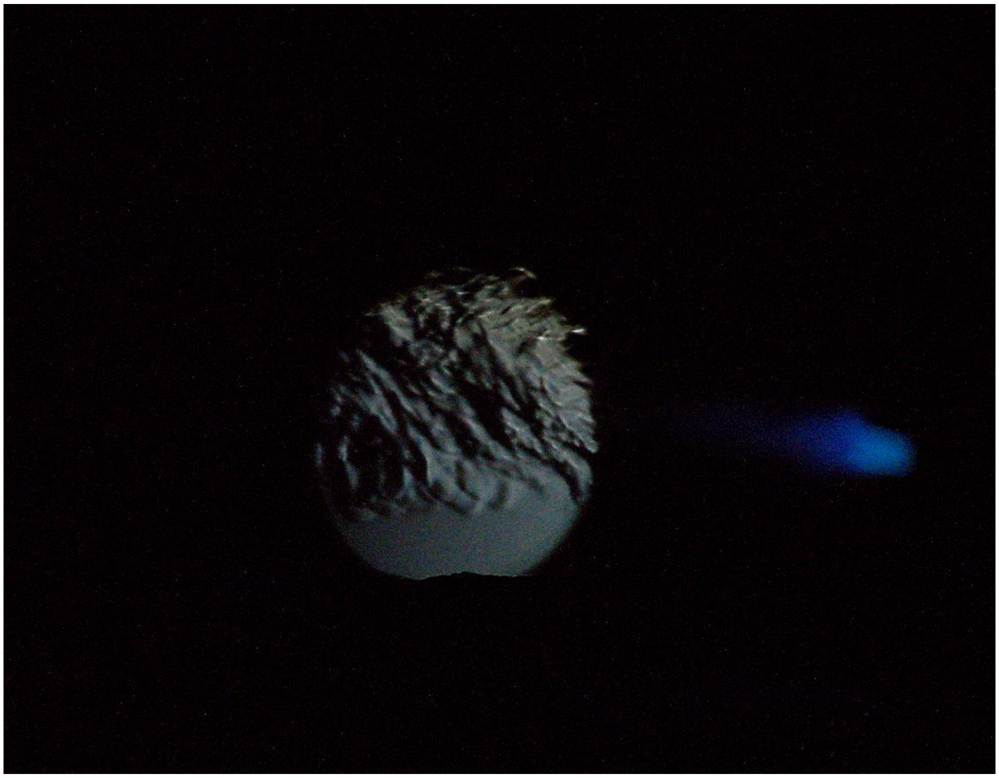

Team First Report: Schlieren Imaging

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Introduction

This image was taken for the Team First project as part of The University of Colorado's Graduate Mechanical Engineering course in Flow Visualization. This was the class's first team project. The intent of this project was to experiment with Schlieren Imaging. This is a technique that uses mirrors to capture changes in air flow. This team consisted of myself, Jake Jones, and Nick Rhodes. Our team leaned how difficult and precise this method needs to be, and learned many times now **not** to capture the image. Jake and I set up a work station on campus using the school's schlieren set up. We found a few difficulties with this set up, and learned that there needs to be a strong light point source. Nick set up his own homemade schlieren method and produced the final image we see above.

Flow Apparatus

For the unfamiliar, Schlieren imaging (or photography/videography/flow/etc.) is a very precise method of trying to capture fluid flow that is invisible to the naked eye. How one does this is ingenious. By utilizing mirrors and a point source of light, we can actually see the density changes in a fluid. For a little science background, as light passes through different mediums (read: different densities, temperature, fluids) it refracts. To capture these changes, one focuses the light from the mirrors onto a knife-edge. The mirrors are concave, meaning they direct light onto a focal point. This focal point is where a knife-edge sits. Light that shines through **undisturbed air** shines over the knife-edge to be seen normally. Light that passes through **disturbed air** is bent. This bent light is blocked by the knife-edge, resulting in an image with light and dark areas. These shadows produced show where our flow is disturbed. This could be the result of motion, or density or temperature differences, or showing different mediums altogether.

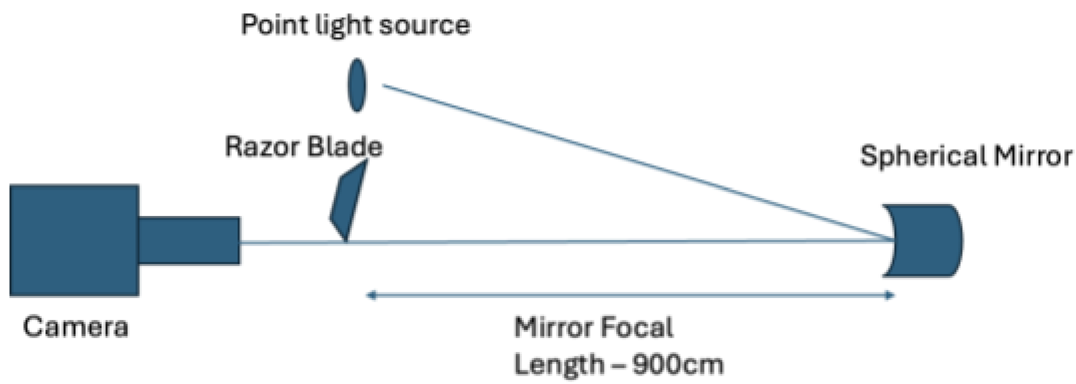
The subject is about 6 inches in diameter, with the blue flame visible off to the side. To capture this type of flow, we used a blowtorch. We can see the fast motion of the air being released from a pressurized tank, and we can also see high temperature changes from the result of this burning gas. This is a highly turbulent system. We can describe turbulent flow numerically using the nondimensional Reynolds Number (Re). [1]Reynolds describes flow as the ration between inertial forces over its viscous forces

$$Re = \frac{\rho V L}{\mu}$$

where ρ is density, V is the velocity of the fluid, L is the length of flow, and μ is the fluid viscosity. [2]For low Reynolds numbers (i.e. below 2000) we can say this flow is laminar, where the viscous forces dominate the flow. At higher Re numbers, inertial forces begin to control the flow, and mixing between layers begins. This is known as turbulence. A flow such as pictured above would have a Reynolds number of about 30,000. As we near closer to the flame, say a few centimeters from the nozzle, this number drops significantly nearing 3-4,000. This indicates a flow in a more laminar/transitional region.

Methods

Getting the Schlieren technique exactly right requires some precise set up. Our team used 4.5” diameter mirror with a 900cm focal length. A 400-lumen headlamp and cardboard with a pinhole was the point source. A regular home razor blade was the knife-edge, and a handheld MAPP gas plumbing torch was our flow source. The sketch below notes our setup.



A Nikon Z5 DSLR camera with a 200mm lens was used to capture the image. A long zoom lens was required here to get a large enough picture of the mirror almost a full meter away. The original uncropped image was taken at 6000 x 4000, and the final image above was cropped to 4000 x 2500 px. Getting the exposure correct was difficult. We needed a high ISO at 10,000, a shutter speed of 1/1600s, and an aperture of f/6.3. The time resolution of the image is about 3 m/s. The post processing techniques used were some cropping of the final image, contrast adjustments (specifically to bring out the shadows in the image) and color correction for the blue flame to highlight its importance in the image.

Discussion

The image reveals high turbulent flow. We can see the different densities and temperature of a torch exhaust, and even see the intricate waves the plume exhibits. This to me is pure beauty. Being able to see the invisible. We know turbulence naturally. We can feel the wind blow through our hair. We see it pick up leaves, blow over grass, and make waves. Tornadoes are natures fastest turbulence. And here we can see what it actually looks like. The image isn’t perfect. Schlieren techniques have been highly developed so this is quite rudimentary. I would love to take this a step further, maybe even seeing shock waves from the nose cone of a fighter jet.

References

[1]Trombley, C. I., & Ekiel-Jeżewska, M. L. (2019). Basic concepts of Stokes flows. In F. Toschi & M. Sega (Eds.), *Flowing matter* (pp. 35–66). Springer. https://doi.org/10.1007/978-3-030-23370-9_2

[2]Saldana, M., Gallegos, S., Gálvez, E., Castillo, J., Salinas-Rodríguez, E., Cerecedo-Sáenz, E., Hernández-Ávila, J., Navarra, A., & Toro, N. (2024). The Reynolds number: A journey from its origin to modern applications. *Fluids, 9*(12), 299. https://doi.org/10.3390/fluids9120299