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MCEN 4151 Flow Visualization
Spring 2018

Plume Glow

Figure 1. A screen capture from "PLume Glow" video

Team First Report
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Music courtesy Josh McNulty

Flow Visualization Spring 2018
Prof. Hertzberg
Mar. 2, 2018

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The quality and amount of art that can be created from a simple candle is quite remarkable. This video was produced as a first team project for Team Epsilon in Prof. Hertzberg's Flow Visualization class. Even though there was only one candle, many hands required involvement in production of this image, as we wanted to harness the power of a team. Two DSLR cameras were used in the production, one Canon 60D provided by myself and a Canon {6D} provided by Phil. A video was playing on either a classroom projector or one provided by Phil, dictated experimentally. Zachary and Yousef manipulated the candle while Eric helped with conception of the project and helped teammates bring the project to completion. I wanted to explore how quadcopters would interact with the fluid, but no quadcopter could be located in the time allotted for the experiment. We practiced healthy team dynamics while creating an end product that highlighted the fluid flow in unique ways.

The flow depicted in the video seems relatively simple: a candle extinguished results in smoldering combustion, thus providing smoke. The smoke is a particulate (solid) matter that results from incomplete combustion of the wax fuel due to low heat. Because the particulate matter is hot, it is propelled upward by a buoyant force. It diffuses outwardly into the surrounding air, while the air diffuses inwardly to the smoke. Once it cools, the buoyant force is no longer dominant, thus the smoke is propelled by the surrounding air. It exhibits the Rayleigh-Taylor instability resulting in the formation of vortices. Pictured in Fig.2 is an approximation of the fluid speed, *U*, at about 0.21 meters per second. The size of the plume shown is approximately *D* = 0.05m or 5cm. Assuming kinematic viscosity of the air doesn't vary from $v = 14.88 \times 10^{-5}\, {m^2}/{s}$, the Reynolds Number, *Re*, can be estimated.

$$Re = \frac{U \cdot D}{v} = \frac{(0.21\, {m}/{s})(0.05m)}{(1.488 \times 10^{-5}\, {m^2}/{s})} = 712$$

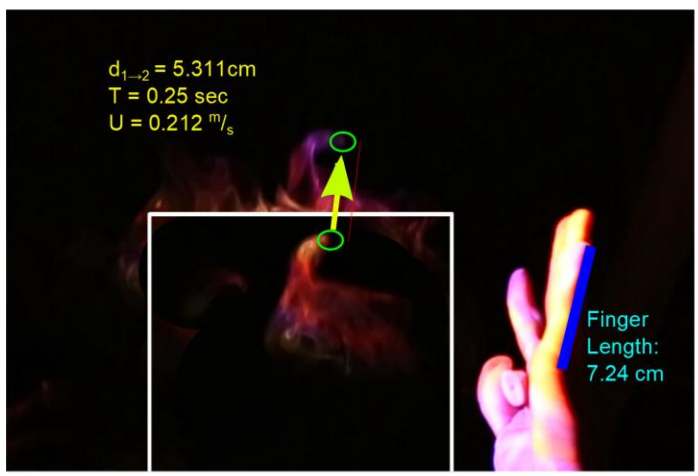

Figure 2. Estimates of scales of the flow. A test shot with hand and two flow shots 0.250sec apart show scale.

The Reynolds number appears to signal laminar flow because it is nearly below 2000, the required number for transitional flow. Other factors must be at play including the size of the room and the fact that the person holding the candle was waving it around at a high velocity to disperse smoke. The smoke was visible due to Mie scattering: the particles are large enough to scatter any color of light that interacts with them .

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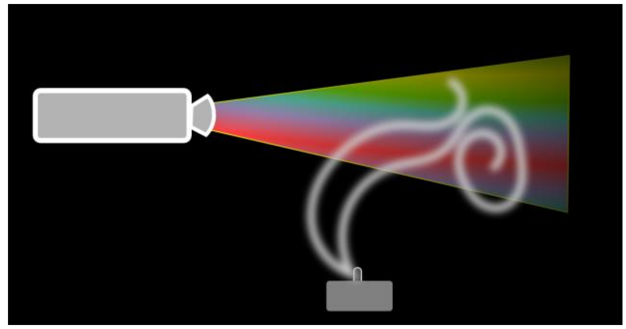

Figure 4. Diagram of setup, projector and candle

The setup for this experiment involves a candle and a projector in a large dark space. By choosing an empty lecture hall in CU-Boulder's engineering building, we were able to release large plumes of smoke while minimizing outside light. The candle used was a standard tealight candle as pictured in Fig. 4. It was lit with a lighter then blown out. One projector used was a handheld-sized projector provided by a teammate. It was set on a desk and aimed about 20˚ up from horizontal. The candle was set about 2 feet from the projector as were the cameras. The classroom projector was an EPSON brand large projector. Since it was hanging from the ceiling, the candle was safely held and waved between 2 and 4 feet away from the projector (see Fig. 3). Too close, and the projector would be in the camera's view and possibly damage the projector lens, too far and the reflected light would have been too dark. In this case, the cameras were about five feet from the phenomenon. The projectors played videos from a laptop, including "The Splendor of Color Kaleidoscope" by Ken Meyering, user HDCOLORS on Youtube: https://youtu.be/q2fIWB8o-bs The videos are provided for free online viewing, commercial sale, and noncommercial reuse.

Figure 3. Tealight candle (Wikimedia Commons)

The cameras used were both Canon DSLR cameras. The Canon 6D was capable of 60fps, 720p video and the Canon EOS 60D was capable of 24fps, 1080p video but the Class 4 SD card in the 60D limited videos to 10 seconds or shorter. The 6D produced much higher quality videos in the end, so less-than-HD video was sacrificed to make a more convincing video. In video mode, many settings were automatic, but care was taken to optimize for low light.

Post-processing for the video was handled by myself. I used REAPER Digital Audio Workstation software with the video mode enabled. This allowed me to edit the video while using advanced techniques for speed control and sound processing for the music. First I cut the videos into usable segments and sorted them into muted tracks based on their quality (See Fig. 6). No brightness/contrast adjustments were made, but speed was adjusted in certain parts (See Fig. 5). Music was recorded in an improvisational session by myself and pianist Josh McNulty a couple weeks prior to editing.

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The image reveals not just fluid dynamics but team dynamics as well. We utilized more than one piece of equipment and built off each other's ideas to produce a final product. I am practiced at editing video and audio using REAPER so that part came easily to me. It is something I could stay up all night doing, even if it causes me to lose sleep – for better or worse. Sometimes I think I made my version of the video more sophisticated than my teammates', but I am proud of what I've created. The fluid physics are quite detailed in some shots and blurry in others. A higher quality camera could be used to get a more detailed and slow-motion view of what's going on. A black backdrop would be preferred, as many of the shots have background artifacts like wooden walls, tables, and lighting fixtures. An idea I have yet to explore is what happens if a remote-controlled quadcopter was flown through the smoke. How would the motion be affected? Are there distinct patterns to how air would fly around a quadcopter?

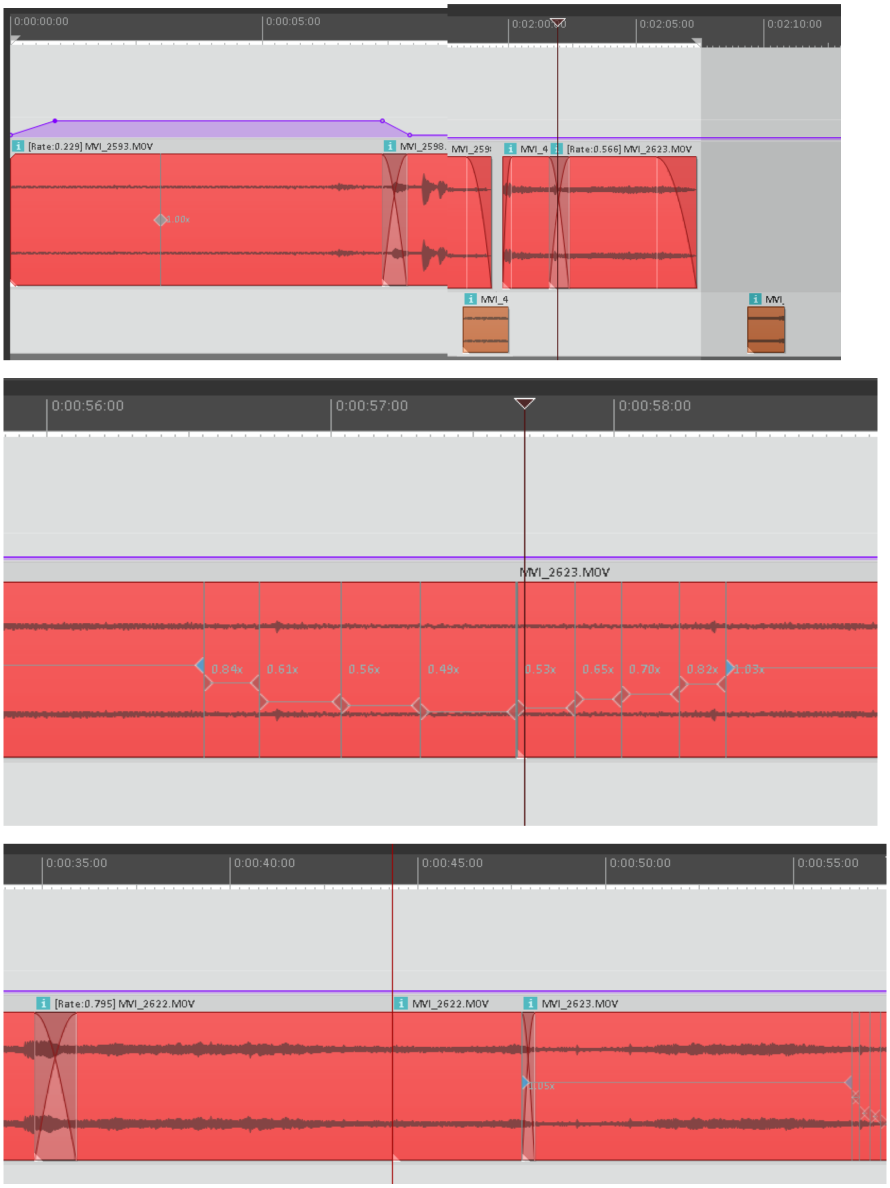

Figure 5. Playback rates at different sections in the video

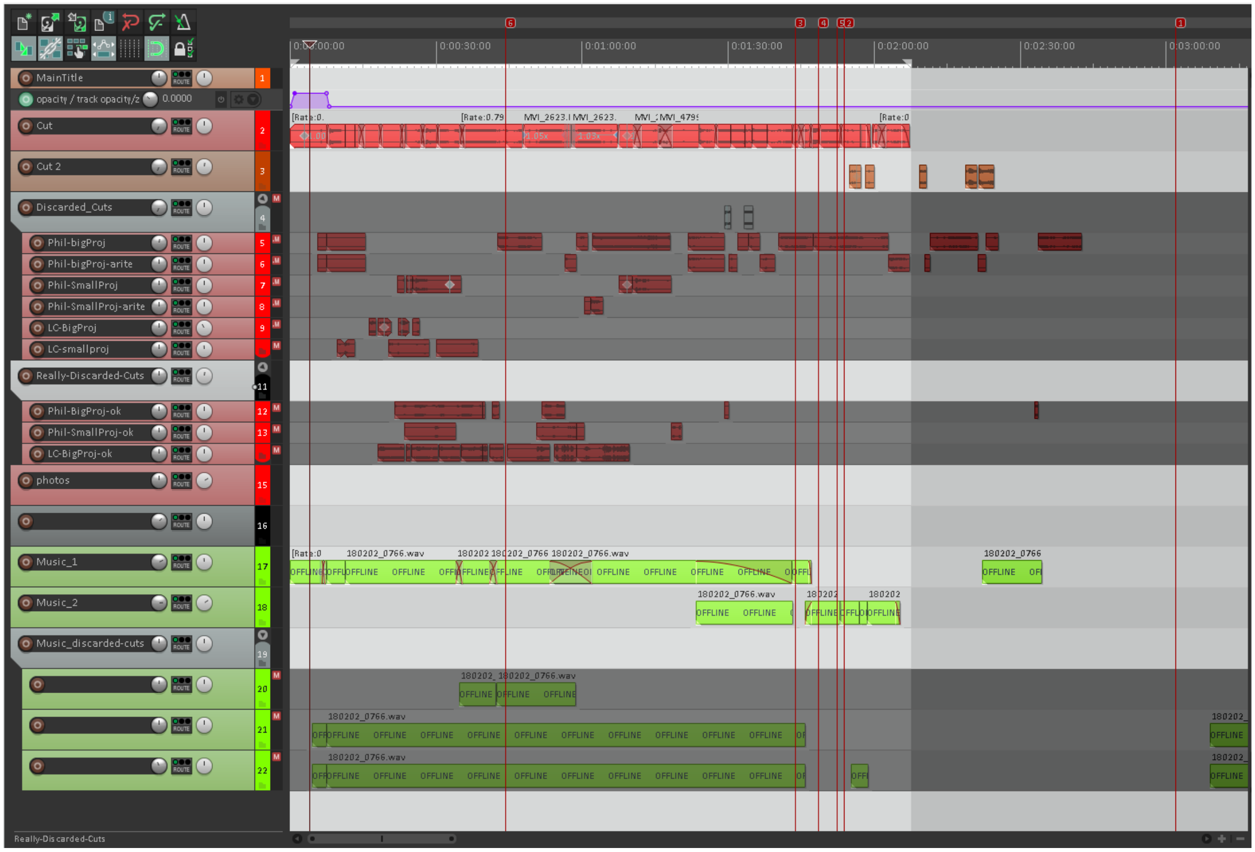

Figure 6. The entire project as exported. Dark gray is muted.

Figure 7. The final mix was taken from seventeen minutes of prepared piano improvisational music