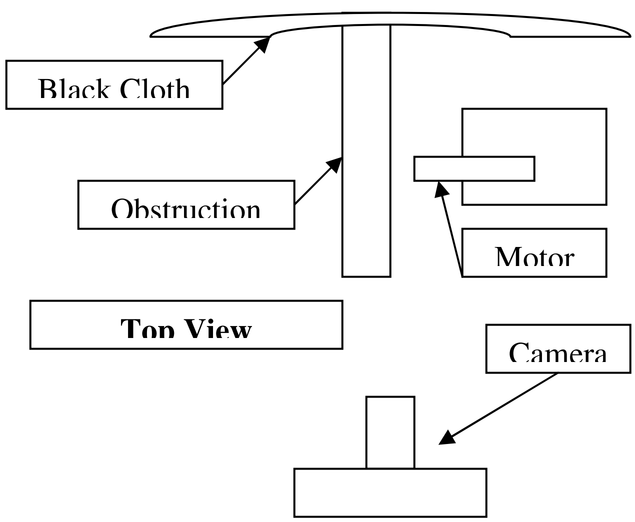
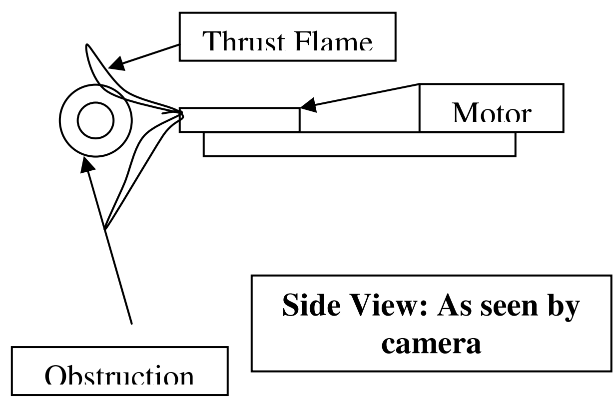
These images are the results of a group of students working on their second collaborative effort for Fluid Flow Visualization. The intent was to capture the flow of a model rocket engines thrust being sent around objects in an otherwise dark environment. These engines produce a lot of debris and waste in addition to a heavy, lingering smoke. Working with them is difficult as triggers and precision is lacking to a great degree of what would be expected in a scientific apparatus. There were several false starts due to faulty igniter leads and old motors.

To accomplish this series of images a test stand was constructed. A motor was placed in a secure clamp and a second stand mounted the obstacles, either a steel 1" solid rod or a length of 1" square, 1/16" thick Aluminum tube, perpendicular to the motor outlet. The camera was placed on a tripod opposite the second stand in the same plane so the image could be captured on axis. The front of the lens was placed and focused at 3' from the tip of the motor. The apparatus was built in a dimly lit garage providing with static air for testing. A black cloth was placed around the side stand to ensure it would not be visible in the final images.





The rod was placed at a distance of 2.25 inches from the nozzle of the motor and the square tube was placed at a distance of 3/4" of an inch. The flow at the nozzle is approximately 3/16" in diameter, however as visible in the center image without an obstruction it is clear that this fans out to some degree and is rather like a spray with an angle of 10 degrees rather then a beam. This is important to note because not all of the motors thrust is projected in the X-Axis direction. A thrust profile from the manufacturer shows that the burn time is not linear. These images did their best to capture them at peak thrust.

QuickTime™ and a
decompressor
are needed to see this picture.

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The thrust is made by a combination of composite (silica) and black powder burning. As this reaction occurs the spent particles are ejected providing imaging to the thrust flow. The flow is concentrated out a small opening (the nozzle of the motor) and at a very high speed; certainly this is a turbulent flow with a Reynolds number in the thousands. As the flow hits an obstacle some of the material hits it, creating a boundary layer and deflecting the flow around it, while the flow slows considerably and looses some material, it is still turbulent. In the case of the square tube, the thrust was actually capable of puncturing through both faces of aluminum however looking inside the tube at the second face shows that the second hole is smaller in diameter then the first (entrance) hole. This creates a backwards flow along the inside surface. Also evident in this image is the fact that the flow begins to fan out again after leaving the tube. This shows that it is a high Reynolds number flow and is turbulent. That hole is approximately 1/4” in diameter. Unfortunately, the thrust is not of uniform density and consists of numerous types of particles, and therefore a more exact, numeric Reynolds number cannot be calculated without the specific composition of the motor.

These images capture light emitting materials (flame) in an otherwise dark environment. This means that the flow is glowing whereas all else is dark. This technique is difficult because the exposure required changes as the flow changes.

The field of view is the same in all three images and is approximately 3”x 5” and is represented by 3072x2040 pixels. The during the exposure time of 1/750th of a second the individual particles appear to have traveled about 1”. This means the fastest particles are traveling at almost 44 MPH at near peak thrust. Specific information for each image is visible in the tables in the appendix. No Photoshop manipulations were performed on the individual images however it was used to create the single triptych image.

The image demonstrates the violent reaction that occurs in solid fuel thrust motors. The flare and scatter helps demonstrate how chaotic the reaction can be at its peak and how uncontrollable it is. This provides an interesting quandary: rocket motors and its applications are inherently modern, yet the power used is clear largely uncontrolled and almost primitive in comparison to every other element. The flow around the obstacles could be clearer. I imagine that much of the flow continues around the rod however it has slowed and cooled to the point where it is no longer visible using this visualization technique. If I were doing the experiment again I would use a constant flame that could be controlled and continuous, like one from a propane torch, that is also flowing at a slower speed in order to better capture the flow. I feel that presenting in a triptych helps provide both symmetry and illustrate the differences between the three flows. This assignment has left me curious exactly what the motors made by Estes are made out of and exactly how the exhaust is handled. Does the nozzle of the motor have any effect on these little motors? To further these ideas I would be interested in capturing similar images using infrared imaging or film.

IMAGE INFORMATION:

Thrust: 1” Round Steel Pipe

Thrust: No Obstruction

Image Date	11/2/07 4:12 PM MST
Camera Model	Canon EOS 10D
Serial Number	620312005
Shutter Speed	1/750th second
Aperture	F2.8
Exposure Bias	0ev
Focal Length	100mm
ISO Speed Rating	ISO 800
Aspect Ratio	3:02
Orientation	Landscape
Depth	16-bit
Color Profile	Adobe RGB 1998

Image Date	11/2/07 4:17 PM MST
Camera Model	Canon EOS 10D
Serial Number	620312005
Shutter Speed	1/500th second
Aperture	F2.8
Exposure Bias	0ev
Focal Length	100mm
ISO Speed Rating	ISO 800
Aspect Ratio	3:02
Orientation	Landscape
Depth	16-bit
Color Profile	Adobe RGB 1998

Thrust: Square 1” Aluminum Pipe

Image Date	11/2/07 4:31 PM MST
Camera Model	Canon EOS 10D
Serial Number	620312005
Shutter Speed	1/750th second
Aperture	F2.8
Exposure Bias	0ev
Focal Length	100mm
ISO Speed Rating	ISO 800
Aspect Ratio	3:02
Orientation	Landscape
Depth	16-bit
Color Profile	Adobe RGB 1998