Hannah Brothers

Flow Visualization: Team Second
With help from Cort Sommer
MCEN 5151
November 3rd, 2025

For the second team assignment of this course, I worked with Cort Sommer to capture how a flame is affected by a forced burst of air. To do this, we created a mini air gun out of a balloon and solo cup, and used it to shoot air bursts at a small flame. We originally intended to use the solo cup to create a vortex to be shot at the flame, but this did not result in the photos we had anticipated. After learning that our original intent could not be met, we decided to capture a photo that demonstrates how small shots of air could affect a flame. Additionally, both of us are new to photography, so we intended to use our recently gained skills to learn how to better capture images of flames at night.

The set-up was created by setting a flammable fire-starter cube onto a baking dish, which was set on 4 solo cups in order to be fully off the ground. The cube was then set on fire, allowing for approximately 10 minutes of burn time. As the flame burned, bursts of air were shot at it in different directions, influencing the flame. In this particular image captured, the flame can be seen enveloping the cube, with a small break on the left side, where a burst of air interrupted the burn. On the right side of the image, sparks can be seen trailing upwards during the exposure. All experiments were conducted on an outdoor concrete pad, with a fire extinguisher and water nearby. All other combustion safety guidelines were followed.

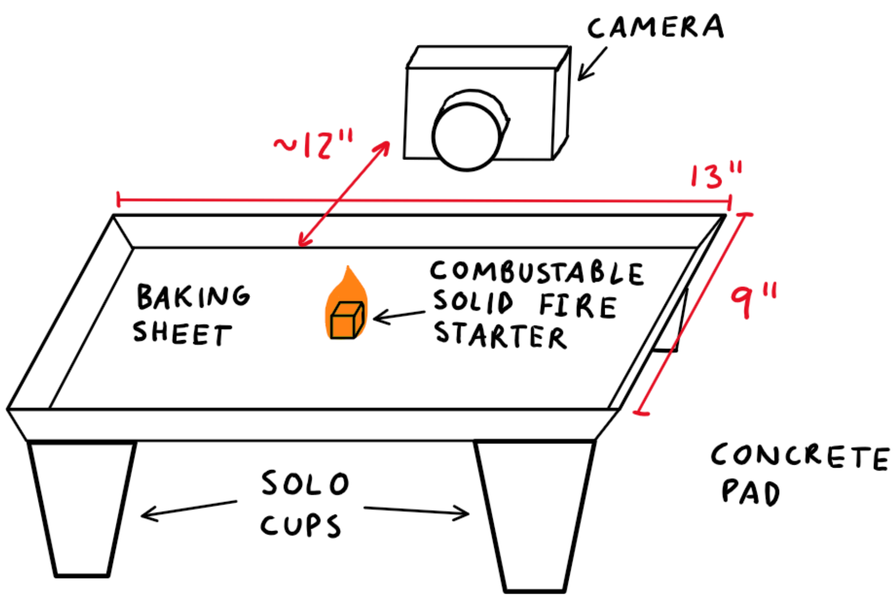

Fig.1. Set-Up Schematic

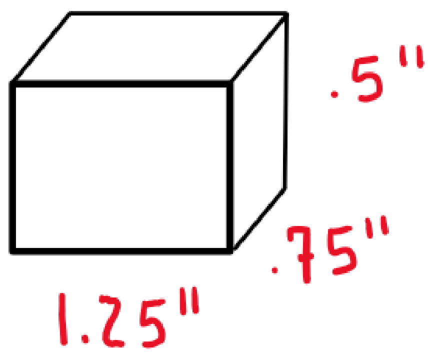

Fig. 2. Fire Starter Dimensions

Several aspects can be examined from this flow, both as how the flow is affected by the air bursts and how the flow demonstrates a method of combustion. To examine the air's effect on the flow, the Reynolds number can be evaluated. This will be examined in two locations. Although the flow appears to be laminar in both locations, this must be proven by calculating a Reynolds number less than 2300. The first location to be examined is on the right side of the image, where sparks can be seen trailing upwards during the exposure. The second location is on the left side of the image, where the flame has been disturbed and has an upwards plume. Both Reynolds numbers can be calculated using

$$Re = \frac{U\ L}{\nu} \qquad \text{Equation (1)}$$

Where U is the fluid's velocity, L is a characteristic length of the flow, and ν is the kinematic viscosity. For this experiment, ν will be assumed to be the kinematic viscosity of air at 1200K. This temperature was chosen based on the orange and red colors of the flame in the original image. For the first area of interest, a Reynolds number was calculated using the distance that the sparks traveled while the shutter was open and a characteristic length of the height of the sparks. This Reynolds number was calculated to be 122. For the second area of interest, the Reynolds number was calculated using the amount that the plume traveled while the shutter was open and a characteristic length of the size of the opening below the plume, which is also approximately equal to the height of the plume. This Reynolds number was calculated to be 245. Both of these Reynolds numbers validate that the fluid flow is laminar, however it is important to note that the second Reynolds number is twice that of the first. This shows that there is faster-traveling flow where the flame was influenced by the air, due to the higher velocity of the air burst.

Other important aspects of this flow that should be examined are the methods of heat transfer and combustion for this experiment. This is important to discuss, as combustion and heat transfer can occur through several mediums and in many different manners. Heat transfer during the combustion of a solid can occur by the flame's radiation, conduction or convection of the gas of the flame, or conduction through the solid. Oftentimes, all three of these methods occur, however there is typically one that prevails. For a flame spreading over a solid, as is the case for this experiment, heat transfer through conduction through the solid is most prevalent [1]. This aligns with the method of combustion. For this experiment, combustion occurs through a process called smoldering. Smoldering is a form of combustion where heat is released by the oxidation of a solid porous medium [3]. The general chemical equation that describes smoldering is given below [3]

$$Solid\ Fuel\ +\ O_2 \rightarrow Solid\ Product\ +\ Gaseous\ Product\ +\ Heat$$

For this experiment, the solid fuel is the fire starter and the solid product is char (which can be seen atop the fire starter cube). This experiment demonstrates a small-scale version of smoldering; however, it is an important form of combustion to understand as many materials are porous, such as wood, and can combust through this process.

To visualize this flow, a Esbit Solid Fuel Cubes fire starter was lit, while air bursts were shot at the flame. The air guns were created by tying an un-filled balloon and then cutting the lower half of it off and stretching the tied section over the mouth of a solo cup. A circular hole was then cut on the bottom of the solo cup, with approximately a 0.75 inch diameter. When the balloon is stretched back and released, a concentrated burst of air is created. All photos were shot at night, allowing for the flame to act as the photo lighting. Additionally, minimal winds were present, in order to not influence the flame.

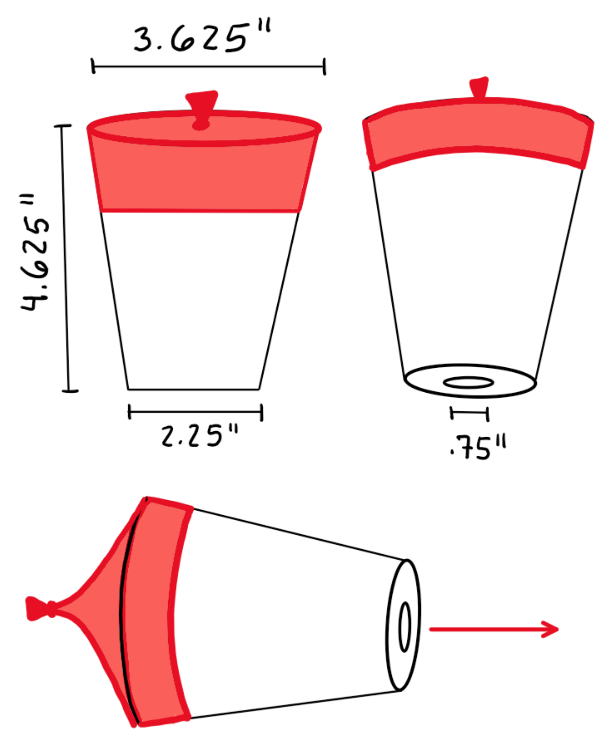

Fig. 3. Schematic of Solo Cup

This fluid motion was captured on my Nikon D80 camera with an ISO of 250, a shutter speed of 1/30, and an aperture of f/5.6. This was taken with an 18-135mm lens with a focal length of 80mm. The field of view is approximately 6 times the diagonal width of the cube by approximately 5 times the diagonal width of the cube. This is about 9 inches by 7.5 inches. The flow phenomena was approximately 12 inches from the camera lens. The original image had pixel dimensions of 3900x2611 and the post-processed image had pixel dimensions of 3746x2611. During post-processing I altered the color calibration, exposure, sigmoid, rgb curve, color balance rgb, contrast, and crop. My primary intent with post-processing was to increase the saturation of the flame's color and to bring out the blue in the flame.The original image before cropping and post processing is shown below.

Fig. 4. Original Image for Team Second

Overall, this image reveals the manner in which a flame can be disturbed by a concentrated burst of air. The image shows a viewer both how a flame can form around a fire starter, and how it can be easily influenced. When the science of the image was evaluated, it was determined that the primary mode of heat transfer is through conduction of the fire starter and the form of combustion is smoldering. Artistically, I like how well this image captures the full range of colors present, and how ghost-like it appears. I feel that I have fulfilled my intent with this image, especially by learning more about how to capture images of flames at night and how to show the beauty and malleability of a flame. After photographing this image, I am curious to see if there is a better way our team could have tried to capture a vortex influencing a flame. If I were to develop this idea further I would try cutting different sized holes in the air guns to create larger vortices and perhaps try shooting a vortex from directly above the flame.

REFERENCES:

[1]A. Fernández-pello, and F.A Williams. "A Theory of Laminar Flame Spread over Flat Surfaces of Solid Combustibles." *Combustion and Flame*, vol. 28, 1 Jan. 1977, pp. 251–277, https://doi.org/10.1016/0010-2180(77)90032-3. Accessed 23 Mar. 2025.

[2]Engineering Toolbox. "Air - Dynamic and Kinematic Viscosity." *Engineeringtoolbox.com*, 2003, www.engineeringtoolbox.com/air-absolute-kinematic-viscosity-d_601.html.

[3]Schult, D A, et al. "Propagation and Extinction of Forced Opposed Flow Smolder Waves." *Combustion and Flame*, vol. 101, no. 4, 1 June 1995, pp. 471–490, https://doi.org/10.1016/0010-2180(94)00239-o. Accessed 3 Nov. 2025.

APPENDIX:

A. Calulations
    a. General Properties, Assumptions, and Notes:

Property (With reference #)	Name	Value
U_{flame}	Estimated Velocity of Flame	$1in/(1/30s) = 2.5\,ft/s$
L_{flame}	Characteristic Length of Flame	$1in = 0.083ft$
U_{plume}	Estimated Velocity of Flame Plume	$2in/(1/30s) = 5.0\,ft/s$
L_{plume}	Characteristic Length of Flame Plume	$1in = 0.083ft$
$\nu_{air,1200K}$	Kinematic Viscosity of Air at 1200K[2]	$16.926ft^2/s \times 10^{-4}$

Assumptions:

- The flame is at approximately 1200K

- The experiment was conducted at 1atm
- The characteristic length of the flame is based on the height of the sparks captured on the right side of the image
- The characteristic length of the flame plume where the air burst influenced the flame is based on the height of the hole in the flame

Equation 1: $Re = \frac{U\ L}{\nu}$

b. Reynold's Number Calculations for Flame:

Equation 2:

$$Re = \frac{U_{flame} L_{flame}}{\nu_{air,\,1200K}}$$

$$Re = \frac{(2.5 ft/s)(0.083 ft)}{16.926 ft^{2/s}}$$

$$Re_{flame} = 122 \rightarrow laminar\ flow$$

c. Reynold's Number Calculations for Flame Plume at Air Burst Influence:

Equation 3:

$$Re = \frac{U_{plume} L_{plume}}{\nu_{air,\,1200K}}$$

$$Re = \frac{(5.0 ft/s)(0.083 ft)}{16.926 ft^{2/s}}$$

$$Re_{plume} = 245 = 2Re_{flame} \rightarrow laminar\ flow$$