

(Air)foiled

MCEN 5151 - Team Second

Beck Hermann, 11/3/2025

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Figure 1: Team First Submission, (Air)foiled, by Me

(Ari)foiled is my image submission for 2025 Team Second. The image depicts a 3D printed NACA 2412 airfoil captured using a Z-style Schlieren imagery setup. The team wanted to use a new form of photography to view how densities from hot air move around a common mechanical engineering shape. I successfully exported this frame from a 50-second video of a lighter flame underneath a suspended airfoil using a code written for Microsoft PowerShell, a program meant for video and photo editing. This image is a 90-degree counterclockwise rotation of the original video. My teammates, Duncan Laird and Domenic Decaro, helped in all steps of the setup and videography.

The flow apparatus used was from a classic Bic lighter that was held to continuously produce a flame. This flame was held underneath a 3D printed airfoil. This allowed the flow of the lighter flame to displace around the suspended object. The rotation seen in Figure 1 is to resemble a real airfoil, with the illusion that fluid is coming from left to right. A boundary layer due to viscous effects can be seen on the bottom of the airfoil. See Figure 2, below, for a diagram of the flow apparatus and Schlieren setup.

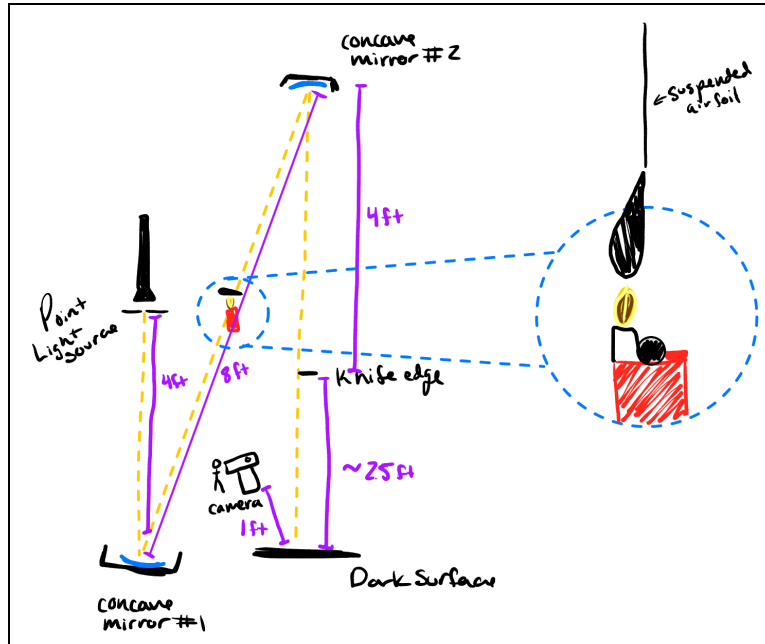


Figure 2: Flow apparatus sketch showing the schlieren setup and lighter-airfoil setup. Not to scale

The flow phenomenon we wanted to capture was the thin boundary layer along the bottom (note that for this report, when I mention the “bottom” of the airfoil, I am referring to the *original* left side from the image. The thin white layer is this so-called “bottom”) of the airfoil. To describe the boundary layer, we must first understand the flow. To do this, we can analyze the Reynolds number, Re , which is calculated below in Equation 1. To measure the characteristic diameter, I estimated it to be 0.006 m near the airfoil based on a comparison against a ruler, the velocity to be ~0.12 m/s based on frame analysis, where the flame moved 2” in 0.4 seconds. The density of butane vapor is 2.51 kg/m^3 and its viscosity is $7.5 \times 10^{-6} \text{ Pas}$ (National Library of Medicine).

$$Re = \frac{\rho V D}{\mu} = \frac{(2.51 \text{ kg/m}^3)(0.12 \text{ m/s})(0.006 \text{ m})}{(7.5 \times 10^{-6} \text{ Pa s})} = 241$$

This describes a very laminar flow, which is predictable and mixes slowly. This is consistent with what we can see when we examine a flame coming from a lighter - steady shape and slow movements. This laminar flow hits the airfoil, and goes around it, and transitions to heated air and a turbulent flow as it falls off the object and swirls uncontrollably.

When the hot air comes into contact with the airfoil, it is invisible to the naked eye, but thankfully, due to Schlieren Imagery, we can see the density gradients and see the boundary layers form. While the turbulence is caused by deflection, the boundary layer is formed due to the viscosity of the air paired with a no-slip condition. This means that the velocity of the fluid along the surface of the airfoil is zero, and increases to the free stream value as it moves down. Density gradients, which the schlieren reveals, are created by temperature-induced refractive index gradients as well as the viscous shear forces. Together, these effects cause a thin region of laminar flow near the airfoil surface to transition into the wispy, mixed turbulent flow farther from the airfoil (Embry-Riddle University).

Although most planes fly in such extreme conditions that the air going “into” their airfoils has extremely high velocities and Reynolds numbers, a study by S. Yarusevych, P. E. Sullivan, and J. G. Kawall suggests that boundary layers still form at low Reynolds numbers and laminar flow. This confirms

that my analysis of the image is correct and that these boundary properties hold true. Both sides will form boundary layers universally and behave differently (Yarusevych, 2005), which can be seen in my image.

While our airfoil was oriented vertically, with the flow coming from the bottom, the physics governing boundary layer formation still hold. Oregon State University, and all other fluid textbooks and research, state that the boundary layer formation is due to no-slip conditions, and no gravity or directionality is associated. According to Delphine De Tavernier, Carlos Ferreira, and Gerard van Bussel 2019, we are still able to analyze the vertical airfoil as a horizontal airfoil and say the same physics applies. Vertical-axis wind turbines apply this concept to effectively generate wind power, and the shape is still being studied to optimize vertical airfoils.

The visualization technique used was Schlieren imagery, with a z-shape setup. The materials used included two concave mirrors, a bright flashlight with a pinpoint hole, a dark sheet of paper, and a knife edge, all sourced from Professor Sunberg. We were inside an apartment with all lights shut off and the setup placed on the kitchen floor.

The field of view was about 8" across and 6" tall to ensure, and about 1 foot away from the page that the setup projected on. The camera zoomed in to capture the desired FOV using a point in the middle of an 18-65mm focal range. The camera used was a digital Canon Rebel T3i that shot the video with an original size of 1920x1080 pixels, and I cropped my image to 988x988 pixels. As shot and as playback, the frame rate is 30 frames/second. The aperture was F5.6 and the ISO was 128000. A lot of post-processing was done so I could get the sharpest and brightest image, but the majority was cropping and contrast adjustments. Figure 4 shows the original image before editing.



Figure 3: Original image

Overall, the image shows a unique phenomenon of density gradients, boundary layers, and airfoil physics coming together to produce a beautiful flow visualization. I like how I was able to get the perfect frame grab that shows all aspects of the flow, and was able to post-process it to show Schlieren against the

black background. I think the fluid physics are shown very well, and my teammates' videos provide even more context because we each chose a different way of presenting the flow. My intent was fulfilled, and I would be proud to hang this image up and present it. I would like to increase the sharpness of the image and would develop this idea further by trying different shapes and a Schlieren setup. However, Schlieren imagery is incredibly hard, and I would need a lot of time and trials. I am looking forward to working with my group further.

Sources

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