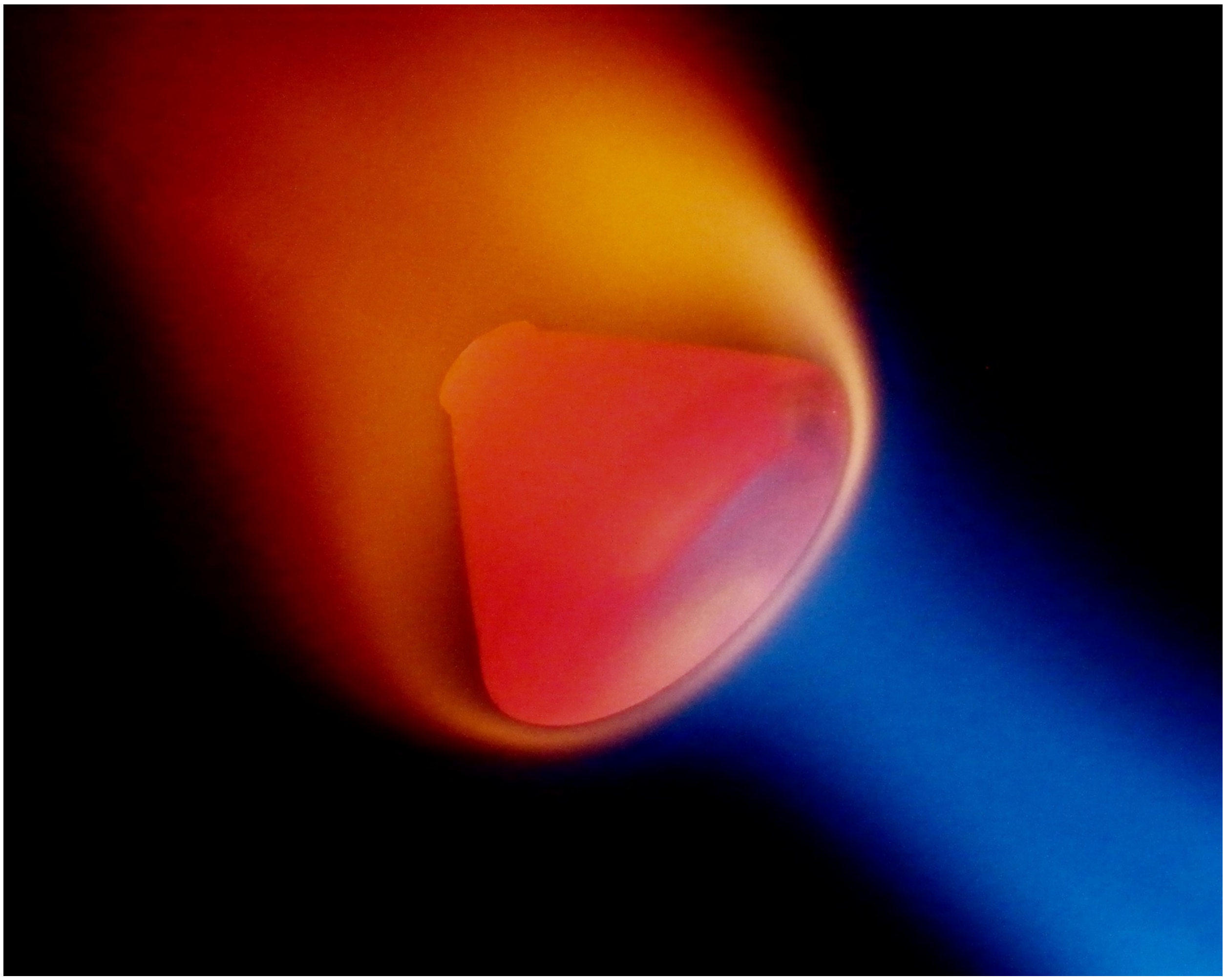
Blackout

MAPP Gas Torch Impinging on a Scale Model of the Apollo Command Module

Project 1: Group Phi



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Intent

The Mercury, Gemini, and Apollo Space Programs achieved wondrous accomplishments during the 1960's and early 1970's, particularly the success of Apollo 11 which brought mankind to the surface of the moon for the first time. The Apollo crews returned to Earth in a cone-shaped spacecraft known as the Command Module (CM). The CM was equipped with an ablative heat shield to protect the crews from the intense heat generated by re-entry into the atmosphere. During re-entry, the spacecraft was slowed from a speed of 5 miles per second to about 200 mph when the parachutes were deployed. The friction generated enough heat to ionize the surrounding air, covering the spacecraft in a blanket of fire [Kranz, 2000].

Because of the high speeds and the high altitude involved, re-entry has never been photographed for filmed up close. I decided to attempt to recreate a similar situation to investigate the fluid physics occurring during re-entry. My goal was to produce a visually pleasing and interesting photograph that successfully reproduced some of the fluid mechanics involved during re-entry.

Description of Apparatus

A 1/205 scale model of the Apollo Command Module was machined from a ¾" diameter brass rod using a lathe, metal file, and sandpaper for polishing. The dimensions of the model were determined from the original specifications of the Apollo spacecraft [Myers, 1964]. A small hole was drilled in the top of the model for a straightened paperclip to be inserted (Figure 1a). The other end of the paperclip was clipped to a chemistry stand. This allowed the model to be suspended away from any flammable materials and easily oriented in a variety of positions. The chemistry stand was placed on a metal table in a dark room with good ventilation. The camera was placed on a small table-top tripod and positioned near the chemistry stand. A 16 oz. BernzOmatic TS4000 MAPP gas torch was held approximately 2 inches away from the bottom of the model and ignited (Figure 1b). All other objects in the room were moved well away from the apparatus to keep any combustible materials away from the torch flame. Also, I wore safety glasses when operating the torch and kept a fire extinguisher nearby.

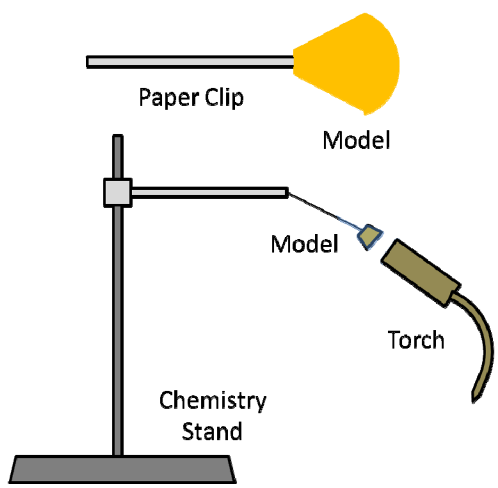

Figure 1: a) Model with paper clip attached. b) Diagram of apparatus used for photography

Fluid Flow Visualization Techniques

The fluid flow was visualized through the emission of light from two sources. First, the combustion gases from the torch flame are hot enough to emit radiation, primarily in the blue visible region, which is why the flame from the torch is blue in color. The photograph was taken when the brass model was heated to the point where it began to glow red. The second source of light is black body radiation of the brass model, which emits light in the infrared and red visible region. The flame from the torch quickly shifts from blue to orange and red as it impinges upon the red-hot brass. The atoms within the solid brass are so energized by the impinging flame that some molecules actually escape the lattice and become suspended in the flow of the flame around the model. During this process, they are constantly emitting black body radiation, which is why the flame becomes orange and red. This will be discussed further and in more detail in a later section of this report.

Photographic Techniques

All photographs were taken using an Olympus FE-370 8.0 megapixel digital camera. This camera has a focal length range of 6.3-31.5mm and an aperture range of 1:3.5-5.6. All photographs utilized the camera's "indoor" setting in conjunction with the "super macro" setting with the flash disabled. The camera was placed on a tripod for all photographs. Table 1 lists detailed information about the final photograph.

Table 1: Details of photograph

Photograph Date	Feb. 23, 2009
Field of View	4 x 3.5 inches
Distance from Lens Object	2 inches
Lens Focal Length	7.7mm
Original Image Size	3264 x 2448 pixels
Final Image Size	2387 x 1901 pixels
Shutter Speed	1/25 sec
Aperture	f/4
ISO Setting	100

First, the camera and model were positioned as desired. The lights in the room were turned on and the camera's 10 second timer was set and initiated. With the lights turned on, the camera was able to focus upon the surface of the brass with ease. Once the timer was initiated and the camera had automatically focused, the lights were turned off, darkening the entire room. I ignited the torch and held it in the desired position for several seconds until the timer expired and the image was captured. This process was repeated in excess of 50 times before I captured a desirable, well-focused image.

Image processing was performed using the Paint.NET image editing software. First, the image was cropped so the object and torch flame filled the field of view. Second, the contrast was increased using the "curves" feature. This darkened the flame slightly, allowing more details of the flow to be apparent. The "curves" function was also used to increase the intensity of red and blue colors in the image. Lastly, the "clone stamp" tool was used to remove the paper clip from the image. The paperclip was removed so the model would appear as if it were floating freely, just like the actual Apollo CM during re-entry. I also felt that the paperclip was a bit distracting from the fluid flow around the model. The original image can be found in the Appendix.

Fluid Mechanics and Physics Demonstrated

Flow Impinging on a Blunt Body

As the torch combustion gases flow past the Apollo model, they exert a drag force upon the model. As the fluid impinges upon the surface of the model, its inherent viscosity creates a shear stress upon the body. The net shear force, called the drag force, is governed by the following equation,

$$F_D = \frac{1}{2}\rho U^2 A C_D$$

where ρ is the density of the fluid (combustion gases), U is the velocity of the fluid, A is the projected area of the object, and C_D is the drag coefficient [Munson, 2006]. The projected area of the Apollo CM is a circle, and in the case of the model, the diameter is 0.75 inches. The methods required to measure the density and velocity of the combustion products exiting the torch were not available to me, so unfortunately the drag force on the model cannot be calculated. The drag coefficient is a function of the flow Reynolds number and the surface roughness of the model. The Reynolds number equation is,

$$Re = \frac{UD}{\nu}$$

where U is the fluid velocity, D is the diameter of the model, and ν is the kinematic viscosity of the fluid. Again, since the fluid velocity and kinematic viscosity are not known, the Reynolds number cannot be calculated. However, C_D is often determined experimentally. In fact, the drag coefficient for the actual Apollo CM was measured based on actual flight data, which was determined to have an actual value of 1.55 [Moss et al. 2006]. This is in good agreement with typical drag coefficients for blunt bodies [Munson, 2006]. Thus, if the velocity and properties (density and kinematic viscosity) of the combustion gas were known, the Reynolds number and drag forces could be calculated. Despite exhaustive research of scientific literature and manufacturer specifications of the torch, I was unable to find this information.

Emission of Light due to Atomic and Molecular Energy Level Transitions

It was previously noted that the flow was visualized due to the emission of light from combustion gases and the brass model. Specifically, C_2 and CH radicals present in the combustion gases emit light in the blue region of the visual spectrum. The C_2 and CH molecules in the flame are highly energized, or excited, due to their high temperatures. In these highly excited states, the electrons within the molecules transition from high energy levels to lower energy levels, emitting electromagnetic radiation (light) in the process, which produces the blue color of the torch flame [Ito, 1992].

As the flame impinges upon the brass model, the flame takes on an orange and red color. Brass is a metal alloy composed of copper and zinc. The flame heats the copper and zinc atoms into excited electron states, similar to the excitation of the C_2 and CH molecules of the combustion gases. However, the electronic transitions occurring in the copper and zinc atoms are lower in energy, which is why orange and red visible light and infrared radiation are emitted from the brass model, producing orange and red colors in the flame. Note that this is a highly simplified discussion of light emission due to electronic transitions and is meant to cover only the basics needed to understand the flow visualization effects in this situation.

Flow Characterization

As stated previously, not enough information is known about the combustion gas flow to calculate the Reynolds number. However, because the gases are highly energetic from the combustion process, it is reasonable to assume that the flow is turbulent rather than laminar.

Relation to Actual Apollo Command Module Physics

My apparatus and flow conditions are very different than those experienced by the actual Apollo CM during re-entry. For example, the flow velocities during re-entry range from 5 miles per second (hypersonic) to a few hundred miles per hour (sub sonic), which is *much* faster than the gases produced by the torch. Also, the density of air varies drastically between the outermost atmosphere where re-entry begins and 10,000 ft when the parachutes deploy, whereas my scale model was subject to relatively constant density flow. Despite these significant differences, my model demonstrates some similar flow characteristics and flow shapes experienced by the actual Apollo CM. The heat shield on the CM was designed to deflect the heat away from the sides of the spacecraft since the sides were not equipped with heat shields. Thus, the capsule was aerodynamically shaped so that the flow of hot gases would separate from the surface of the spacecraft [Kranz, 2000]. My apparatus demonstrates this separation of flow from the heat shield area (Figure 2). The gases near the sides of the model are darker, indicating that they are at a lower temperature than the deflected flame, which is bright orange and yellow.

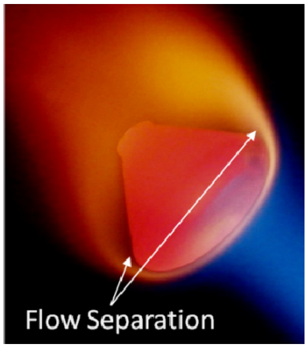

Figure 2: Separation of flow from the model surface

Image Discussion

I am very pleased with my final image. Not only is it beautiful and interesting, but it also is a realization of my original intent. I took over 50 photographs using various techniques before I finally captured an image I was happy with. I am especially pleased with the colors and texture of the image. The reds and oranges are balanced by the blue flame and black background, making the image quite dramatic. I am also very pleased that I was able to reproduce some fluid mechanics that are similar to those encountered by the actual Apollo capsules during re-entry, despite the vastly different flow characteristics in each situation. Also, I was able to apply some of my lessons from the Get Wet assignment to improve my image for this project, such as the use of a tripod and more advanced image processing using computer software. I cannot think of any way in which I could improve this image. I worked very hard fabricating the model and fine-tuning my photographic technique, and the time spent has paid off with a wonderful, interesting, and captivating image.

References

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Appendix

Original Photograph