AerE 344: Undergraduate Aerodynamics and Propulsion Laboratory

Lab Instructions

Lab #07: **Quantifications of the Turbulence Characteristics in the Wake of an Airfoil by using a Hotwire Anemometer**

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AerE344 Lab 07: Quantifications of the Turbulence Characteristics in the Wake of an Airfoil by using a Hotwire Anemometer

The objective of this lab will be to measure the boundary layer profiles from the top and bottom surfaces of an airfoil by measuring velocities just downstream of the airfoil trailing edge. You will use the hotwire anemometer you calibrated last week for this experiment.

What will be available to you for this lab:

- A thermometer and barometer for observing ambient lab conditions (for calculating atmospheric density).
- A computer with a data acquisition system capable of measuring the voltage from the hot wire anemometer.
- A hotwire anemometer placed just downstream of the trailing edge of the airfoil. This probe is mounted on a traverse that can be moved vertically through the airfoil wake.

What you will do during the lab time:

- Conduct your wind tunnel experiments at motor speed of 10 Hz. Acquire wake velocity profiles for AOA=4, 8, 12 and 16 degrees. **BE SURE** that you start from outside the wake and go all the way to the other side of the wake. You do not want to miss any of the profile.

Required Plots:

- Velocity distribution in the wake (for each angle of attack)

- Turbulence intensity distribution in the wake (for each angle of attack and for upper and lower surfaces)
    - "Turbulence intensity" is defined as the RMS of the velocity fluctuations divided by the mean velocity
- Calculated values for momentum thickness and more to be described in the lab writeup guidelines.
- Power spectrum plots of the hotwire measurement data.

Your report must provide details on:

- How you chose your measurement points
- Reynolds number of tests and incoming flow velocity.

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Writeup Guidelines

The report for this project will be a formal lab report.

Required Plots:

1) The velocity distributions for your group's data involve plotting the mean velocity profiles based on your hotwire anemometer measurements. Plot y/δ vs U/U_e where U_e is the velocity external to the boundary layer (the freestream value). δ is the thickness of the boundary layer. Plot the boundary layer from the top surface and the bottom surface as separate curves with "*y*" indicating the positive distance from the surface—NOT positive for the top surface and negative for the bottom surface.
2) Turbulence intensity profiles also come from the hot wire measurements:
   a. "Turbulence intensity" is defined as the RMS of the velocity fluctuations divided by the mean velocity
   b. NOTE: To calculate the RMS velocity from your RMS voltage calculation, you can use a Taylor series expansion of your hot wire calibration polynomial:
      i. If your calibration polynomial is of the form: $\overline{U} = C_0 + C_1\overline{v} + C_2\overline{v}^2 + C_3\overline{v}^3 + C_4\overline{v}^4$, where $\overline{U}$ is mean velocity and $\overline{v}$ is the mean voltage.
      ii. Then the rms velocity can be expressed as: $u_{rms} = \left.\frac{\partial \overline{U}}{\partial v}\right|_{\overline{v}} v_{rms} = \left[C_1 + 2C_2\overline{v} + 3C_3\overline{v}^2 + 4C_4\overline{v}^3\right]v_{rms}$, where u_{rms} is the rms velocity, v_{rms} is the RMS voltage, and the term in parenthesis is evaluated at the mean velocity.

3). The power spectrum plots of the hotwire measurements

By using the FFT transformation of the time sequences of the hotwire measurement data, the vortex shedding frequency in the wake of the airfoil can be determined. Please include 2 representative plots for each tested AOA case.

Required Comparisons/Descriptions:

1. Calculate momentum thickness, θ , according to the following equation: $\theta = \int_0^Y \frac{u}{U_e}\left(1 - \frac{u}{U_e}\right)dy$ where *Y* is some point outside the boundary layer. From the momentum thickness calculate the drag coefficient according to the relation: $C_d = \frac{2\theta}{L}$, where the L is the chord length of the airfoil. How do these drag coefficients compare with your pitot tube rake from the last lab?

2. What is the Reynolds number of your test? $\text{Re} = \frac{\rho U_\infty c}{\mu_\infty}$
   a. Is this a laminar boundary layer or a turbulent boundary layer? The transition from laminar to turbulent is approximately $\text{Re} \approx 2 \times 10^5$

3. From the velocity profile plots, estimate the boundary layer thickness, δ, for your profiles. How do these compare with theoretical estimates as given by the following expressions? How is this related to where you chose to measure velocity?
   a. $\frac{\delta}{x} = \frac{5.0}{\sqrt{\text{Re}_x}}$ for laminar flow
   b. $\frac{\delta}{x} = \frac{0.37}{\text{Re}_x^{1/5}}$ for turbulent flow