Team Second Report: Hidden Hairdryer Flow

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FlowVis MCEN 5151

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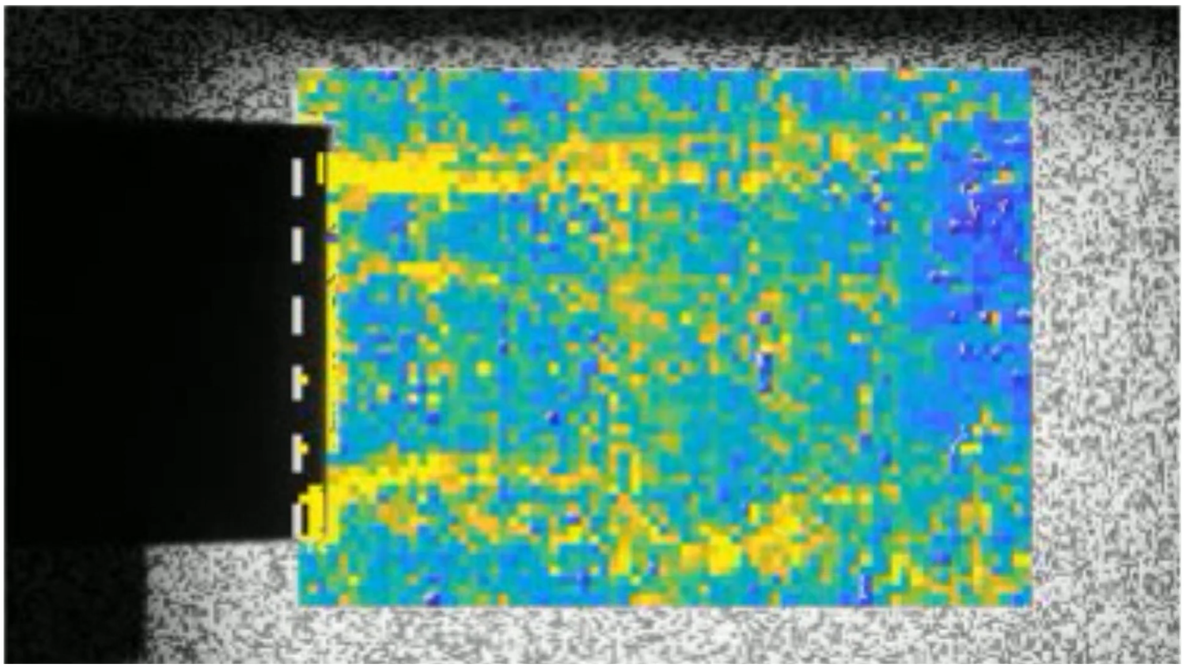

Figure 1: A frame from a video of a hairdryer which has been processed using background oriented schlieren techniques. It shows two major plumes situated on the edge of the hairdryer nozzle.

1 Introduction

This video came about as a result of the Team Second assignment of FlowVis. My team members for this project were of Luke Freyhof and Alana Martinez. For this assignment we wanted to try a technique that required more post processing to see the resulting flows. We landed on trying to use background oriented schlieren (BOS) after finding some code and documentation by Josh the Engineer [1] that was able to show results with basic, at home setups. This technique was able to be artistic by being very illustrative since we are not seeing the flow directly but rather we are using a color map to show what is happening. The scientific elements of this image where reached by being able to illustrate properties of the flow that can not be seen with the naked eye by taking advantage of how the intrinsic properties of air change in this system.

2 Flow Physics

The main driver of the flow areas we can see in figure 1 come from differences in the density of the air. The hairdryer is creating these jets of air with a different density compared to its surroundings. One non-dimensional number we can use to quantify the behavior is the Richardson number. This

Figure 2: Frame of the original video before any of the BOS processing. No flows or gradients of any kind are visible because the changes in air density caused by the heat and flow of the hairdryer are very small and we need to amplify them by looking for small pixel shifts that vary from the original undisturbed background.

describes the relation between local buoyancy and inertia and is given by: $Ri = \frac{g(\Delta\rho/\rho)D}{U^2}$ where g is gravity, ρ is the density and difference in the density of the air, D is the hairdryer nozzle diameter, and U is the speed of the airflow from the hairdryer. The difference in the density is related to the difference in temperature, which is easier to estimate in this case: $\frac{\Delta\rho}{\rho} = \frac{-\Delta T}{T} \approx \frac{-30}{300} \approx -0.10$. Using this we can estimate our Richardson number.

$$Ri = \frac{g(\Delta\rho/\rho)D}{U^2} = \frac{(9.81m/s^2)(.1)(.05m)}{10^2(m/s)^2} \approx 3.0 * 10^-4$$

This is a very small Richardson number which tells us that for the region near the nozzle we have momentum dominating over the buoyancy which is causing these distinct straight plumes. Buoyancy starts to become more dominate the farther away from source, as the the flows mix with the ambient air reducing the differences in temperature/density.

3 Visualization

We used background oriented schlieren as our main visualization method. This uses the idea that the index of refraction will be different in air due to the density differences at varying temperatures[3, 2]. These changes are normally fairly small but using a computer code to search and compare small pixel shifts we are able to show these small changes that the camera is able to capture. For this project we used the code created by Josh the Engineer to process our images and videos[1].

Our setup, shown in figure 3, included a vertically mounted hairdryer pointing upwards in front of our TV static background from Wikimedia commons, and a tripod mounted camera. The background was lit from behind from by a 10 watt LED panel.

The original video was captured at 24 fps and was about 27 seconds long. For the post-processing of this video I only took 1 frame per second to run through the code to help reduce the computation needed. I then exported the video to 1 frame per second to match the pacing of the original clip but with less time detail. Even so, we are able to see distinct straight plumes that form on the edges of the hairdryer that dissipate as we move away from the source. Even with this limited visualization we are still able to see distinct features and how they evolve with time.

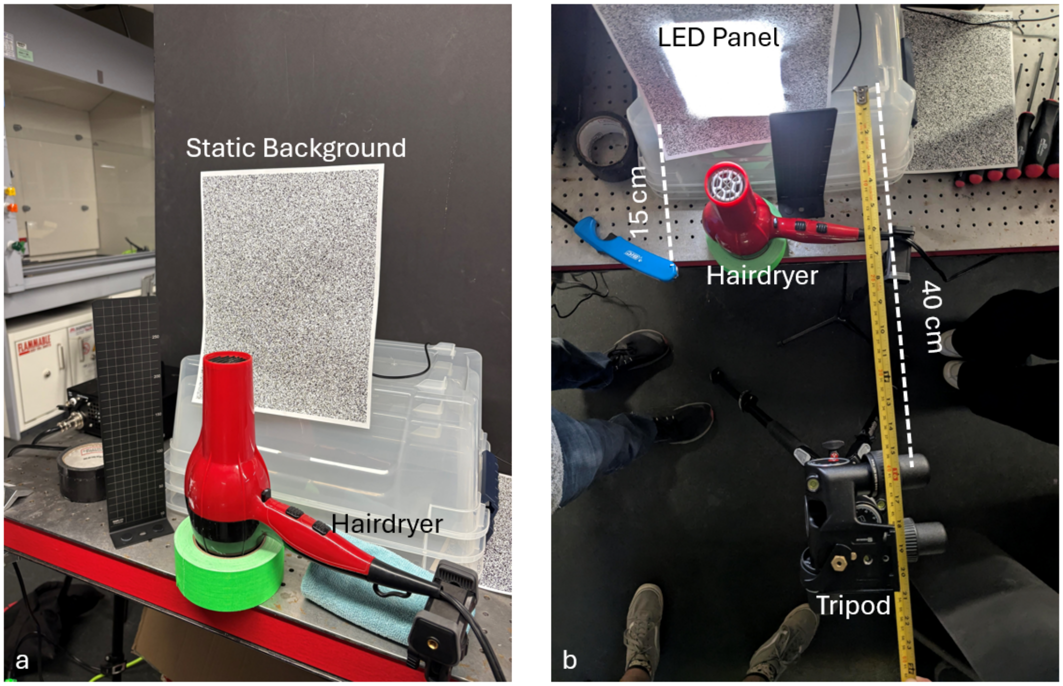

Figure 3: These images show the setup used for this experiment and were taken by Alana (a) and Luke (b). The first shows the static background that we printed out in order to use background schlieren processing. Image b then shows the spacing between the tripod, hairdryer and the backgound. Image b also shows the how the background was light from behind using an LED panel.

4 Photo Details

The original image was taken with a Nikon D3100 on a tripod 40 cm away with a Nikon DX SWM VR aspherical lens. The original video was recorded at 1920 x 1080. The processed BOS videos where exported to a lower resolution in avi format with only 505 x 305 pixels due to how the program exported frames. I was able to include a few different versions of the processing in the final edited video. The edited video was then exported back into 1920 x 1080 but the processed frames do not have that resolution. We can estimate the spacial and time resolutions to also better understand what was captured.

For the spacial resolution we can compare the sizes to our hairdryer which has a diameter of 5cm or 50mm. $s = \frac{50mm}{210px} = 0.24mm/px$ where compared to our full field of view horizontally is $0.24mm/px * 505px \approx 120mm = 12cm$. We can then say we are able to make out features that are larger than 0.48 mm (or are at least 0.48 mm apart). The temporal resolution of this visualization is not very big because I only took 1 frame per second of video which was originally captured at 24 fps. With this we are seeing averaged movement rather than the smaller structures that can be in this flow. The mean motion at this scale is 0.14 px/frame at 1 frame per second giving us: 0.14 px/s * 0.24 mm/px = 0.034 mm/s = $3.4 * 10^{-}5$ m/s. This means we are capturing the much slower net displacement rather than the instantaneous motion which happens on a much smaller time scale.

5 Reflection

This video was an interesting first dive into schlieren type photography. It was very fun to try post-process an image to highlight a flow that is invisible to the naked-eye. More finetuning on the parameters of the program could be made to try and make a smoother and more detailed image. In the future another attempt at filming or processing this style of image would be improved by not sacrificing so much resolution in the program by setting a window and search sizes that are more appropriate for the image scales and now that I am more confident in the processed results I would be interested in increasing the temporal resolution to see smaller time evolutions and not just the larger averaged behavior. Another aspect that would be interesting to explore would be different types of backgrounds to test which are better for BOS imaging.

References

[1] JoshTheEngineer. *DIY Background Oriented Schlieren: How To Take Pictures Like NASA*, October 2019. Version 1.

[2] Markus Raffel. Background-oriented schlieren (BOS) techniques. 56(3):60.

[3] Christopher T. Wanstall, Ajay K. Agrawal, and Joshua A. Bittle. Implications of real-gas behavior on refractive index calculations for optical diagnostics of fuel–air mixing at high pressures. 214:47–56.