Nitrocellulose Combustion Visualization

Group Project #1

Flow Visualization

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Purpose

This picture and associated video were created for the first group assignment for the spring 2011 Flow Visualization class at CU Boulder. The purpose of the high-speed video was to utilize an interesting and visually appealing method to investigate the behavior of nitrocellulose (C_6H_7 $(NO_2)_3O_5$) as it is burning and comparing its combustion behavior for different folding configurations (1). Since the nitrocellulose (flash paper) burns very quickly, it is difficult to see the physics of the combustion at full speed. By using the high-speed camera the team hoped to be able to see details of the combustion that would otherwise go unseen.

Experimental Setup

The experiment was set up in an interior room in the Durning Laboratory at CU Boulder, where little ambient light was present. The setup included a metal-framed stand that stood approximately 0.5 meters above the ground. From this stand a single strand of copper wire extending from the frame was mounted which held a single 3in x 2in sheet of flash paper to be combusted. The camera was located approximately 0.75m away at the same height as the paper above the ground, providing a field of view of approximately 5.5in x 7in. The background material was a black cloth that was used to heighten the contrast between the flame and the background, as well as to eliminate any distracting elements from the background (Figure 1).

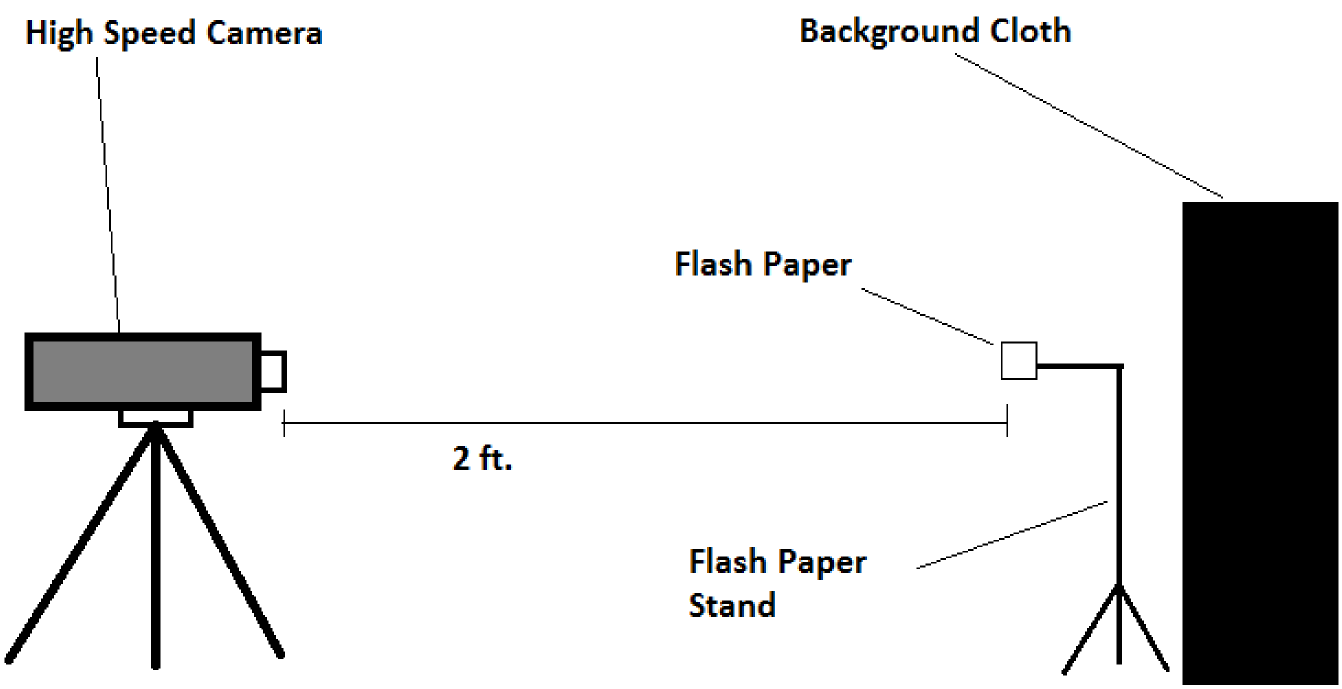


Figure 1: The setup for the flash paper combustion and video capture

The flash paper was attached to the metal wire and was mounted on the stand, which was originally designed to carry a current from a 12 Volt battery allowing it to heat up to the combustion temperature of the flash paper of 170^{o}C to ignite the paper (1). This design was later abandoned, because when the wire heated up it burned though the thin layer of paper it was attached to and the paper would drop out of the field of view before igniting fully. The team addressed this problem simply by hanging the paper from the wire and igniting it instead with a disposable butane lighter, which would prove to show interesting results in the video footage. The lighter was lit approximately one–third of a meter directly below the paper and slowly brought upwards closer to the paper until the paper combusted. It was not necessary to directly touch the flame from the lighter to the flash paper in order to cause it to ignite.

Visualization of the Combustion

The high speed camera used to capture the footage was a Vision Research Phantom series camera and the frame rate was originally set at 5,000 frames per second. The final video was edited to have a final playback speed of 40 frames per second because most of the detail could be satisfactorily viewed at this speed. At this speed, we can compare the time of the actual combustion for the two cases. The first combustion occurred over a period of 0.638 seconds, and the second combustion occurred over a period of .632 seconds. This shows that the folding arrangement (unfolded for the first combustion and folded twice for the second) made little difference in the combustion time of the flash paper. Additionally, the paper burned at similar temperatures since the color of the flames for both trials were relatively consistent (2) (3). This led the team to conclude that there was little difference in the configuration of the flash paper in its combustion behavior.

In the video it can be seen during the second combustion the flash paper and the mounting wire are ejected from the flash paper stand and the flash paper goes tumbling down out of the field of view. The flash paper in this trial was folded twice into a rectangle of approximately 1.5in x 1in. As the paper ignited, the folds in the paper formed a pocket which acted as a nozzle for the flame (Figure 2). This caused the flame to exit the fold horizontally and acted as thrust, pushing the flash paper off of its mounting on the metal bar.

Figure 2: The trail of flame to the right of the paper gave the paper thrust ejecting it from the mounting bar

The speed of the flames and ejected particles produced by the flash paper vary, but reach a maximum velocity of about 5.3 m/sec when the paper is ejected from the stand.

At approximately 1 minute 45 seconds into the video the flame from the butane lighter can be seen interacting with the flame produced by the flash paper. The difference in the combustible material and flame temperature allows the butane-derived flame to be seen within the flash paper flame. The interaction between the two flame types causes the butane-derived flame to curl into a vortex within the flash paper flame, which then disappears due to mixing.

Camera Configuration and Visualization Details

The settings and specifications of the camera can be found in table 1. The field of view was chosen to be approximately 5.5in x 7in because the team wanted the flow to fill the frame as much as possible, reducing background distractions and allowing for maximum detail of the combustion process. The distance from the lens of the camera to the flash paper was approximately 0.75m. The camera resolution was 1280 x 800, and the exposure time was 40 microseconds. The team chose to film the combustion at 5,000 frames per second rather than a faster frame rate because the Phantom camera could maintain full resolution at this frame rate. As it turned out, this frame rate was more than adequate to observe the combustion of the flash paper.

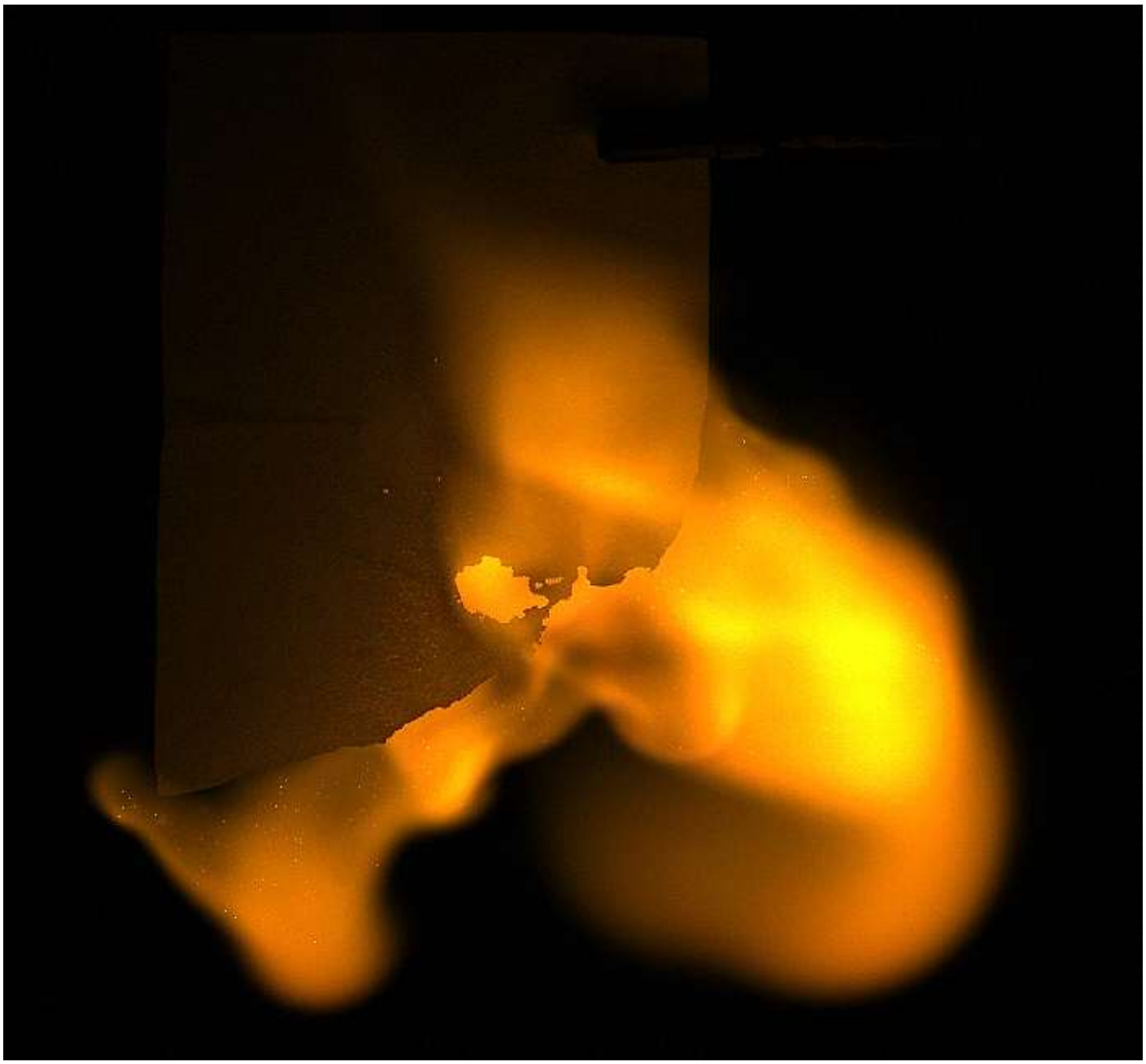
Table 1: Camera Specifications

Camera Manufacturer	Vision Research
Camera Type	Phantom 675
Frame rate	5,000 frames per second
Resolution	1280 x 800 pixels
Exposure Time	40 microseconds
Field of View	Approx. 5.5 inches by 7 inches
Distance From Camera to Object	Approx. 0.75 meters
Height of Camera Above the Ground	Approx. 0.5 meters
Number of Frames Taken	3,190 frames for video clip #1, 3,161 frames for video clip #2

The two video clips were converted from the proprietary .cine file extension used by Vision Research to .avi using the Cine Viewer software provided by Vision Research. The output frame rate of the files was also changed to 40 frames per second. The .avi files were then further processed using Adobe After Effects to reverse the playback of the first video clip. The video was finalized using Adobe Premier where cross dissolves were added to smooth the transition between the two clips, and credits were also added at the end.

As a whole, the video exceeded expectations for the visualization of the combustion of nitrocellulose. The physics of the image came out very well with the simple shapes of the paper that were used. If the team could do more work on this, the team would like to set up a more complex system including more complex paper shapes, as well as placing objects around the paper so that the flames would have more of a forced path. Also, since there was also the unexpected mixing of the flame from the butane lighter and the flash paper flame, the team would also use a variety of flame types to ignite the paper to see different flame interactions like the interaction seen with the butane lighter.

Since the camera time was limited, the team was only able to capture two shots. The team would benefit from additional trials to get much more complete results. Additionally, it would have been beneficial to have more time to do additional post-processing and video editing with the image to see if there are any effects which could add even more aesthetic appeal to the video. Overall, the team is very happy with the results of the experiment—it provided an interesting and beautiful video of a flow that could otherwise not have been visualized.



References

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