Flow Vis Spring 2011 Steven Hendricks
Team Project #1 3/15/11

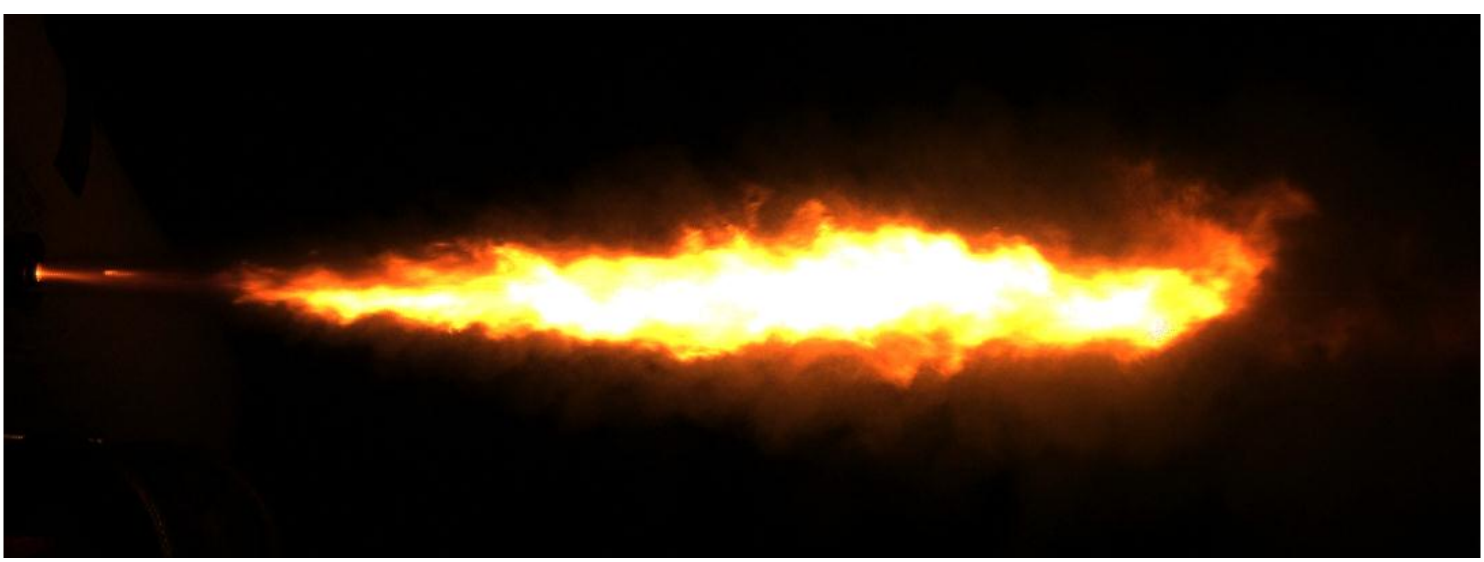
Rocket Engine with High Speed Camera

For the first team project our group decided to take advantage of the high-speed camera demonstration which was held by Vision Research and The University of Colorado on Thursday March 3rd 2011. We had several ideas for objects to put in front of the camera but we ended up filming matches igniting and an Aerotech G-64 rocket motor. I chose to fire the rocket motor because the exhaust gases are dispelled at an amazingly fast rate and I wanted the camera to capture some of this movement so that we could view it in slow motion. In the end, after a first attempt at video editing and troubleshooting I am pleased with the resulting movie and wish to do further research with different rocket motors and the high-speed camera.

This project required the rocket engine to be statically fired in a safe and controlled manner while the camera had to simultaneously be triggered in order to capture the 2 seconds of burn-time. The rocket motor was clamped to a shop stool using a vice and three C-clamps which were weighted down with numerous sand bags. The rocket engine was ignited electronically with an igniter and a motorcycle battery from a distance of about ten feet. Since the rocket was burning a solid fuel mixture of ammonium perchlorate and aluminum powder, and based on past experience, I can assume an average exit velocity of roughly U=500m/s. The gases were being directed through an optimized nozzle and had a combustion temperature of roughly T=3000K, viscosity of μ=75e-6 NS/m^3, and density of ρ=0.15 kg/m^3.[1] In order determine the turbulence of the flow, the Reynolds number was calculated and is shown below for a point in the center of the stream-length at L= 0.25 meters.

$$Re = \frac{\rho U L}{\mu} = \frac{0.15\left(\frac{kg}{m3}\right)\cdot 500\left(\frac{m}{s}\right)\cdot 0.25\,(m)}{75e-6\,\left(\frac{Ns}{m2}\right)} = 250{,}000$$

The Reynolds number calculation shows that significant turbulent flow exists halfway down the rocket exhaust stream. However, one point in the flame that I find particularly interesting is the spot directly after the nozzle exit. This is an especially interesting point in the flow because the gasses are moving the most



rapidly and they are also the densest at this point. Using adjusted values for the velocity and density at the nozzle exit indicates less turbulent flow near to the transitional region at 125,000.[1] Since the fuel is being expelled so fast from a high pressure reservoir to a lower pressure environment a shock disk is created normal to the flow direction which increases the temperature of the exhaust gases and causes any remaining fuel in the flow to ignite.[2] This feature is the bright flame color that we witness in the bulk of the picture. The shock disk is the dot a few inches behind the nozzle and once all fuel is ignited, it glows brightly downstream and flows in a very turbulent fashion as it continues to expand. The amount of physics going on in the rocket engine is vast and detailed but the behavior that it presents is awesome and exciting.

The Aerotech G-64 White Lightning rocket motor was obtained from hobbylinc.com and is a reload kit for the 29/40-180 case which is available to everyone for purchase. The motor was assembled the day we performed the firing and was filmed at about 5:30 pm with the aid of many people from the flow visualization class including Professor Hertzberg and the technicians from Vision Research. We lit the motor in the courtyard of the Durning Lab after the sun had mostly gone down and a large black fabric sheet was held up as the background. There were no lights used during the filming in order to focus the attention on the light being emitted from the rocket engine. The lighting was a tricky component to tackle because I only had one rocket engine and thus we had to predict its performance and adjust the camera accordingly.

I chose to use the high speed camera in order to view the gas emission in a drastically slowed down manner. I was aware that the gases were being expelled with supersonic velocity but I wanted to see evidence of this and witness how the flame behaves at such high speed. Fortunatly, Professor Herzberg had arranged a demonstration from the folks at Vision Research who graciously agreed to film sequences for the students of the spring 2011 Flow Vis class. Vision Research brough several cameras with them but the one that we ended up using during filming was the Phantom V710 High Speed Digital Video Camera. The camera was set up approximately three to four feet from the rocket nozzle and was oriented to capture the entire flame, which I assumed to be approximately two feet in length. The framrate of the camera during filming was 7000 frames per second (fps) and the shutter speed was three microseconds thanks to the complex computer capabilities contained within the camera. The resolution obtained from the megapixel camera was 720 by 480 pixels in the final video and it recorded 16,000 to the computer's hard drive during the two-second burn.[3] Once the video was captured, I used Adobe Premier Elements 9 to edit and create my video submission. I wanted to present the rocket flow in an extremely slowed down manner while still viewing it fluidly and in its entirity so it is shown at 30 fps with no color alterations. I chose to show the entire burn of the motor because a great visual of the thrust profile is accurately presented over the duration of the video. A combination of good timing, equipment, and safety allowed us to perform the firing in a successful manner.

In the end I was super excited to get a high-speed video of a rocket engine burning so that I can view it in slow motion and I am happy to watch it over and over. There is a lot going on in the flow through the nozzle and it presents itself very artistically anf beautifully. One thing that lends further research is the fact that there are many different formulas of rocket engines that burn with different colors and effects. If I had more acess to such great help and equipment I would gladly do further research with high speed flow and combustion.

Refrences

1. Kreith, Frank and Bohn, Mark; Principles of Heat Transfer 6th Edition, Thompson 2001
2. http://www.aerospaceweb.org/question/propulsion/q0224.shtml
3. http://www.visionresearch.com/Products/High-Speed-Cameras/v710/