Owen Brown

Team 1st Report

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This film was a collaborative effort involving Chris Davidoff, Mathew Davis, and Casey Munsch. The flow phenomena observed is a buoyant plume rising, with a transition present from laminar to turbulent behavior. A mesmerizing film that captures the eye as the physics of the flow change, along with the colors, across the frame.

The smoke release by a combustion process is a well-research problem because of its relation to air quality (e.g. carbon monoxide in industrial factories/kitchens and second-hand cigarette smoke in public places), and the fundamental understanding of the smoke dynamics is essential to proper smoke management systems. So, what is going on when we blew out the small flame? The source of the smoke is made of hot combustion products that have a gradient, or difference, in temperature from their ambient surroundings. This temperature gradient creates a change in density gradient creating a buoyant force causing the products to rise. This type of plume is referred to as a buoyancy-driven round plume, with open boundary conditions [1].

The plume is broken into two regions, the laminar zone and the turbulent zone. Entering the frame of the film is the thin laminar sheet flow that is smooth, until it is perturbed mid-way transitioning to a turbulent mix of chaotic motion. This instability is known as the Kelvin Helmholtz instability, which is mixing the unseen air with the smoke. The Richarson number can be a good indicator for how unstable the interaction will be. It is expressed as,

$$Ri = \frac{\frac{g}{\rho}\nabla\rho}{(\nabla u)^2}$$

where $\nabla\rho$ is the change in density across the fluids, g is gravity, and ∇u is the velocity across the interaction. The critical Ri = 0.25, which any number less is dynamically unstable[2].

In order to isolate the flow behavior, we used a mini-projector to create a light field in an otherwise dark room. Figure 1 below is a screen capture of one isolated vortex about to form. This filming technique highlights the flow formation more so than having the more come all the way across the screen. It helps to isolate and frame what is happening within the shot, rather than all of this thinned smoke outside of focus.

Figure 1: Screen capture of plume forming a vortex as it rises in view of the projector

The shot was captured by Chris Davidoff, on his Nikon D850. This camera used a prime-lens set-up with a 55mm f/1.4 and a fixed tripod. The focus is on the lower half of the plume. The camera was recording at 120 frames/second, an ISO of 2500, and the video picture was 1080p. The high frame rate achieved a slow-motion effect of 4x and there was additional editing that slowed the motion to 8x. All of the video editing and slide-work was done using the ITLL's licensed video software. No outside color effects were added to maintain the physical experiments true of colors.

This film captured so much more than I had expected with the original experiment. Having the plumes appear in easily digestible laminar flow and develop as they twist into beautiful vortices only to disappear just before they would normally dissipate. It just has a calming effect to the viewer. The ambient dilute colors of the projector add to the frame. Other than some framing issues with an imperfect background I really enjoy this piece. Overall, an interesting piece to watch with even more interesting fluids going on.

[1] Merci, B., & Beji, T. (2016). *Fluid mechanics aspects of fire and smoke dynamics in enclosures*. Boca Raton: CRC Press/Taylor & Francis Group.

[2] Kundu, P. K., Cohen, I. M., Hu, H. H., & Ayyaswamy, P. S. (2010). *Fluid mechanics*(4th ed.). Amsterdam: Academic Press.