MIE 340
Prof. Perot
Handout #12

Boundary Layers

External Flows (atmosphere, vehicles, buildings, you, …)

The boundary layer (vorticity) is a thin layer close to the wall. It grows thicker as you go downstream, and will always become turbulent if the wall is long enough.

Note: The Reynolds number is defined differently than for pipes. $Re_x = \frac{\rho U_\infty x}{\mu}$

where the velocity is taken far from the body, and x is the distance from the leading edge.

Or sometimes $Re_L = \frac{\rho U_\infty L}{\mu}$ where L is the total length of the body in question.

Laminar if $Re_x < 5x10^5$. (in real life it actually happens anywhere from $1x10^5$ to $3x10^6$)

SOME DEFINITIONS

Drag coefficient: $\boxed{C_D = \frac{2D}{\rho U_\infty^2 wL}}$ where w is the width of the body.

Skin friction coefficient: $C_f = \frac{2\tau_w}{\rho U_\infty^2}$ where τ_w is the shear-stress at the wall.

99% Thickness – the distance where $u/U_\infty = 0.99$.

Displacement Thickness: $\delta^* = \int_o^\infty (1 - u/U_\infty)dy$ gives equivalent shape.

Momentum Thickness: $\delta_\theta = \int_o^\infty (u/U_\infty)(1 - u/U_\infty)dy$ gives equivalent drag. $C_D = \frac{2\delta_\theta}{L}$

Lots of objects act like a **<u>FLAT PLATE</u>**, in which case:

Laminar:

$\delta_{99}/x = 5.0/Re_x^{1/2}, \delta^*/x = 1.721/Re_x^{1/2}, \delta_\theta/x = 0.664/Re_x^{1/2}$

$C_f = 0.664/Re_x^{1/2}, \ C_D = 1.328/Re_L^{1/2}$

Turbulent:

$\delta_{99}/x = 0.37/Re_x^{1/5}, \delta^*/x = 0.0463/Re_x^{1/5}, \delta_\theta/x = 0.036/Re_x^{1/5},$

$C_f = 0.0576/Re_x^{1/5}, C_D = 0.072/Re_L^{1/5}$

Note 1: Turbulent and rough walls: See Fig 9.15 (page 511)
Note 2: The formula's are for one side. *Many objects have two sides*.

Lots of objects act like **BLUFF BODIES**, in which case:

Look C_D up on pages, 523, 533, and the tables on 536-538 .

It is *extremely* important that you know what area these charts are using, and also what Reynolds number, and if the object is 2D or 3D.

A **bluff body** is any object which is so fat, that the flow can not pass smoothly around the object. Like a ball – the streamlines separate from the object, and leave a pocket of recirculating fluid behind the object.

The drag on bluff bodies is mostly 'pressure drag', due to the fact that the object has to push the fluid out of its way. It is usually proportional to the frontal area.

In contrast, the flow moves easily around objects which can be approximated by a flat plate (such as a wing or flat fish). The drag on those objects is dominated by viscosity or friction, and tends to be proportional to the total surface area of the object.

LIFT is really just a result of pressure differences (remember Bernoulli's Eqn). But it is often tabulated like drag and found nearby. Some Lift Coefficients (defined just like the drag) are tabulated at the end of Chap 9 (pages 542-543).