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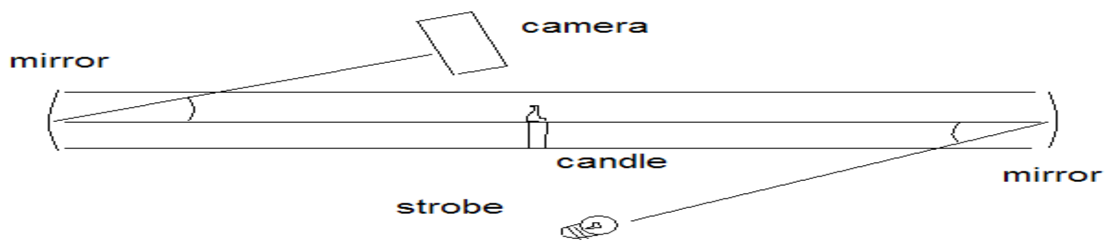
Flow Visualization
Final Project

Schlieren

For our final group project, we wanted to use a visualization technique that had a higher degree of difficulty but would yield more dynamic results than simply photographing a flume. So, we chose to use the Schlieren imaging technique, and it worked very well. The setup is very difficult to fine-tune (or even to get working at all), but the payoff is tremendous, because it allows you to see on film a fluid behavior that may have always been intuitive, but never before actually seen. In this case, it was the movement of air caused by temperature variations. It is incredibly interesting to see something that you have always felt but never seen; heat. The patterns that are developed by heat sources have always been one of the most direct ways you can **feel** fluid flow, but it's nothing that was ever possible to see. By using the Schlieren visualization technique, I gained an extraordinary perspective on seemingly ordinary physics phenomenon.

The apparatus we used for our Schlieren technique was set up as follows:



In this image, the mirrors are actually directly facing the camera and the strobe light, respectively. The angle between the mirrors and their respective objects is 6 degrees. The distance between the mirrors is 275 inches, and the mirrors have a focal length of 48 inches. The objects are each located one focal length from their mirror; 48 inches away. The candle was simply placed in between the two mirrors, with the height of the candle just reaching the bottom of the mirror. On top of the candle was a small aluminum funnel, with an orifice of 0.25 inches in diameter, to help channel the convective heat flow. The flow in my image appears to be a transition of convective air flow from a laminar state to a turbulent state. By estimating the temperature of the air around the candle to be 80 degrees Celsius, and the room temperature to be 23 degrees Celsius, and the distance from the candle to the instability as 10 cm, the following formula[1] can be used to obtain the velocity of the air flow due to convection:

$v_c = 0.65\,[g\,l\,(t_s - t_e) / (273 + t_e)]^{1/2}$ (1)

where

v_c = *velocity in center of airflow (m/s)*

$g = 9.81$ - *acceleration of gravity* (m/s^2)

l = *vertical distance from bottom of the surface (m)*

t_s = *temperature surface* (^oC)

t_e = *temperature surrounding environment* (^oC)

This results in an estimated fluid velocity of 2 meters/second. The Reynolds number for this flow is therefore 12,820, assuming a length of flow of 10 cm. This places the flow in the linear regime for shear flow. However, the Richardson number for this flow is 0.245, meaning that it is unstable. But, because the flow was coming from a funnel which acted as a pipe, I believe that the transition zone for this convective air flow more closely resembles that of a pipe, rather than a shear layer, which would put the Reynolds number for transitional turbulent flow on the order of 10^3 or 10^4, instead of 10^5. I believe that explains the interesting curling patterns forming, which resemble a Kelvin-Helmholtz instability—it is flow in a transition zone, not a purely laminar flow.

As mentioned before, we used the Schlieren visualization technique, whereby two mirrors are placed a distance away from each other with their centerlines aligned, but which point oppositely away from the centerline at the same angle. A strobe light is positioned along this angle towards one mirror, and a camera or ground glass is pointed towards the other mirror along that angle. In our case, our camera had no lens, and so we placed it at one focal distance from the mirror, (plus or minus a little bit) so that the image would project directly on to the imaging sensor (CCD) of the digital camera, which is very small. A razor-blade edge was placed on the edge of the projected image. By using this technique, a single pulse of the strobe light in a pitch-black room will show the density variations in any fluid flow, with darker patches representing more dense flow, and lighter patches representing less dense flow. We used a single pulse of an EG&G Electro-Optics PS302 strobe lightest to 400 V and 1/100th of a second to capture our image.

The photograph was taken with a Nikon D80, no lens (focal length of 0, f-stop of 0), the exposure was 1.3 sec, the ISO was 400, and the resolution was 1632 pixels on the x-axis by 2592 pixels on the y-axis. The size of the image is about 10 by 15 cm. In Photoshop CS2, an adjustment was made to the levels to make it brighter, and a curves adjustment was also used to increase the contrast.

Overall, I really enjoyed this project. The setup was extremely difficult and complicated, but it was worth it for the overall artistic and scientific value of the images gained. I believe the fluid physics shown are very interesting, because the laminar to turbulent transition that is shown is of a very graceful and dynamic nature. Artistically, I think the flow is reminiscent of a river or waterfall because of the turns and gradual lengthening of the arcs in the flow. I think that the fact that the image is uncluttered highlights the intensity and drama of the flow, and creates a very visually compelling photograph. In the future, I wish that I would have been able to get the flow a little bit more in focus. However, that would take almost endless practice and patience to achieve, and its understandable that some engineering departments have entire rooms devoted to permanent Schlieren setups. I think some really interesting projects to try with a devoted setup would include the human body in silhouette, maybe with a model wearing a flame-retardant suit and lit on fire. Maybe.

References

1. "Convective Air Flow." Engineering Toolbox. 12 December 2007 http://www.engineeringtoolbox.com/convective-air-flow-d_1006.html