Ignition

The clip of a cigarette lighter being ignited was shot in the ITLL lower break-out room. A high speed camera was used to capture the process of ignition by a cigarette lighter. The purpose of the small video clip is to image the complex phenomena of ignition. Ignition is a very important episode in which modern society is completely dependent upon. For example, most cars have a spark ignition internal combustion engine that runs on gasoline. Likewise, gas turbines, which are used to power airplanes and make electricity, rely upon ignition to burn fuel. Ignition is defined as the process of initiating combustion. Combustion is used by engineers to convert the energy stored in a fuel (chemical energy) to a "functional" form of energy, or work that the engineer can use for a practical application. According to Stephen Turns [1], there are two rules-of-thumb that govern ignition and its converse, flame extinction.

Criterion 1 – Ignition will only occur if enough energy is added to the gas to heat a slab about as thick as a steadily propagating laminar flame to the adiabatic flame temperature.

Criterion 2 – The rate of liberation of heat by chemical reactions inside the slab must approximately balance the rate of heat loss from the slab by thermal conduction.

The first criterion is basically stating that there exists a minimum ignition energy to start the combustion process. The minimum ignition energy is in essence the amount of energy required to heat the gas (fuel plus oxidizer) from its initial state to the adiabatic flame temperature (also called the flame temperature). Therefore, the striker on a lighter is used to disperse sparks (see Figure 1) that allow the local temperature of the gas, butane and air mixture, to be heated to the adiabatic flame temperature of this mixture and thus causing combustion (see Figure 2).

Figure 1. Sparks from the Striker

Figure 2. Combustion of the gas

The second criterion is used to determine whether a flame will continue to propagate, or cease (flame extinction). The second criterion in essence states that if the heat loss due to thermal conduction is greater than the heat generated by chemical reactions, then the temperature will begin to decrease until the conditions are no longer ideal for the flame to exist. Further more, "experiments show that a flame will propagate only within a range of mixture strengths between the so-called lower and upper limits of flammability" [1]. The flammability limits are usually defined as the percent fuel by volume in the mixture, or as a percentage of the stoichiometric fuel requirement. According to the Air Liquide website, a company that specializes in the sales and distribution of various gases, the flammability limits of butane in air is 1.5-8.5 vol% [2]. These flammability limits were obtained from the Material Safety Data Sheets (MSDS) for butane located on Air Liquide's website. A measurement of the fuel percent by volume for the this lighter was not done due to the complexity and scope of the experiment, but suffice it to say that the fuel percent had to be within the flammability limits since ignition was observed. The minimum ignition energy for butane depends heavily on the initial temperature of the mixture as well as the fuel percent by volume. For hydrocarbons in air, the minimum ignition energy is on the order of 0.2 mJ [3]. Over all, and most importantly, a firm understanding of the first and second criteria, and in general, ignition, is extremely important to fire safety, and engineers since so many systems depend upon ignition.

The sketch below in Figure 3, gives a perspective on the overall set up of the experiment. Figure 3 is a top view of the set up.

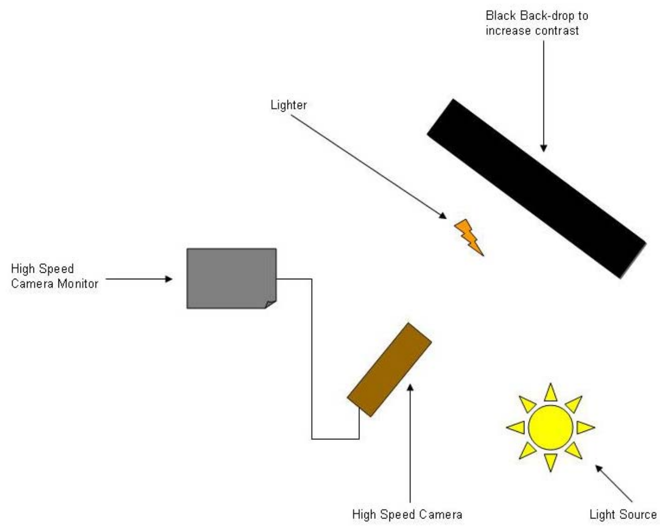

Figure 3. Experimental Setup

Initially, the light source might seem to be out of place. After all, shining light on the flame will not make it brighter in the photograph. But, the high speed camera needs a huge amount of light, as expected due to the fact that there is, relatively speaking, a small amount of time for light to impinge on the photosensitive surface as each frame is shot. In order for the group to visualize the lighter without a flame in the high speed camera's monitor, a light source was directed at the lighter. The light source was directed on the lighter and used to focus the camera. The approximate angle between the camera, and the light source was 120º. The camera was about 23 inches or approximately 2 feet from the lighter. The field of view for the lighter is approximately 7 inches by 7 inches. The lighter was started, or struck by a thumb. Mechanizing the initial strike of the lighter would improve repeatability. The original clip from the camera was extremely dark; therefore Adobe Premier was used to lighten the image.

<u>Photographic Technique</u>

- Camera – Olympus i-Speed High Speed Digital Camera

  - Used at 150 fps (frames per second)

- Lens – Nikon AF Nikkor
  - 28 – 88 mm, 1: 3.5 – 5.6D
- Focal Length – approximately 75 mm
- F-Number – 3.5, largest aperture since there was very little light
- Photoshop processing – Adobe Premier 6.5 was used to make the clip lighter.
  - Brightness Contrast Filter
    - Brightness 96.8%
    - Contrast 82.4%

The file format is MPEG4.
This produces a 12 MB clip, which allowed a lot more detail to be visible. .
A smaller web version was also produced by reducing the resolution to 40%, which produced a file that is about 470 KB.

This short clip entails the striking and igniting of a cigarette lighter. Ignition is a very complex phenomena that has enormous impact on modern society. Fire safety, and modern combustion engines are two of several topics that depend highly on a solid understanding of ignition. This image reveals that the sparks that disperse off a lighter serve to cause the gas (butane and air mixture) to be locally heated to the adiabatic flame temperature, and thus initiate combustion. In other words, the sparks are the source for the fuel and oxidizer to overcome the minimum ignition energy. The initial transient affect of the butane gas near the lighter beginning to combust is extremely fascinating. If I had to due this experiment again, I would change a few things. I would like to have mechanized the starting of the lighter in order to make this process more reliable and repeatable. I would also like to measure the percent fuel by volume to see if this experimental value fit within the known lower and upper flammability limits. Furthermore, I would like to understand and delve into the transient phase between ignition, and the steady flame. That portion of the video clip is extremely captivating.

References

[1] Turns, Stephen R., An Introduction to Combustion, Second Edition, McGraw Hill, 2000. ISBN 0-07-230096-5

[2] website for the MSDS sheet for butane, 10/18/2004 http://www.airliquide.com/en/business/products/gases/gasdata/index.asp?GasID=8

[3] Shepherd, Joseph E., et al., **"Spark Ignition Energy Measurement in Jet A",** http://www.galcit.caltech.edu/EDL/publications/reprints/ie.pdf, 10/18/2004.