Team Second Fall 2025

Blue Flame Vortex

Nathaniel Wheaton Flow Visualization 5151-001, 11/2/2025

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Figure 1: A blue flame vortex viewed from above

Intent

The scientific intent of this experiment is to explore the formation and development of a fire vortex generated by creating a rotating column of air. The color of the flame helps to visualise the air currents which make up the vortex. I chose to visualise vortexes because I have always been fascinated by the fine details in their motion, and decided to continue the “Theme” from Team First.

Experimental Setup

We generated a vortex using a wire mesh trash can attached to a variable rate fan (acting as a turntable) which rotated the entire column of air within the enclosure. This vortex generator utilised a Sterno chafing fuel dish, at the moment of the photo, the vortex was ~6 inches tall. The mesh trash can had a diameter of ~1 ft, and a height of ~1.5 ft. The rate of rotation was controlled with an adjustable wall light switch dial wired into the cable for the fan, the optimal rate of rotation was ~0.5 Hz (≈30 rpm). For lighting, there was no additional lighting needed as the flame is self illuminating.

Flow Analysis

The fire vortex was initiated within the column of heated air above the Sterno fuel dish. The flow was generated by the rotation of the mesh trash can and fan assembly. This rotation imparted velocity to the air, creating a rotational column of air which twisted upward, forming a vortex similar to small-scale whirlpools observed in swirling flows [1]. We can calculate the Reynolds number using the outer diameter for our characteristic length and finding the velocity from the rotational rate, using ν = 1.6*10^-4 ft/m^2 for air.

$$Re = \frac{UL}{\nu} = \frac{2\pi r f L}{\nu} = \frac{2\pi * 0.5 * 0.5 * 1}{1.6 * 10^{-4}} = 9817.5$$

This relatively high Reynolds number indicates that the outer region of the rotating cylinder was turbulent, while the inner core, having a smaller diameter, experienced lower Reynolds numbers and likely remained closer to laminar behavior. This aligns with observations of swirl-driven vortices, which maintain coherent rotation but are prone to instabilities as the Reynolds number increases [2]. During the capture process, I noticed that there was a critical speed at which the flame vortex was the most stable, this is somewhat similar to the research done by Chan *et al.* [3], their research found that as the Reynolds number changes there are regions of stability where the vortex can form without being destabilised, the velocity region I noticed may be one of these stable regions.

Photographic Technique

The image captures the overall shape of the vortex from above, including the outline of the sterno burner. The camera is pointed downwards ~45 degrees. Some of the fine details are missing from the final image, this is likely due to the denoising algorithm I used in Darktable, this could be fixed in the future by lowering the ISO and adjusting other settings to compensate for the low light conditions.

The unedited photo has a field of view of about 8 in x 6 in. The distance to the lens is about 2.5 ft. I used a DSLR camera, specifically the Canon Eos Rebel T3i. The original dimensions of the image are 5202 x 3464. The F-stop used was f/7.1, the exposure time was 1/50 sec, the ISO was 6400, the focal length was 55mm. The original image is shown below:

As can be seen in the unaltered image, there is quite a bit of graininess due to the high ISO used. I fixed the large amount of graininess by using denoise in Darktable. Additionally I cropped the image to highlight the phenomenon, the final image has a resolution of 634 x 900 pixels.

References

[1] M. Ghodrat, F. Shakeriaski, D. J. Nelson, and A. Simeoni, “Experimental and numerical analysis of formation and flame precession of fire whirls: A review,” *Fire*, vol. 4, no. 3, p. 43, 2021, doi: 10.3390/fire4030043.

[2] F. Maršík, Z. Trávníček, B. Weigand, F. Seibold, and Z. Antošová, “Swirl flow stability: Thermodynamic analysis and experiments,” *Continuum Mech. Thermodyn.*, vol. 36, pp. 891–910, 2024, doi: 10.1007/s00161-024-01303-6.

[3] S. T. Chan, J. T. Ault, S. J. Haward, E. Meiburg, and A. Q. Shen, “Coupling of vortex breakdown and stability in a swirling flow,” *Phys. Rev. Fluids*, vol. 4, no. 8, Art. no. 084701, Aug. 2019, doi: 10.1103/PhysRevFluids.4.084701