

Fire Vortex Flow

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Course: Flow Visualization (MCEN 4151)

Assignment: Team Third



Figure 1 - Final image of fire vortex with post-processing.

Context and Intent

This image was created for the Team Third assignment, where our group set out to visualize a controlled fire vortex, or “flame tornado.” The scientific intent was to capture how buoyancy-driven combustion flow interacts with imposed swirl inside a cylindrical confinement to form a coherent, rotating flame column. The artistic intent was to isolate a tall, vividly colored flame vortex against a completely dark background, emphasizing its spiral structure and multi-hued gradients. After testing single- and dual-source setups, the final image was obtained from a quad-source configuration, which produced the most dramatic and stable vortex.

Flow Apparatus and Physics

Apparatus Geometry and Setup

The vortex chamber consisted of a cylindrical steel-mesh wastebasket 14.75 inches (0.375 m) tall with a 9.25-inch (0.235 m) diameter, mounted on a rotating turntable. Four shallow metal fuel trays were arranged underneath in a 2×2 grid, each containing ~12 cotton balls soaked in 100% methanol (HEET). Approximately 3 tablespoons of methanol were used per run.

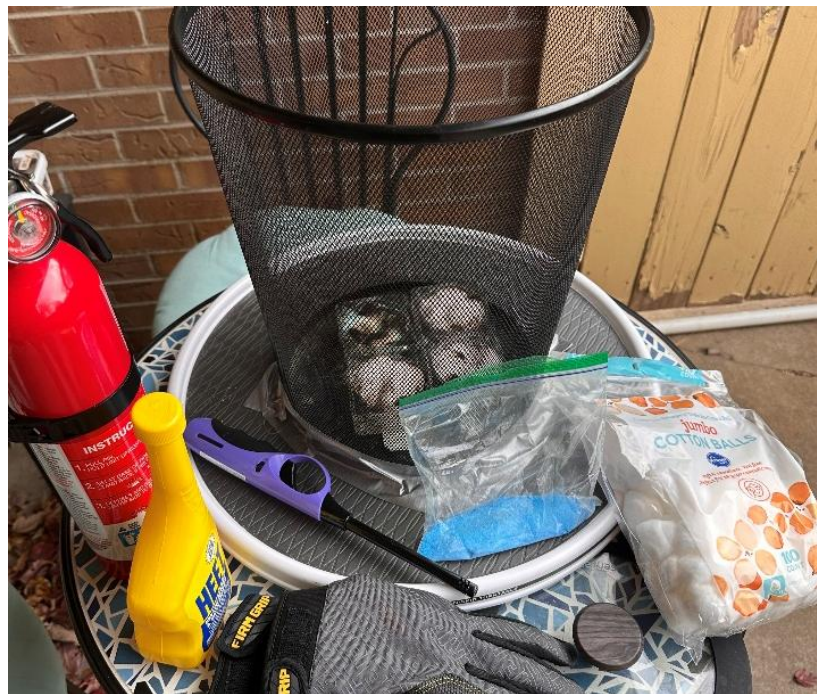


Figure 2 - Apparatus setup

Safety Plan

Safety procedures followed the official Team Third Flow Visualization Plan. Key measures included:

Equipment

- Class B/ABC fire extinguisher within arm's reach
- Metal pot/lid used to suffocate the flame and remove oxygen
- Heat-resistant gloves
- Long-reach lighter for safe ignition
- Non-flammable work surface: concrete/metal

Operational Safety Precautions

- Experiment performed in a well-ventilated, fire-safe area
- Only one designated team member ignited or adjusted the flame
- No loose clothing; long hair tied back
- Fuel volumes intentionally minimized (3 tbsp methanol)
- Never left flame unattended
- Turntable and mesh handled using gloves
- Flame extinguished by smothering with a metal lid
- Area confirmed cool before cleanup

Our team adhered strictly to these precautions throughout testing, including during single, double, and quad-flame trials.

Color Chemistry

To create multi-color emission, only two of the four fuel trays contained copper sulfate powder.

- Copper-treated flames emitted strong blue/green (Cu^+ transitions).
- Untreated flames emitted yellow/orange (sodium from cotton) and blue/purple (methanol).

As the plumes merged, this produced asymmetric color bands that wrapped helically around the vortex column.

Flow Physics

The fire vortex results from the interaction of buoyancy, swirl, and confinement. The methanol flames generate a strong buoyant plume that draws cooler air inward at the base. When the cylindrical mesh is rotated, the incoming air acquires tangential velocity, creating azimuthal flow around the flame. As the hot gases rise, this swirl is stretched vertically, intensifying rotation and tightening the flame column into the helical shape seen in the final image.

Because the final setup used four ignition sources, each plume initially produced its own entrainment zone and vorticity field. As these plumes rose into the confinement chamber, their shear layers interacted and merged, forming a single coherent vortex. The uneven coloration, due to copper sulfate added to only two sources, reveals this merging process, showing how the distinct flame regions twist together as they ascend.

The cylindrical mesh further stabilizes the vortex by smoothing the inflow and suppressing large-scale turbulence. Combined with the manually imposed rotation of roughly 40 rpm, this confinement maintains a narrow, stable core that sustains a visually distinct vortex for several minutes.

Nondimensional Analysis

- Visible flame height: ~18 inches (0.46 m)
- Estimated vortex diameter: ~4 cm (0.04 m)
- Rotation rate: ~40 rpm (4.19 rad/sec)

Tangential Velocity

$$u_{\theta} = \omega r = 0.084 \text{ m/s}$$

Buoyant rise velocity estimate for methanol flame: $U \approx 0.5 \text{ m/s}$

Reynolds Number

$$Re = \frac{UD}{\nu} = \frac{0.5 \cdot 0.04}{3 \times 10^{-5}} \approx 670$$

This indicates transitional flow, consistent with the coherent but wrinkled flame sheet seen in the image.

Swirl Ratio

$$S \approx \frac{u_{\theta}}{U} = 0.084/0.5 \approx 0.17$$

a moderate swirl sufficient to tighten the flame column.

Pressure Deficit

$$\Delta p \sim \frac{1}{2} \rho u_{\theta}^2 \approx 0.004 \text{ Pa}$$

Typical of small-scale swirl-dominated buoyant plumes.

Visualization Technique

The flame served as its own illumination source. No external lighting was used. Color was enhanced only through the copper sulfate added to two of the four trays. Earlier tests with potassium chloride and boric acid were not part of the final image. Running the experiment in a darkened room eliminated background distractions and ensured the high contrast needed to isolate the vortex.

Photographic Technique

Camera: Canon EOS 7D Mark II

Lens: Sigma 150–600 mm f/5–6.3, set to 546 mm

Distance: ~2.5 m, mounted on a tripod

Exposure Settings

- ISO Speed: ISO-10000
- Shutter Speed: 1/60 sec
- F-Stop: f/6.3

The fast shutter speed was crucial for freezing rapid flame-sheet motion.

Post-processing (no sharpening or noise reduction applied):

- Brightness +25%
- Contrast +75%
- Saturation –15%
- Structure +40%
- Shadows –15%
- Warmth +15%
- Red +5%, Green +10%, Blue 0%
- Highlights +10%, Midtones –5%, Shadows –10%, Blacks –10%

- WB Temperature +16, Radius 5 px

These edits were performed in Nik Collection Viveza, maintaining physically realistic flame colors while increasing clarity. The final image was cropped in Photoshop from 3670 x 5496 pixels in the original to 2296 x 2296 pixels in the final.

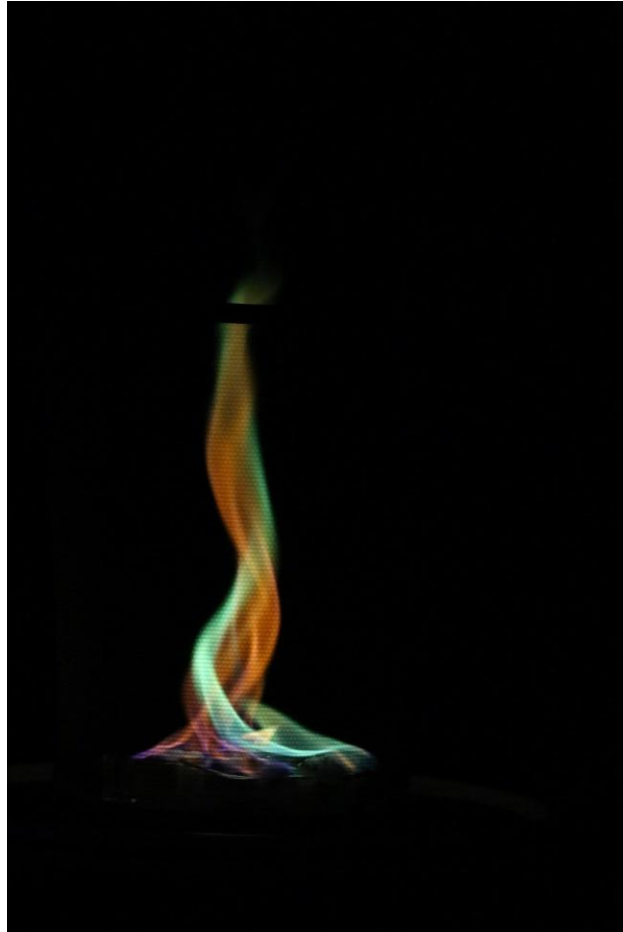


Figure 3 - Original photograph (jpg) before post-processing.

Interpretation and Reflection

The final image clearly reveals the spiraling structure of a buoyancy-driven, swirl-supported fire vortex. The decision to add copper sulfate to only two of the four flames created a naturally uneven color pattern that made the merging dynamics visible in a way that symmetric coloring would not.

Artistically, the multi-hued, elongated spiral against a completely black background gives the flame a dramatic, almost sculptural quality. Scientifically, the image captures transitional-scale turbulence, vortex merging, and swirl-enhanced flame stabilization.

A minor limitation is faint moiré from the mesh cylinder; using a finer mesh or a thin internal diffuser could reduce this.

Overall, the image successfully fulfills both the artistic and scientific goals of the assignment and is reproducible using the documented geometry, fuel parameters, and safety procedures.

References

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