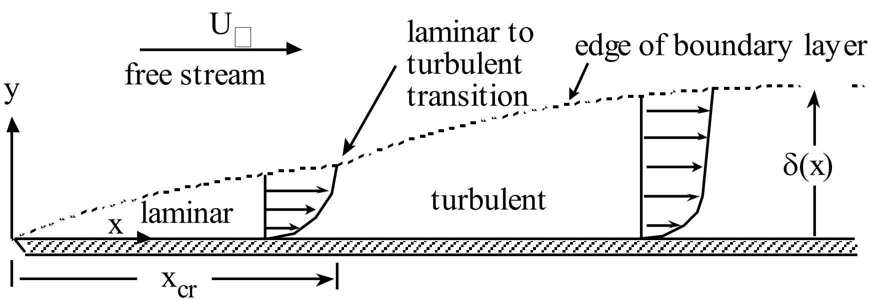
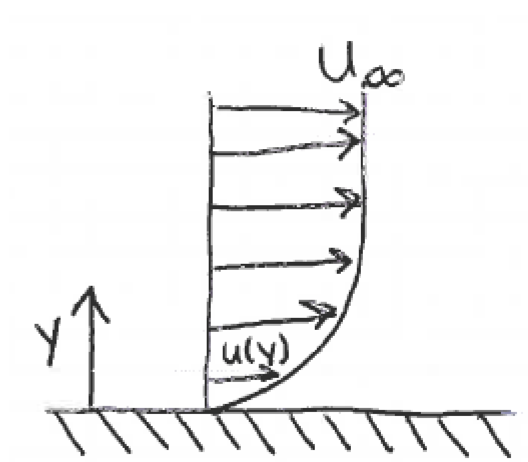
# Inside Wind Tunnel 3

A moving fluid adjacent to a solid boundary has the same velocity as the boundary. As the distance from a boundary increases, the fluid velocity changes until it equals the free stream velocity or if there are two boundaries, the velocity of the other boundary. The boundary layer is the layer of fluid near a surface that has experienced a change in velocity caused by shear stress at the surface. The boundary layer is confined to a region which is relatively close to the boundary. As distance, in the direction of flow, along the boundary layer increases, the thickness of the boundary layer increases. The boundary layer can be either laminar or turbulent in nature and this determines the shape of the velocity distribution within the boundary layer.



[1]

The velocity distribution in the laminar boundary layer is relatively simple in that it is governed by one relation. The boundary layer height, "δ", occurs at the height, "y", where $u(y) = 0.99U_{\infty}$.




[1] http://www.eng.auburn.edu/~tplacek/courses/

The thickness of the laminar boundary layer of a flat plate is given by:

**Equation 1: Laminar Boundary Layer Thickness**

$$\delta = \frac{5x}{\sqrt{Re_x}}$$

The laminar boundary layer will become turbulent at a Reynolds number approximately equal to 2,300 for very thin, smooth plates. If the boundary is not smooth, then the change to a turbulent boundary layer will occur at smaller Reynolds numbers.

**Equation 2: Reynold's Number**

$$Re_x = \frac{\rho U_\infty x}{\mu}$$

The turbulent boundary layer is more complex than the laminar boundary layer. Where the velocity distribution in the laminar boundary layer was given by a single relation, the velocity distribution in the turbulent layer consists of three distinct regions. The fluid layer adjacent to the boundary is the viscous sublayer. This layer, which is very thin, remains relatively smooth. The next region is governed by a logarithmic velocity distribution and the other region is governed by the velocity defect law.

The velocity distribution in the viscous sublayer is related to the shear stress and viscosity by Newton’s viscosity law. The results of this are

$$\frac{u}{u_o} = \frac{y}{\frac{v}{u_o}} \qquad \text{where} \quad u_o = \sqrt{\frac{\tau_o}{\rho}}$$

The thickness of the viscous sublayer, δ’ is given by

$$\delta' = 5\frac{v}{u_o}$$

The next region is governed by the logarithmic velocity distribution. The equation governing this region is valid for values of $\frac{yu_o}{v}$from 30 to 500. The velocity distribution is given by

$$\frac{u}{u_o} = 5.75\log\left(y\frac{u_o}{v}\right) + 5.56$$

The outermost region is governed by the velocity defect law. This is valid for $\frac{y}{\delta} > 0.15$. The velocity defect law relates the deviation of the fluid velocity, or “defect”, from the freestream velocity. The velocity distribution in the turbulent boundary layer can be approximated by:

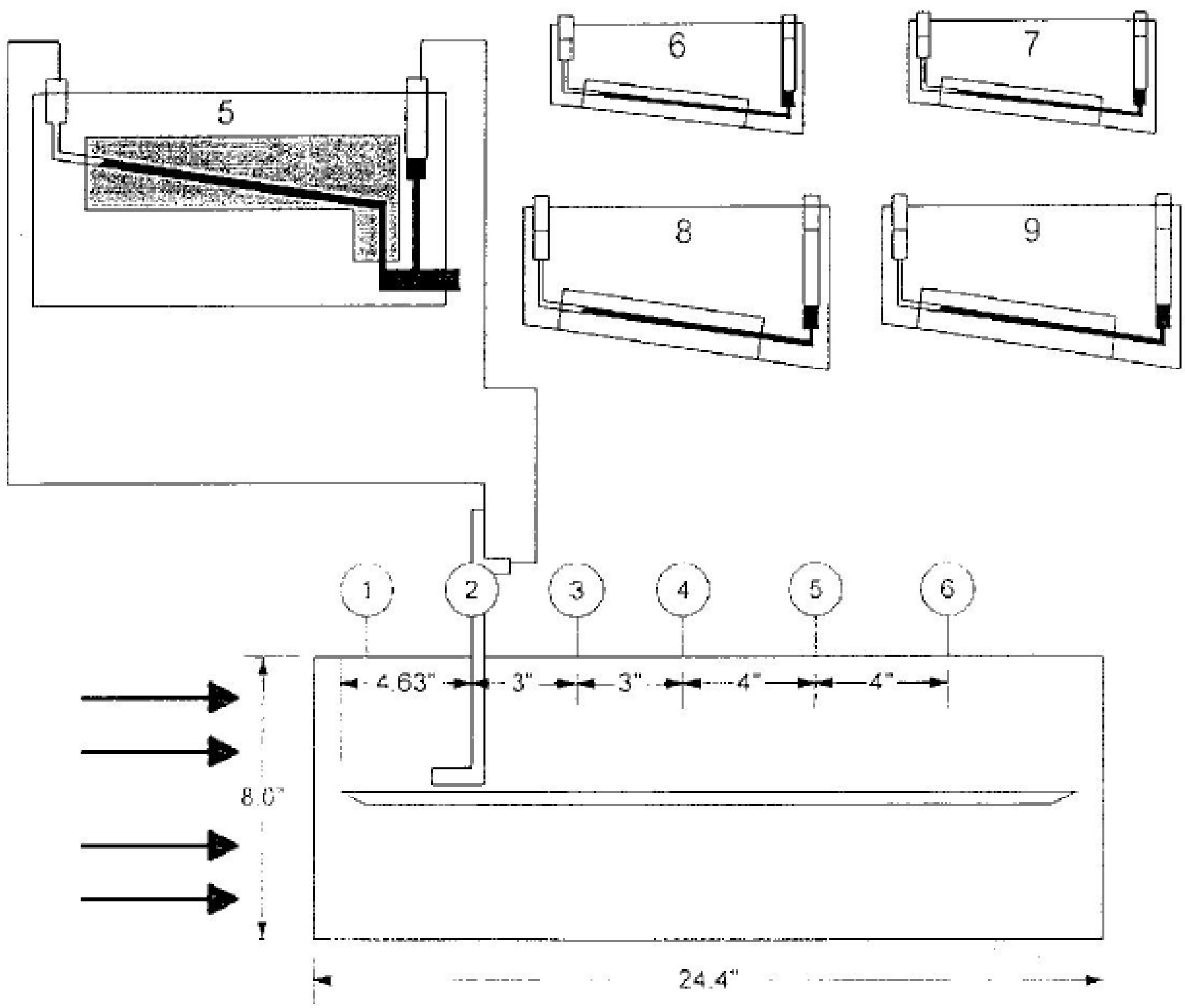
$$\frac{u}{U_o} = \left(\frac{y}{\delta}\right)^{\frac{1}{7}}$$

and the thickness of the boundary layer is given by

**Equation 3: Turbulent Boundary Layer Thickness**

$$\delta = 0.37 \frac{x}{{Re_x}^{1/5}}$$

**Experimental Setup:**



**Procedure:**

1. Turn off the fan & power if necessary.
2. Install the smooth twin-channel duct as shown.
3. Zero manometer 5.
4. Connect the hoses to the appropriate manometer shown.
5. Insert the probe in hole 2 and put it in far enough to just rest on the surface of the duct divider. (Note: Due to the shape of the probe, no boundary layer will be evident at hole 1.)
6. Turn the fan on to 70, and make sure all unused holes are covered.
7. Take readings every 0.1 cm upward until 5 readings are the same. (Note: The markings on the calibrated mount are 0.2 cm.) When taking the readings, it is important to not shake or bump the table as well as to not walk near the inlet or exit of the wind tunnel.
8. Calculate the free stream velocity using the velocity pressure measurement that steadied out and the simplified Bernoulli's equation found in Inside Wind Tunnel 2.
9. Repeat this process for the rest of the holes in the duct.
10. Now, replace the duct with the rough edged twin-channel duct.
11. Repeat steps 5 through 9 with the rough twin-channel duct.

**Table 1: Data table for velocity pressure measurements in the smooth duct**

| | Velocity Pressure (W.C.) | | | | |
|---|---|---|---|---|---|
| Δy (cm) | Hole 2 | Hole 3 | Hole 4 | Hole 5 | Hole 6 |
| 0.2 | | | | | |
| 0.3 | | | | | |
| 0.4 | | | | | |
| 0.5 | | | | | |
| 0.6 | | | | | |
| 0.7 | | | | | |
| 0.8 | | | | | |
| 0.9 | | | | | |
| 1.0 | | | | | |
| 1.1 | | | | | |
| 1.2 | | | | | |
| 1.3 | | | | | |
| $U_\infty$ (ft/s) | | | | | |
| $U_\infty$ (m/s) | | | | | |

**Table 2: Data table for velocity pressure measurements in the rough duct**

| | Velocity Pressure (W.C.) | | | | |
|---|---|---|---|---|---|
| Height (cm) | Hole 2 | Hole 3 | Hole 4 | Hole 5 | Hole 6 |
| 0.2 | | | | | |
| 0.3 | | | | | |
| 0.4 | | | | | |
| 0.5 | | | | | |
| 0.6 | | | | | |
| 0.7 | | | | | |
| 0.8 | | | | | |
| 0.9 | | | | | |
| 1.0 | | | | | |
| 1.1 | | | | | |
| 1.2 | | | | | |
| 1.3 | | | | | |
| $U_\infty$ (ft/s) | | | | | |
| $U_\infty$ (m/s) | | | | | |

**Table 3: Summary Table for boundary layer measurements and calculations**

| | Smooth Duct | | | | Rough Duct | | | |
|---|---|---|---|---|---|---|---|---|
| Hole # | Distance (m) | Reynold's Number | $\delta_{Measured}$ (cm) | $\delta_{Calculated}$ (cm) | Distance (m) | Reynold's Number | $\delta_{Measured}$ (cm) | $\delta_{Calculated}$ (cm) |
| 2 | | | | | | | | |
| 3 | | | | | | | | |
| 4 | | | | | | | | |
| 5 | | | | | | | | |
| 6 | | | | | | | | |

12. Determine the boundary layer height (height of the first pressure reading that stopped changing) from the data collected in steps 8 and 10. Record under $\delta_{Measured}$ in Table 3.
13. Calculate Reynold's number at each distance from the inlet for each duct. Determine whether the flow is laminar or turbulent. Record in Table 3.
14. Calculate the boundary layer thickness at each hole using the appropriate equation. Record in Table 3 under $\delta_{Calculated}$. Compare the calculated boundary layer thickness to the measured.
15. Graphically show how distance from the duct inlet effects the boundary layer height measured. Discuss the effects of surface roughness.
16. Answer the following questions in your conclusions section.

**Questions:**

1. Did the distance $\Delta y$ increase or decrease as the distance from the leading edge of the divider increased?
2. Did the free stream velocity increase or decrease as the distance from the leading edge of the divider increase? Why?
3. Did the rough edge produce a smaller or larger boundary layer?