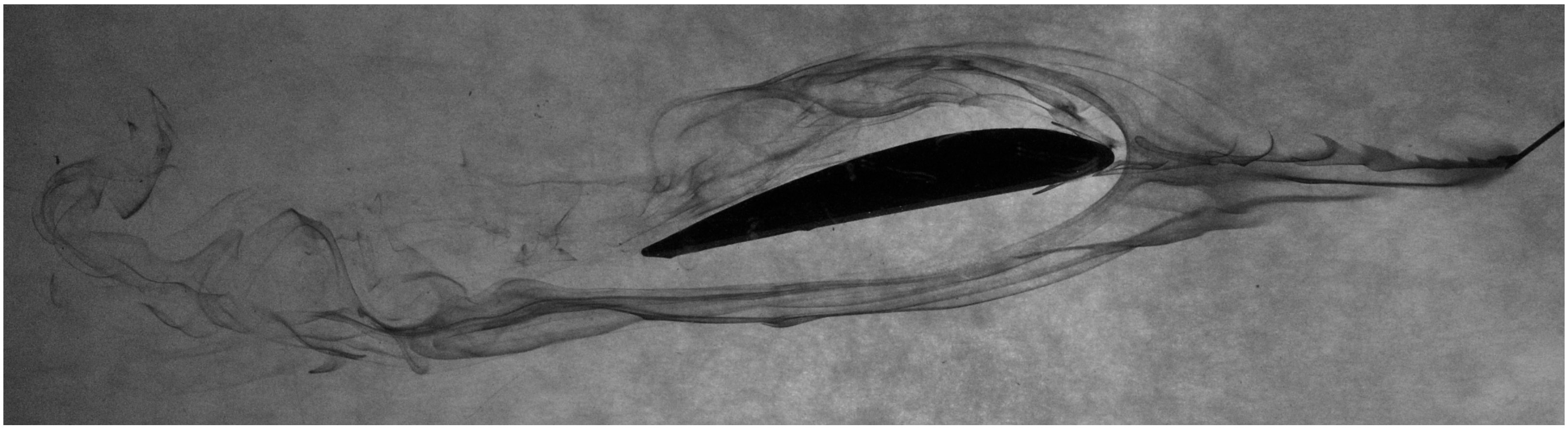
IV 4: The Flume

Kendall Shepherd
Assisted by: Lana Pivarnik, Cole Smith, and Robbie Cooper
MCEN 4151 - Flow Visualization
11/16/2022



I. Overview of Experiment

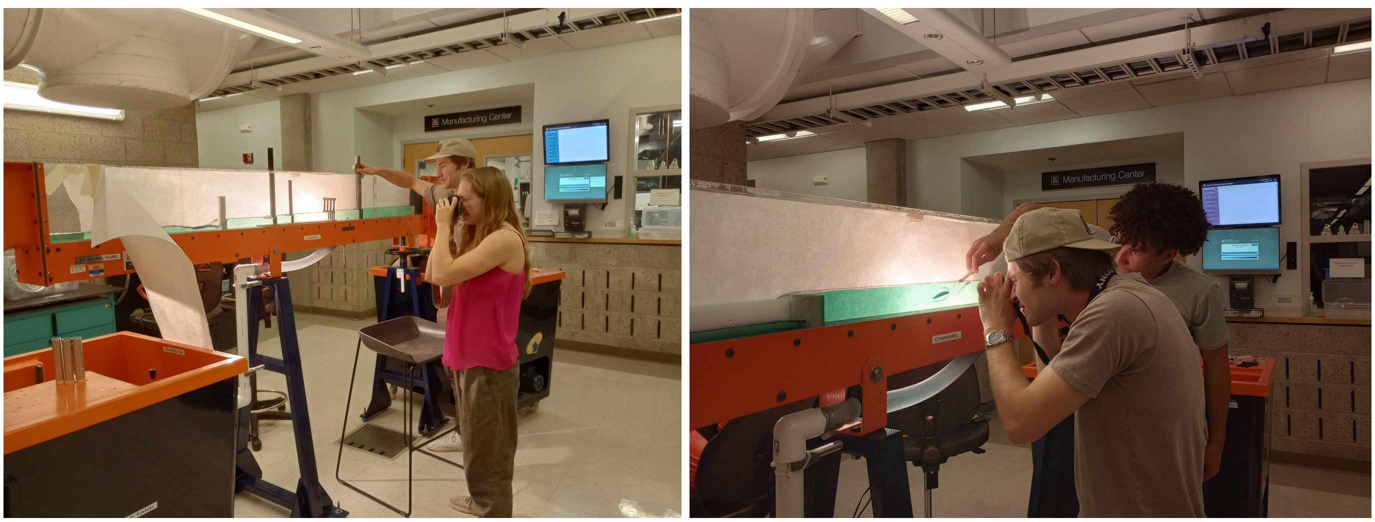
My goal for this project was to use the flume to capture an image that shows flow around different objects. We wanted to inject dye into the water which would then visualize how fluid moved around an object that was obstructing the flow.

We 3D printed a cross section of an airfoil and a dye injector. The dye injector ended up not working and we instead used a syringe to inject the dye. While waiting for the 3D printed airfoil, we experimented with other objects to obstruct flow like square cross section pipes and large metal cylinders.

I originally just wanted to see how air would flow around an airfoil, but I ended up getting an image of what causes airplanes to stall.

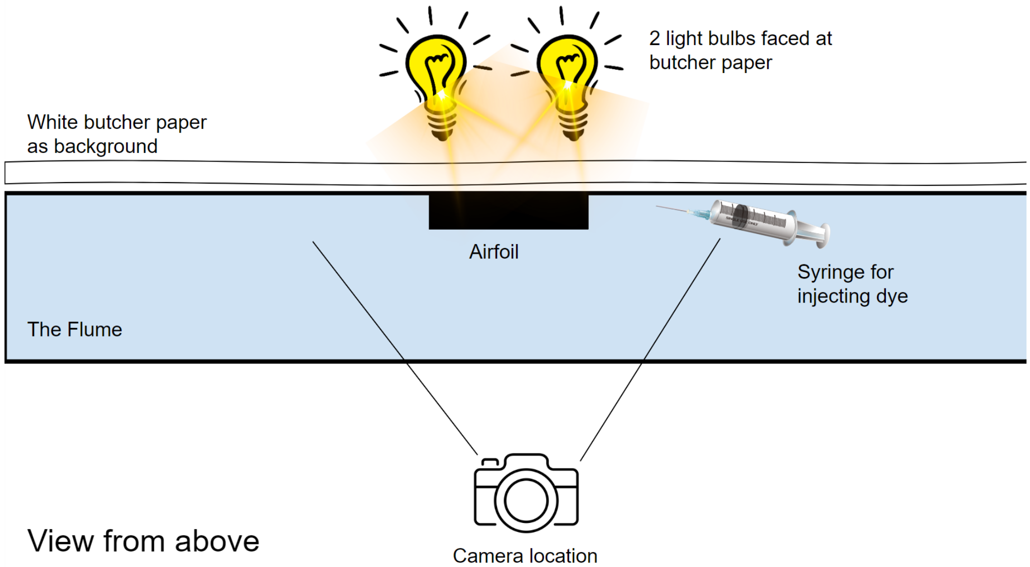
II. Setup

For this set up we used the Flume in the University of Colorado Boulder ITLL's basement. The Flume is a device that makes water flow through an open channel. The angle of the channel and volumetric flow rate of the water are able to be changed. We had it set at an angle of 0° and the volumetric flow rate at 0.27 L/s.



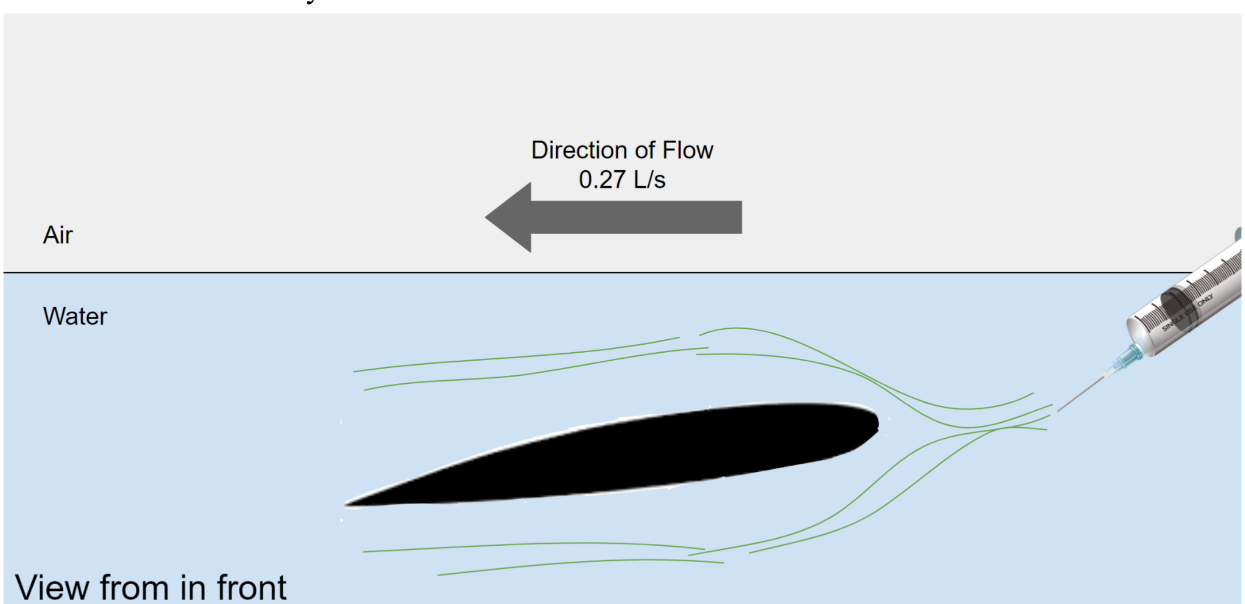
Using the flume to create open channel flow and observe obstruction in stream

We also placed a sheet of white butcher paper on one side of the Flume to act as a background and also help diffuse the incoming light. For lighting we used two lamps to light the butcher paper from behind. We used one 300 watt lightbulb and one 250 watt flood light that both had metal lamp shade reflectors.



Set up of the Flume, lighting, and camera

When using the airfoil cross section, we taped it to the wall of the Flume on the side with the butcher paper. We then used a syringe filled with food dye to inject the coloring approximately 2in upstream of the front edge of the airfoil. When injecting the dye, we tried to keep a steady and light flow of dye. For best results, we found that undiluted food dye had the most vibrant effect.

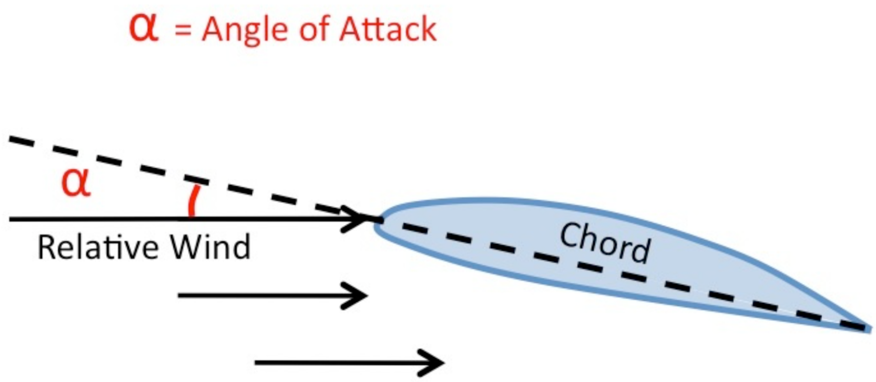


Injecting food dye upstream of the airfoil

III. Fluid Mechanics

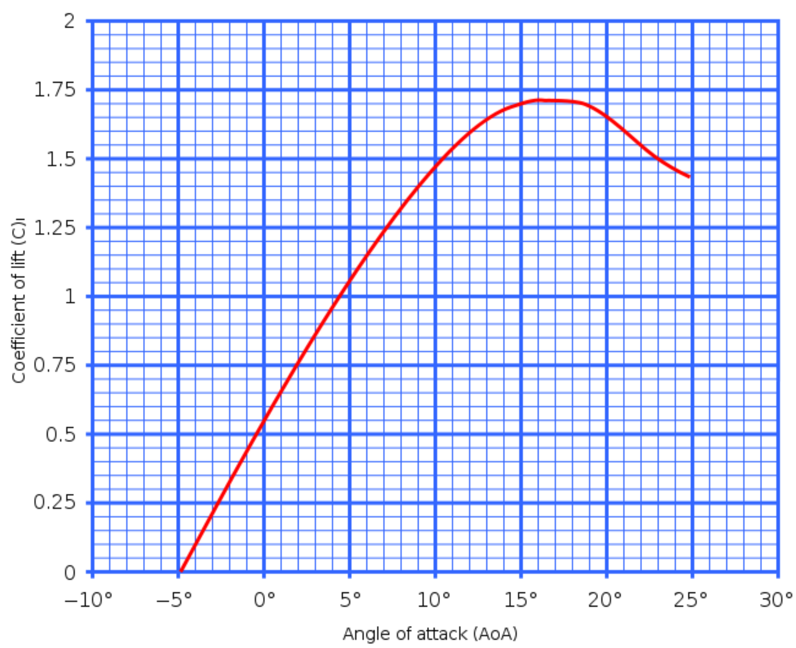
This image is demonstrating what causes airplanes to stall mid flight. Stall is when the coefficient of lift decreases due to an angle of attack exceeding 15-16°.[1] The coefficient of lift is a unitless number that represents how much lift an airfoil produces[2].

The angle of attack is the angle at which the relative wind (wind created by the aircraft traveling in a direction) meets the airfoil[3].



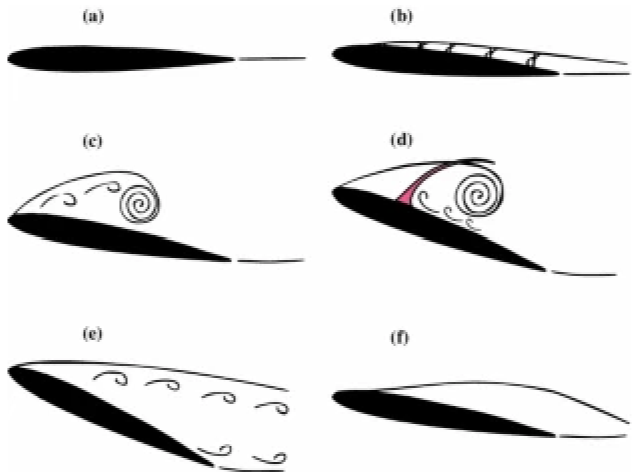
Angle of attack on an airfoil[3]

At about 15-16°, is the critical angle of attack. This angle produces the maximum coefficient of lift. However, it is also known as the "stall angle of attack" since any larger angle will result in a decrease of the coefficient of lift, and ultimately will cause the airplane to stall[4].



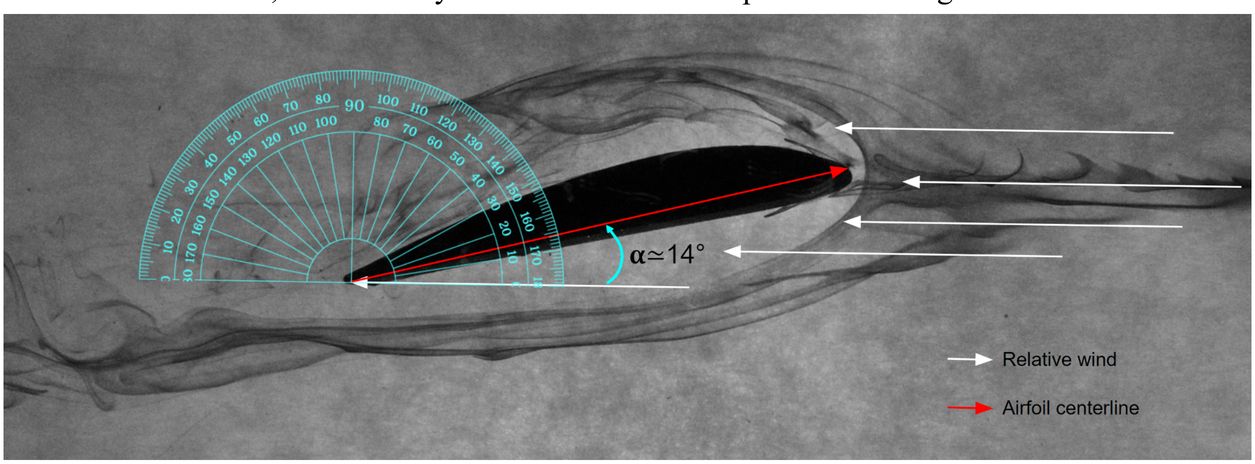
Coefficient of lift vs Angle of attack[4]

At low angles of attack, the flow around the airfoil remains laminar (flow that follows smooth streamlines). But as the angle of attack increases, turbulent flow (flow that has chaotic changes in direction, pressure, and velocity) and vortices start to appear. These turbulent flows create more drag on the airfoil and reduce the coefficient of lift[5]. This sudden drop in the coefficient of lift is called stalling. Unlike a car, when an airplane stalls, it doesn't mean that the engines stop working, it means that the lift force on the wing significantly decreases and results in a loss of altitude[6].

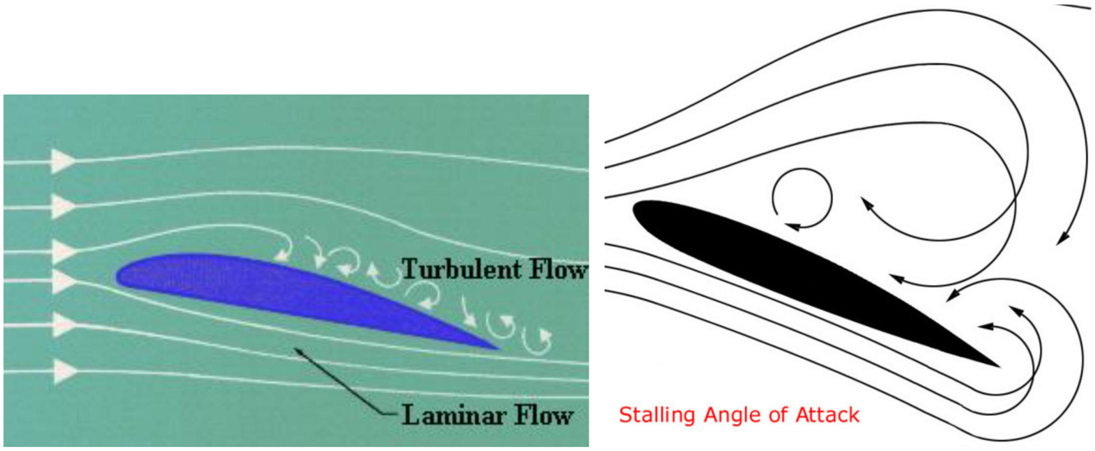


Turbulent flow develops as angle of attack increases. Turbulent flow develops in figure c, also angle of maximum lift. Airplane stalls at figure e, when vortices detach from the airfoil. Flow reattaches to airfoil in figure f, and the plane regains stability[7].

When working with the Flume, we unintentionally placed the airfoil at an angle of about 14°. In this image we are able to see that the flow underneath remains laminar while the flow on top starts to become turbulent. At this angle, the airfoil is close to maximum lift, however any further and it could experience stalling.



Angle of attack on the airfoil in the photo



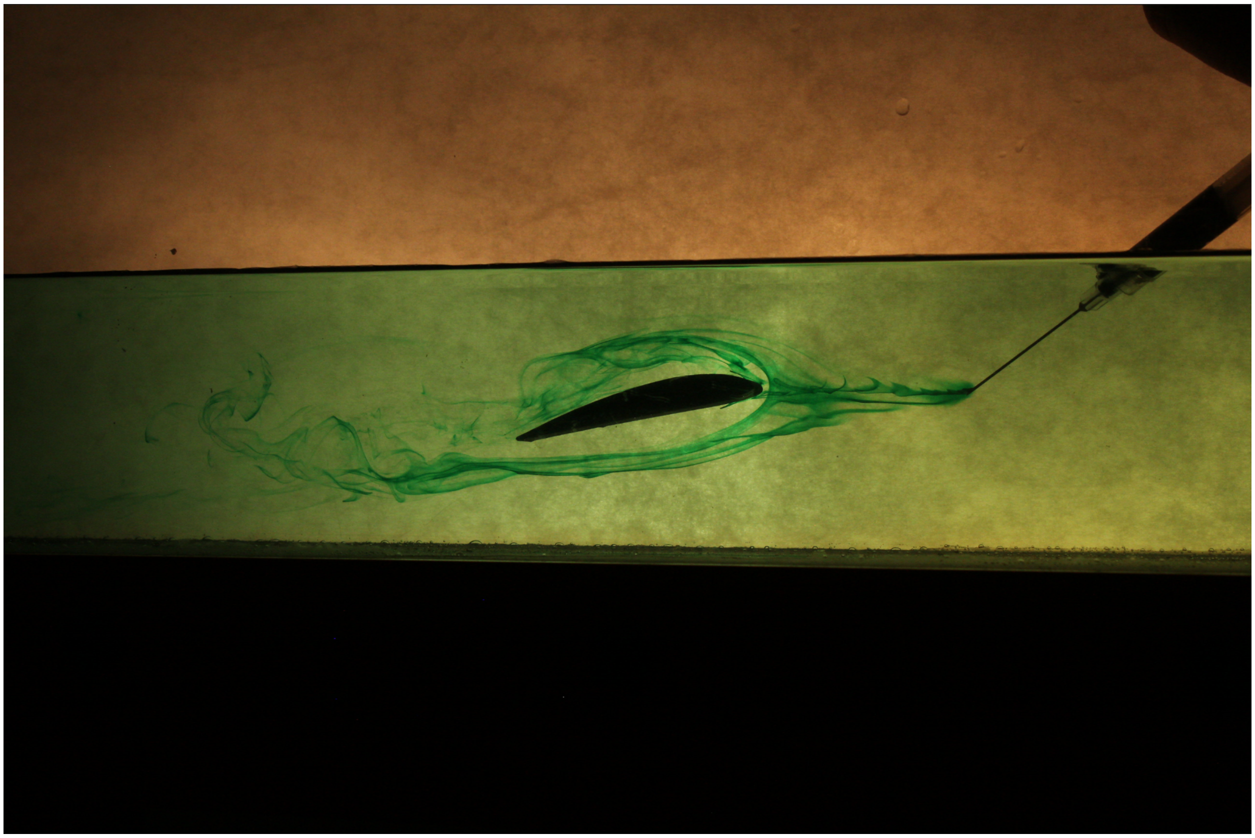
Turbulent flow on top and laminar flow underneath[8,9]

IV. Photographic and Visualization Techniques

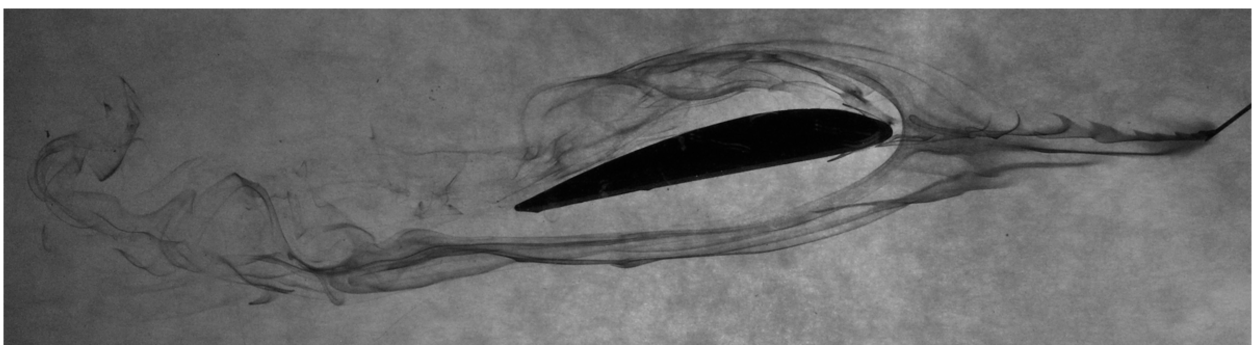
This photo was taken on a Canon EOS REBEL T5. The settings that I chose were; ISO:800, F-Stop:f/9, Shutter Speed:1/2500s, and Focal Length:41mm. I wanted a fast shutter speed to ensure no motion blur and in turn had to adjust the ISO and aperture to compensate for the lighting.

When editing this photo I mainly played with the coloring, contrast, and brightness. I made the image grayscale because I did not like the colors. After many trials with food dye, the water started to become discolored and created an unpleasant greenish yellow against the white butcher paper. The downside of the grayscale was that it reduced a lot of the vibrancy and contrast that the green dye had. I also edited the contrast and brightness to try to highlight the dye even more. The original photo size was 5184x3456 pixels. I cropped the photo to 1200x324 pixels.

I believe that this image is both spatially and time resolved. There is no motion blur and I also think that all necessary details are clearly able to be seen in this image.



Original Photo



Edited photo

V. Image Remarks

I am really happy with how this image turned out. I think that this image very clearly captures the flow that is occurring. I even learned about airplane stalling which is new to me. Even though I am a big fan of color, I really like how this image turned out in black and white. I am also happy that I got to crop it into a unique aspect ratio. I also really like the small details in this image. Like the little spikes that appear in the dye streaming from the needle. I also like the two little strands that appear at the very front of the airfoil that look like the whiskers of a catfit.

I wish that I had been able to have better success at editing out the texture of the butcher paper in the background, but overall I don't think it distracts too much.

References

[1]Wikimedia Foundation. (2022, October 15). *Stall (Fluid Dynamics)*. Wikipedia. Retrieved November 16, 2022, from https://en.wikipedia.org/wiki/Stall_(fluid_dynamics)

[2]Benson, T. (2021, May 13). *The lift coefficient*. NASA. Retrieved November 16, 2022, from https://www.grc.nasa.gov/www/k-12/rocket/liftco.html

[3]*Angle of attack (AOA)*. SKYbrary Aviation Safety. (n.d.). Retrieved November 16, 2022, from https://www.skybrary.aero/articles/angle-attack-aoa

[4]Wikimedia Foundation. (2022, June 8). *Angle of attack*. Wikipedia. Retrieved November 16, 2022, from https://en.wikipedia.org/wiki/Angle_of_attack#Critical_angle_of_attack

[5]YouTube. (2016). *Dynamic stall of an aerofoil in ramp-up motion*. *YouTube*. Retrieved November 16, 2022, from https://www.youtube.com/watch?v=uUGlPxAw9J0&ab_channel=APSPhysics.

[6]YouTube. (2014). *What is a stall? YouTube*. Retrieved November 16, 2022, from https://www.youtube.com/watch?v=ZuGPcvC4vbw&ab_channel=flight-club.

[7]Mulleners, K., & Raffel, M. (2013, February 8). *Dynamic stall development - experiments in fluids*. SpringerLink. Retrieved November 16, 2022, from https://link.springer.com/article/10.1007/s00348-013-1469-7

[8]*Laminar Flow Airfoil*. The Aviation History Online Museum. (2015, June 1). Retrieved November 16, 2022, from http://www.aviation-history.com/theory/lam-flow.htm

[9]*Angle of Attack*. The Aviation History Online Museum. (2015, June 1). Retrieved November 16, 2022, from http://www.aviation-history.com/theory/angle_of_attack.htm