintain all focus on the fiery fish. Finally, I cut large portions of emptiness our from above and below the fish to give the final form a panoramic look. I think this really helped to achieve the effect I had originally desired. The original and final images are shown below (left and right respectively).

Conclusion

Overall, I am very satisfied with how this image came out. I can't say that I've seen an image of a fireball that came out as artistically different as this one (even if the fact that it looks like a fish was lucky). The clarity of the image helps to make it beautiful while also highlighting the amazing fluid physics occurring here. It would be an interesting experiment to capture an image with this same setup, but move the point of interest to the moment of combustion. That is, using the same photographic and visualization techniques, we could capture the spray oil igniting. Or taking that same idea even farther, capturing this phenomenon with a high speed camera in the 2000-4000 frames per second range. This would truly highlight the step by step nature of combustible fluid ignition and flame propagation.

References

[1]WiseGEEK. "What is Ethanol Combusiton?"Accessed at: www.wisegeek.com/what-is-ethanol-combustion.htm. February 20, 2011.

[2]Peters, Norbert. Turbulent Combustion. Chapter 1.1 – "What is specific about turbulence with combustion?" Cambridge University Press, 2000. Page 3.

[3]Yuan, Liming. "Ignition of hydraulic fluid sprays by open flames and hot surfaces." Pittsburgh Research Laboratory, NIOSH. Accessed at: www.cdc.gov/niosh/mining/pubs/pdfs/iohfs.pdf