Fire Vortex

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Flow Visualization, MCEN 5051

Image / Video Assignment #3

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Introduction

The goal of the third project was still similar to that of the previous ones. I wanted to image fluid dynamics in an aesthetic and creative way. However, in the previous projects, I had imaged liquids for both. Moreover, both previous assignments were done with oil, water, and dye. For this project, I wanted to do something entirely different and work on expanding my skills with more experience. For that reason, I chose to image fire. I found out that by spinning a perforated trash can with a flame source inside, a fire vortex column will form from the airflow. I struggled more than I expected to with this image, but I learned a lot from it.

Fluid Dynamics Used

Vorticity Accelerated Combustion:

Looking at the combustion chemical equation for isopropyl alcohol we can see that an important part is oxygen which serves as the catalyst for the reaction.

$$C_\alpha H_\beta O_\gamma + \left(\alpha + \frac{\beta}{4} - \frac{\gamma}{2}\right)(O_2 + 3.77N_2) \longrightarrow \alpha CO_2 + \frac{\beta}{2}H_2O + 3.77\left(\alpha + \frac{\beta}{4} - \frac{\gamma}{2}\right)N_2$$

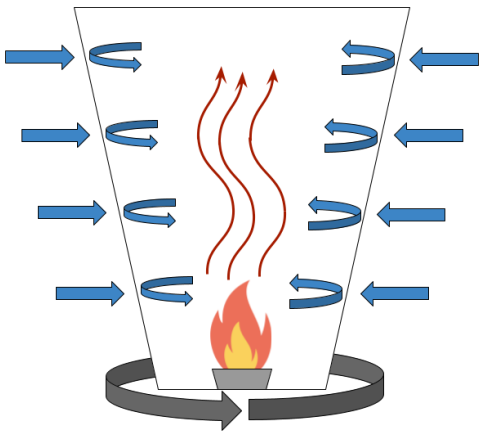
EQ 1. Standard $C_\alpha H_\beta O_\gamma$ Fuel Reaction Chemical Equation in Air

To create the fire tornado air is "sucked in" by the spinning trash can. The trashcan imparts angular momentum on the volume of air in the form of shear forces as it enters the trash can, thus the air is flowing with vorticity relative to the flame source.

$$\vec{\omega} = \nabla \times \vec{v} = \begin{pmatrix} \frac{\partial}{\partial x} & \frac{\partial}{\partial y} & \frac{\partial}{\partial z} \end{pmatrix} \times \begin{pmatrix} v_x & v_y & v_z \end{pmatrix}$$

EQ 2. Fluid Vorticity Field Equation

This circulation of air provides fresh oxygen to the flame source and increases the rate at which the combustion reaction can take place as more fresh oxygen is introduced. The heat of the reaction creates an upward convection current and causes the flame to rise. As it rises the vorticity in the air imparts its angular momentum on the flame and causes the flame volume to also rotate.



Producing the Flame Vortex

This setup seemed trivial, yet creating the flame vortex was not as easy as I imagined. At a high level, to create the flame vortex a perforated trash can, a small heat resistant container, isopropyl alcohol, cotton balls, and a method to spin the trash can are all required. To make the flame source, soak the cotton balls in the alcohol, then place the soaked cotton in the heat-resistant container (I used a metal food ramekin). Then the container needs to be adhered to the center of the inside base of the trashcan. Then to create the vortex it is as simple as lighting the alcohol on fire and spinning the trash can. To spin the trash can I recommend using a lazy Susan. I did not have a lazy Susan and I ended up getting the best results mounting the trash can to a drill and spinning it that way. Spinning burning liquid can be dangerous so be careful if you attempt this.

Camera Setup and Image Acquisition

The setup for this experiment was somewhat complicated. I used a custom 3-D printed bearing mount to rotate the can. I also placed a small DC motor with speed control next to the trash can in order to rotate it while I was operating the camera. That whole setup was placed on a stool in front of a black paper background. I used a 16-35 mm f/4L IS USM Canon Lens. The camera used is a Canon 1dx mark ii DSLR camera and the image settings were set at 35 mm, ISO 8000, f/5.6, at exp 1/1000 sec.

Fig.4 Camera Setup

The photo was post-processed in photoshop and lightroom. The main edits were cropping and simple color grading. The main goal of the editing was to enhance the brightness and warmth of the fire, as well as make the grating of the trashcan less distracting and visually helpful. I also used photoshop to remove some noise from the high ISO.

Conclusion

The goal of this project was to challenge myself to image a flow that was not a liquid and to also image in low light. I think I did both of these things relatively well. What I was mainly disappointed by was the fact that I was unable to get the full fire vortex to work. Getting the rotation speed and the rotation axis right was critical and it took more time than I was expecting.

References

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https://en.wikipedia.org/wiki/Vorticity

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