LAB 7: Boundary layers

(Due by 5 pm *one week* after the lab day)

The members of our group are: ______________________

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Objectives:

- ☐ **Observe** the presence of a boundary layer over a flat plate.
- ☐ **Observe** the effect of freestream velocity on the thickness of the boundary layer.
- ☐ **Calculate** a theoretical boundary layer thickness and compare it to measured results.

In this lab, we will measure the stagnation pressure of air inside the boundary layer at a fixed location and flow velocity. Figure 1 shows how the flow velocity varies with respect to distance from the plate at various streamwise locations. The distance from the leading edge of the plate is denoted by x, the vertical height from the plate is y, the freestream velocity is U_∞ and the local flow velocity inside the boundary layer is $u(x,y)$.

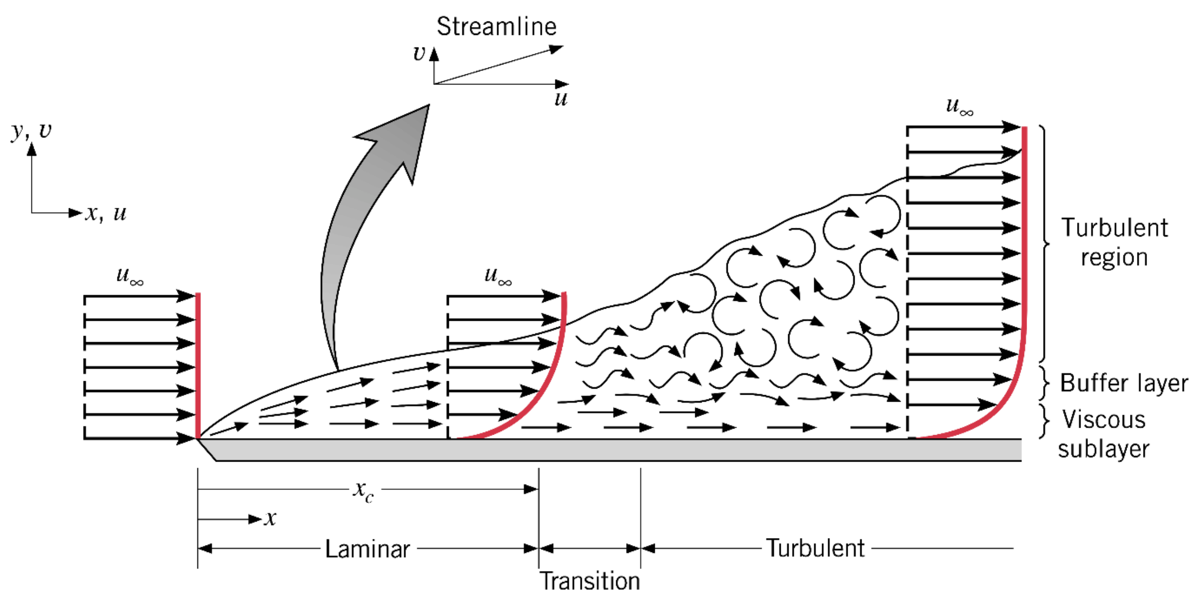

Figure 1. Velocity field in the boundary layer (Source: Bergman, Lavine, Incropera, and DeWitt. Fundamentals of Heat and Mass Transfer, 8th Ed. Wiley)

Viscous forces in the boundary layer cause additional loss in the flow, reducing the *stagnation* (total) pressure within the boundary layer. However, the *static* pressure in the boundary layer is equal to the static pressure outside of the boundary layer at the same downstream distance x. By measuring the stagnation pressure at different vertical heights within the boundary layer (using a stagnation probe attached to a *traverse*) and measuring the static pressure in the tunnel (using a Pitot-static tube), we can determine the velocity profile in the boundary layer.

Note that from our discussions in class, for the flow over a flat plate, the transition to turbulence id often cited as occurring at a Reynolds number of $Re_x = 5\times10^5$. However, imperfections on the plate surface or turbulent conditions upstream of the plate could cause this transition to occur at a much lower Reynolds number. Based on previously conducted experiments in our wind tunnels, we expect all the boundary layers that you will measure to be turbulent, even though the Reynolds numbers will likely be less than 5×10^5.

Activity 1: Fluid properties

Measure and record the temperature and pressure in the room. Use these to find the density and viscosity of air to be used in later calculations. Record the values below.

$T =$ ________ $P =$ ________ $\rho =$ ________ $\mu =$ ________

Activity 2: Collecting boundary layer data in wind tunnel

1. Identify the wind tunnel (WT1 is the large one and WT2 is the small one) that you will be taking measurements on in Table 1. Before turning on the wind tunnel, lower the stagnation probe so that it lightly touches the surface of the plate. **Make sure you do not lower it too much and cause the stagnation probe to bend**. Zero the traverse indicator at this location by rotating the bezel on the dial on the traverse and pressing the button on the up/down indicators.
2. Measure the distance from the leading (upstream) edge of the plate to the stagnation probe and record it as x in Table 1.
3. Connect the *static* and *stagnation* ports of the Pitot-static tube to the *low*- and *high*-pressure ports of the inclined manometer, respectively. Your instructor will inform you of your group's target height on the inclined manometer. Gradually turn up the air speed in the wind tunnel such that you reach this target height.

Table 1: Wind tunnel, probe location, and Pitot-static tube information

Wind tunnel (Circle your tunnel)	Pitot-static tube target height on inclined manometer [inH_2O]	Probe location, x [ ]
WT1 (larger)		
WT2 (smaller)		

4. Without changing the flow speed in the wind tunnel, disconnect the *stagnation* port of the Pitot-static tube from the inclined manometer and connect the *stagnation probe*

tube (which is attached to the wind tunnel traverse) to the inclined manometer in its place. The static port of the Pitot-static tube should remain connected to the low-pressure port of the manometer.

5. Record the height you observe on the inclined manometer. Make sure that the stagnation probe is still in contact with the surface of the plate. This will be *your minimum reading*.
6. *Very gradually* raise the stagnation probe to the next probe distance in Table 2. Record the inclined manometer height. Make sure to wait until the fluid in the manometer completely stops before taking your reading. (This make take several minutes.)
7. Repeat Step 6 until you have completed all the measurements.
8. Once you have completed data collection for your group, collect data from the group that performed this experiment with the other wind tunnel record their information in Tables 1 and 2.

Table 2: Data for boundary layer experiment

	Wind tunnel 1 (larger tunnel)		Wind tunnel 2 (smaller tunnel)	
	Probe distance y from the surface of the plate [in]	Stagnation probe inclined-manometer fluid height [in H_2O]	Probe distance y from the surface of the plate [in]	Stagnation probe inclined-manometer fluid height [in H_2O]
1	0.00 (at surface)		0.00 (at surface)	
2	0.005		0.005	
3	0.010		0.010	
4	0.015		0.015	
5	0.030		0.030	
6	0.045		0.045	
7	0.060		0.060	
8	0.100		0.100	
9	0.140		0.140	
10	0.180		0.180	
11	0.220		0.220	

12	0.260	
13	0.300	

0.260	
0.300	

Data post processing after the lab session

1. Fill in Table 3. Include your group's data and the data for the group who performed experiments with the other wind tunnel and calculate the Reynolds number for each case.

Table 3: Experimental Reynolds numbers

	Wind tunnel (circle)	Probe location, x [ ]	Experimental local Reynolds number, Re_x
Your group's data	WT1 (larger tunnel) WT2 (smaller tunnel		
Other group's data	WT1 (larger tunnel) WT2 (smaller tunnel		

Sample calculation

Show your calculations for Re_x for your group's data. Include all intermediate calculations from the raw data and all unit conversions.

Sample calculation

Show your calculations for velocity within the boundary layer at a location of $y = 0.03$ inches from the plate surface. Include all intermediate calculations from the raw data and all unit conversions.

2. Create a single plot showing both sets of measured velocity profiles. The plot should show the flow velocity on the horizontal axis and the probe height from the surface on the vertical axis. Use only symbols (no lines). Your own dataset should be shown as circles. Use another marker type for the other data. Indicate which data set corresponds to which Reynolds number. Attach the plot to this handout.
3. Remember that boundary layer thickness δ is defined as the y location where the velocity reaches 99% of the freestream velocity U_∞. Examine the two datasets and estimate the measured boundary layer profile's thickness. Compare your experimental result to the predicted boundary layer thickness assuming turbulent flow. Record your results in Table 4.

Table 4: Boundary layer thicknesses

	Experimental boundary layer thickness δ [mm]	Predicted boundary layer thickness δ [mm]	Percent difference
Your group's data			
Other group's data			

4. Plot dimensionless boundary layer height, δ/x, for a turbulent boundary as a function of Reynolds number. (I.e., predicted dimensionless boundary layer thickness.) Make the Reynolds number range start from $Re_x = 0$ (the leading edge of the plate) to a value slightly larger than the largest measured Re_x seen in your experiments. Plot this as a line with no symbols. On the same figure plot the two measured boundary layer heights using the same symbols and no markers. Attach the plot to this handout.

Questions and discussion of results

1. Discuss how you estimated the boundary layer thickness(es) for your experimental data.

2. Comment on the differences between your experimentally obtained boundary layer thickness and the predicted values. If the results differ significantly, think of possible reasons why that may be the case.

To be turned in

This completed lab handout, along with the extra plots, is due at 5:00 pm one week after your lab day. Only one copy should be turned in for each group.