Flaming Liquid

Group Gamma Project 2

Lucy Dean, Joseph Duggan, Tim Jarrell

Flow Visualization – MCEN 4228

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Intoduction

The intent of this submission was to photograph flaming liquid in flight and at impact on a surface. Flaming liquid is especially interesting because of the entertaining contradiction it presents—considering that the most common liquid present on earth is non-flammable, and is usually used to extinguish flame. The most impressive previous submission on the website of flaming liquid was that of David Harbaugh, Jen Masini, Chris Fauble, and Robin Parsons in the 2004 class of the ignited ethanol poured down a metal pipe; this submission inspired us to image flaming liquid in the first place:

Figure 1. Image by team of David Harbaugh, Jen Masini, Chris Fauble, and Robin Parsons [1]

The novel aspect of our approach was to visualize a flaming liquid in flight and on impact with splashing. In addition to this, we intended to set our image apart further by changing the color of the liquid from the previous blue flame produced by ethanol.

Procedure

The flow apparatus involved a lab test stand, beaker, turning rod and multiple cameras about 4 feet from the splash zone.

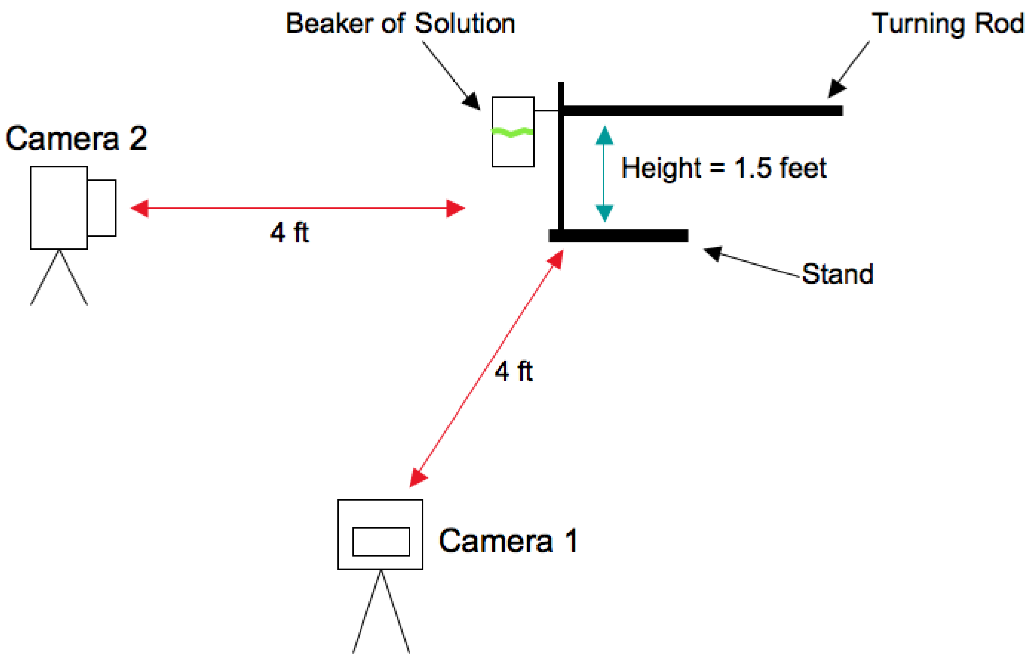

Figure 1. Flow apparatus

We poured the test solution from the beaker and observed the splash pattern and size and then positioned the cameras outside of that area. Most of our images have a width of 2-3 feet with the pool of flames occupying most of that area. The solution was ignited by match held by a Kevlar glove. The photographers were then queued to start shooting images in rapid succession, and the fluid was poured. The pouring of 200 ml of the solution took approximately 3 seconds. The liquid fell 1.5 feet and accelerated to a maximum velocity of 9.79 feet/sec. At the base of the pouring liquid, the diameter was 0.5 inches resulting in a Reynolds Number of 5.09 x 10^{-5}, which means that our flow was completely laminar throughout the pour (Re ~ 0). With exception given to the moment of impact, both the flow out of the beaker as well as the flow over the concrete floor were laminar flows. Below are the characteristic properties of the flow which dictate the Reynolds number [2,3]:

Free-stream velocity: 9.79733333 feet / second
Characteristic Diameter: 0.5 in
Fluid Density: 791.8 kg/m^3
Fluid Dynamic Viscosity: 590000 Pa-s
Reynolds Number = 5.09 x 10^{-5} ***Laminar Flow***

Materials

The flammable liquid was a mixture of methanol (99.8% grade) and boric acid. The chemicals were obtained from the chemistry stock room in the Christol Chemistry building on campus. The methanol provides the liquid and the property of flammability; the boric acid powder is added to impart the green color. The idea of using such a mixture was sourced from another previous Flow Visualization submission by David Levine et al. [2], who used crude versions of the chemicals in the form of anti-freeze and roach pesticide. Using the purest forms of the chemicals imparted a much brighter color to the flame than that of Levine, and gave the flames a light, “evergreen” coloration. The 600mL beaker was filled with ~200mL of methanol for each pour (enough methanol to visualize the pour, and develop an end pool of ~2ft in diameter). At first, the team used a 1:3 vol./vol. mixture of boric acid to methanol as suggested by Levine, but found that only a fraction of the added solute (boric acid) dissolves enough to saturate the liquid. With an excess of boric acid in the beaker at all times, we were assured the solvent (methanol) was constantly saturated for each pour, and simply refilled the beaker with fresh methanol before every trial; we found this method to be quite convenient and recommend it to anyone duplicating the experiment. The only lighting used here was the natural illumination provided by the flaming liquid. It should also be mentioned the photos were taken at ~32ºF, giving us an abundance of cold condensed oxygen in the air which aids in combustion.

Image #1 by Lucy Dean

Figure 2. Image by Lucy Dean

- Field of view 2ft
- Distance from object to lens 4 ft
- Focal Length 53mm
- Camera: Canon EOS Rebel XS
- Format: Digital, Original and final Image width 3888 pixels, height 2592 pixels. Taken with a Canon Rebel XS.
- Aperture f/5.6, shutter speed 1/100s, ISO setting 1600
- Nothing was done to the image in Photoshop.

"The image shows the flame flowing up and the liquid being poured down. You can clearly see the liquid in focus and a little splash at the bottom. The flames are rising up in the beaker. The puddle under the beaker is just starting to form, and you can see the liquid flowing away. I really like the colors in the image and the shape the flames are making. I don't love that the stand is in the picture, but I like the line it creates. I like how the bottom of it seems to disappear because it is hidden behind the fire. If I could do it over I would want a quicker shutter speed to try and decrease the motion blur in the image; however, when we tried to increase the shutter speed we weren't getting enough light into the camera. The red and blue colors come from impurities being kicked up and catching fire; I think they make an interesting addition to the image."

Image #2 by Tim Jarrell

Figure 3. Image by Tim Jarrell

- The field of view: 2.5 ft
- Distance to object: 4 ft
- Focal length 44 mm, aperture f/5.6, exposure of 1/160 sec, ISO of 1600
- Camera: Canon EOS Rebel XT
- Format: Digital, original image size: 3,456 x 2,304 pixels, final image size: 2,367 x 2,199 pixels.
- The only changes made to the original were a simple crop and the stamping out of the vertical test stand rod and the three-pronged clamp using iPhoto.

"My image reveals the nature of a flaming fluid when poured and directly after impact. The image was taken about half a second into the pour when the gas created a vortex swirl while leaving the beaker. This vortex was captured only in this image and is very unique to this project. Additionally, the impact on the ground shows the spreading of the flaming pool. Lastly the clear contradiction of the liquid and flame is apparent and an excellent visualization of it. What I most enjoy about this image is the smooth liquid flame flow with the swirl coming out of the beaker. If I were to do this over again I would not change much since we captured hundreds of unique and wonderful images."

Image #3 by Joe Duggan

Figure 4. Image by Joe Duggan

- The field of view: 2.5 ft
- Distance to object: 4 ft
- Focal length 55 mm, aperture f/5.6, exposure of 1/160 sec, ISO of 1600
- Camera: Canon EOS Rebel XT
- Format: Digital, original image size: 3,456 x 2,304 pixels, final image size: 3,354 x 2,304 pixels.
- The only changes made to the original were a simple crop and the stamping out of the vertical test stand rod and the three-pronged clamp using iPhoto.

"This image contains all the elements I had envisioned. The flow of the liquid is very clearly visualized—perfectly in focus. The flames that surround the cascading liquid completely envelope it, and create a very nice laminar flame-flow as well as what appears to be a crude vortex forming slightly outside the top border of the image. The shape and color of the pool formed is also very much to my liking. What truly set this image apart from the others, though, is the splash pattern formed at the impact site; this is the feature that I was most hoping to get out of this project during its conception. The only drawback to the image is that it was taken a bit too close, cutting out the lower edge of the flaming pool."

The project was a complete success. Not only did it provide us with images that exactly mirrored our intent, it also gave us images that we weren't expected at all (included in appendix). The other images included in this submission also show great phenomena, including a much larger spectrum of colors caused by a faster pour and the kicking-up of more impurities from the concrete. We are also very proud of the fact that the colors and effects in the image are completely true to the original materials instead of being edited in. At this point, the team is considering moving forward with this concept and adapting it to the 3D methods recently introduced in class.

Works Cited

[1] David Harbaugh et al. (2004), *Group Project 1*. University of Colorado – Boulder, Mechanical Engineering.

[2] Levine, D. (2007). *Group Project 2*. Project Report, University of Colorado - Boulder, Mechanical Engineering.

[3] Wallace Racing. (n.d.). *Free Fall Calculator*. Retrieved April 8, 2009, from Wallace Racing: http://www.wallaceracing.com/free-fall-math.php

[4] eFunda. (n.d.). *Reynolds Number Calculator*. Retrieved April 7, 2009, from eFunda engineering fundamentals: http://www.efunda.com/formulae/fluids/calc_reynolds.cfm#calc

Appendix

Figure 5. Pour from front

Figure 6. Abstract multi-colored flame 1

Figure 6. Pour from side with splash

Figure 7. Abstract multi-colored flame 2

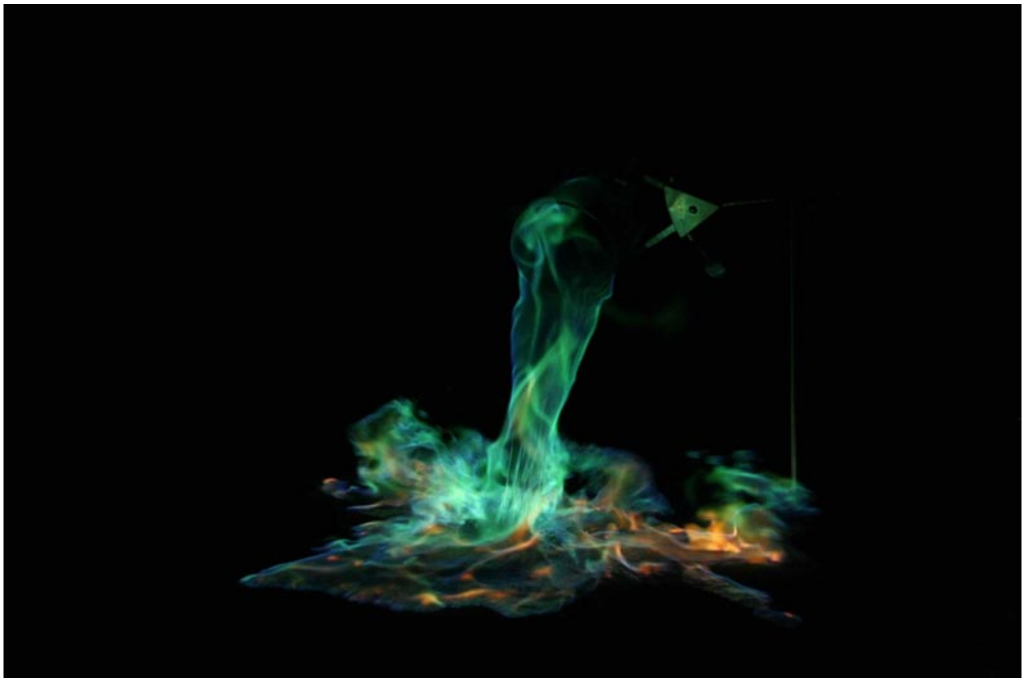

Figure 8. Violent splash with vortex

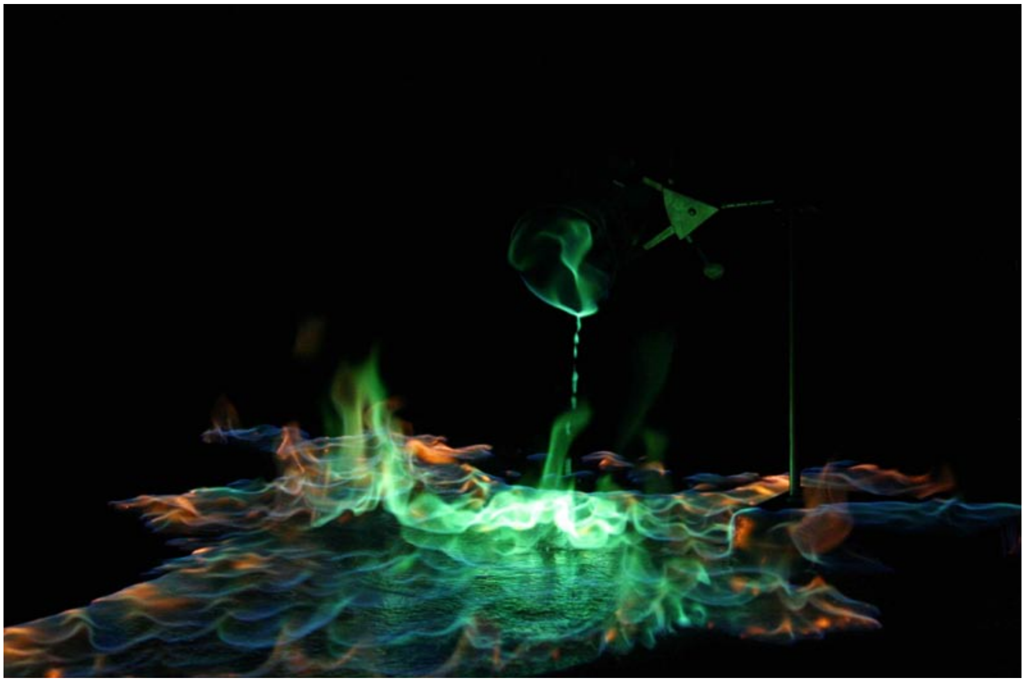

Figure 9. Drip, drip