AerE 344: Undergraduate Aerodynamics and Propulsion Laboratory

Lab Instructions

Lab #08: Measurements of the Boundary Layer over a Flat Plate

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AerE344 Lab 08: Measurements of the Boundary Layer over a Flat Plate

The objective of this lab will be to measure the boundary layer profile on a flat plate using a Pitot rake. You will measure the profiles at 10 difference streamwise locations assigned to your group.

What you will have available to you in the lab:

- A Pitot probe in the wind tunnel for acquiring dynamic pressure throughout your tests.
- A thermometer and barometer for observing ambient lab conditions (for calculating atmospheric density).
- A computer for data acquisition.
- Three DSA units (48 channels) for the pressure measurements.
- A Pitot rake for velocity profile measurements.
- A traverse systeme. This traverse allows motion in the *x*-direction (streamwise) and the *y*-direction (vertical).

What you will do during the lab time:

- Conduct your wind tunnel experiments with incoming flow **at ~ 10 m/s** — acquire velocity profiles at positions through the flat plate boundary layer at 10 STREAMWISE POSITIONS assigned to your group by the TA.

- **IMPORTANT**: Estimate what the thickness of the boundary layer is at your assigned streamwise locations.
    - o Assume transition occurs for Reynolds numbers of $\text{Re}_x = (\rho V_\infty x)/\mu = 10^5$ where μ, the dynamic viscosity, can be assumed to be $1.8 \times 10^{-5} \frac{Ns}{m^2}$
    - o $\frac{\delta}{x} = \frac{5.0}{\sqrt{\text{Re}_x}}$ for laminar flow
    - o $\frac{\delta}{x} = \frac{0.37}{\text{Re}_x^{1/5}}$ for turbulent flow

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Writeup Guidelines

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

You will be examining how the experimental data line up with theoretical and analytical predictions.

Required Plots:

1) Mean velocity profiles at 10 streamwise locations based on your measurements. Plot y/δ vs U/U_∞.
2) Based on the velocity measurement results, find and plot the experimental values of $\delta(x)$ and $\theta(x)$. The plot of $\delta(x)$ should include comparison to the analytical expressions below:
    a. Calculate δ from theory for both laminar and turbulent regions (assume transition occurs for $\mathrm{Re} = 5\times 10^5$)
        i. $\frac{\delta}{x} = \frac{5.0}{\sqrt{\mathrm{Re}_x}}$ for laminar flow
        ii. $\frac{\delta}{x} = \frac{0.37}{\mathrm{Re}_x^{1/5}}$ for turbulent flow
3) Based on the measured momentum thickness and the integral momentum equations:
    i. Estimate local shear stress coefficient, c_f, as a function of *x*
    ii. Find the drag coefficient C_D

NOTE:

The *local shear stress coefficient* is defined as: $c_f = \frac{\tau_w}{\frac{1}{2}\rho U_e^2}$

It is related to the momentum thickness as follows: $c_f = 2\frac{d\theta}{dx}$

An empirical relation you may use for comparison is: $c_f = \frac{0.0583}{(\mathrm{Re}_x)^{0.2}}$

The *drag coefficient* is then the friction drag that results from all the surface upstream of the measurement point and not just the local shear stress.

This drag coefficient is defined as: $C_d = \dfrac{D}{\frac{1}{2}\rho U_e^2 A}$ where *D* is the drag force and *A* is the surface area.

This drag coefficient is related to the momentum thickness as follows: $C_d = 2\dfrac{\theta}{L}$

This drag coefficient can be estimated as: $C_d = \dfrac{0.074}{(\mathrm{Re}_L)^{0.2}}$ where *L* is the length of the plate upstream of the measurement point. Sometimes C_f and C_d are used interchangeably.

Your report must provide details on:

- Discussions of each of the above plots and the concepts required to develop them.
- Reynolds number—based on freestream velocity, V_∞, and the streamwise position, x, of your tests.

REFERENCES:

The following references will help you if you have questions about the boundary layer theory being used in this lab:

1. **Chapter 4** of Bertin, J.J., *Aerodynamics for Engineers*, 4th Ed., Prentice Hall, New Jersey, 2002.
2. **Chapters 17, 18** of Anderson, J.D., *Fundamentals of Aerodynamics*, 3rd. Ed., McGraw-Hill, New York, 2001.