Gasoline and Butane

Flow Visualization

March 22, 2012

Professor Hertzberg

By Mitchell Stubbs

What is more awesome than the phenomenon of fire? I have been camping many times in my life and there has never been a time when a fire hasn't been able to soothe the day's tensions. Flames have a power to seem mystical, but they are really good at achieving equilibrium with their surroundings. For this first team project the goal was to observe the explosive development of multiple fuels suddenly put together in the presence of an ignition source and oxygen. To achieve this we used a combination of butane and gasoline in front of the Olympus high speed camera.

With the camera set up, we filled many small balloons with butane. The ignition source of burning gasoline was dripped off the edge of a knife blade onto the stationary balloon. The balloon is approximately 10cm in diameter. The balloon is the size it is because there is enough gas in the balloon to resist the pressure of the atmosphere. When the gasoline drips off the edge of the blade and falls onto the balloon it burns the surface of the balloon until it bursts, releasing the butane. When the balloon bursts there is much less force resisting the outward pressure of the butane gas, so it streams out of the balloon; the butane then floods out of the balloon in a clear plume. This plume is visible because its turbulent stream pushes the gasoline flame out of the way. The butane plume does not immediately ignite because the mixture is too rich before mixing thoroughly with the atmosphere. Butane needs a mixture of 1.8 to 8.5% butane to air to combust[1]. As the butane plume quickly and turbulently mixes with the atmosphere, the butane ignites in many small specs at the edges of the plume. Even at 500 frames per second these specs spread quickly into a cohesive ball of flame. Given the playback speed of 30 frames per second, I can estimate the rate of expansion of the plume and flame, as well as the reaction time of Sam holding the knife.

Camera frame rate = 500 frames/s

Playback = 30 frames/s

30/500 = 1/16.66 speed

12 seconds for the flame to fully ignite = .72 seconds real time

As it took about one second in the video for the plume to spread about ten centimeters, the plume must have propagated at a speed of 1.67 m/s. Also, it took about three quarters of a second for the flame to fully ignite and reach its optimal combustion ration. Incidentally, it also took Sam the same time to react to the flame and start pulling his hand back. Unfortunately for Sam, the flame spread much quicker than his hand could move. It took only five seconds in the video for the flame to expand to the size of the knife, roughly double the size of the balloon. In real time that is only 3/10s of a second. Not only does flame travel much faster than the human hand, it took Sam over two seconds to even clear the frame. This is good evidence that humans are much to slow to get out of the way of an expanding plume.

To get this shot at such a big reduction in frame rate we used the Olympus high speed camera. We performed the experiment outside of the ITLL on an overcast day, with a black board behind the setup. We noticed there was not enough light to see the balloon at 1000 frames per second, but 500 frames per second was just right. The butane for the balloon was sourced from McGuckin Hardware and the gasoline for the shot was sourced from my motorcycle. The butane is of unknown concentration inside the canister, and therefore unknown inside the balloon. The gasoline was not diluted or altered. There was actually more gasoline required on the surface of the knife than we originally imagined to get the flame to travel to the balloon.

In terms of photographic technique, I really wanted to capture the the hand holding the blade in the shot, as well as have the flame expand beyond the frame. We filled the balloon to approximately 10cm, and positioned it so it filled about 1/3 of the frame. We determined through trial and error that this was right for the flame to fill the frame. Here you can see the 18cm knife fills much of the frame, and the hand holding it. The zoom is enough, however, so one can see the drops of gasoline falling off the knife. The balloon was placed about 1 meter from the lens of the camera, but the zoom is unknown. There were no corrections made to the original footage.

The thing I like most about this image is that it reveals the mixing and ignition of a butane flame in the presence of an ignition source. The camera is fast enough to capture how the little individual vortices of the butane plume ignite first, then a blue flame front propagates from the source of the balloon, followed by the expanding specs of flame. The blue flame diminishes and the specs enlarge until they form a cohesive flame, with the typical look of the flames we usually experience. I like how this video shows that for a flame to develop, there actually has to be a fairly low percentage of accelerant in the atmosphere to ignite. This image also shows how fast a flame can explode, given the right conditions, and how slow humans are in comparison. To develop this idea further, a group could do an experiment with a flame tube to compare the different flame speed of different volatile chemicals.

References

[1] Engineering Toolbox, "Gases-Explosive and Flammability Concentration Limits."
http://www.engineeringtoolbox.com/explosive-concentration-limits-d_423.html