MAE 158 Lecture 3

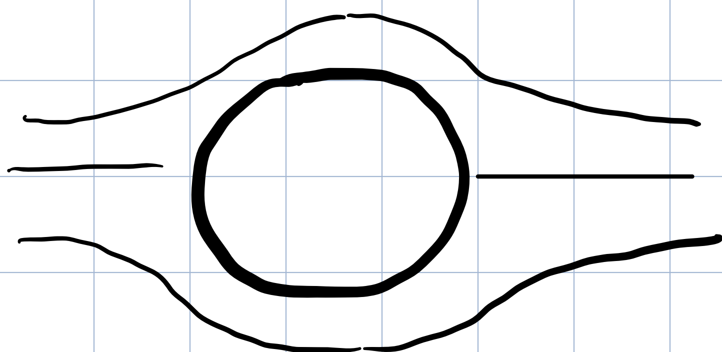
Fall 2024

Announcements:

Ch. 10

Todays Objectives: - Effects of Viscosity & Boundary layers

- Profile Drag

frictionless	real flow
	
Drag = 0	Drag $\neq$ 0

- profile drag (parasite drag)

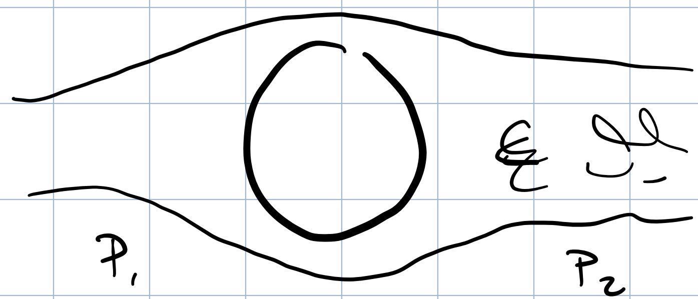
- D_p, profile drag, composed of:

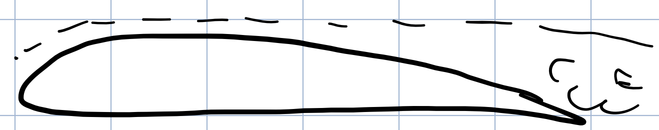
1. skin friction drag $\rightsquigarrow$ D_f

↳ Roughness

2. pressure drag, D_B

→ Bluff body drag

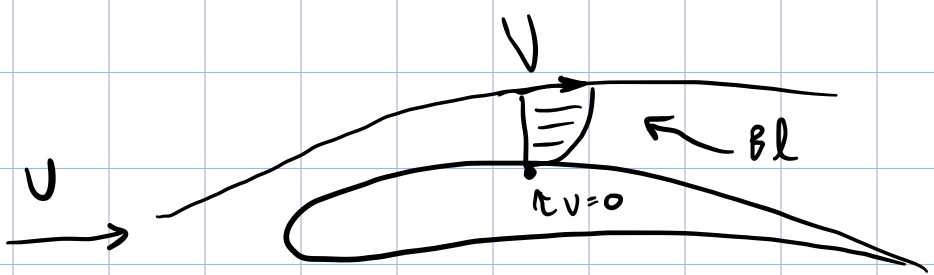


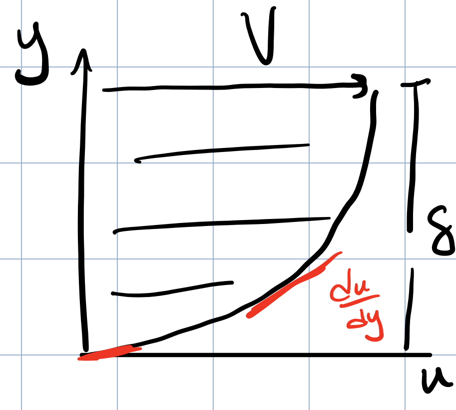


total profile Drag

$$D_P = D_f + D_B$$

must understand Boundary layers





$\delta \equiv$ boundary layer thickness
$u = V$

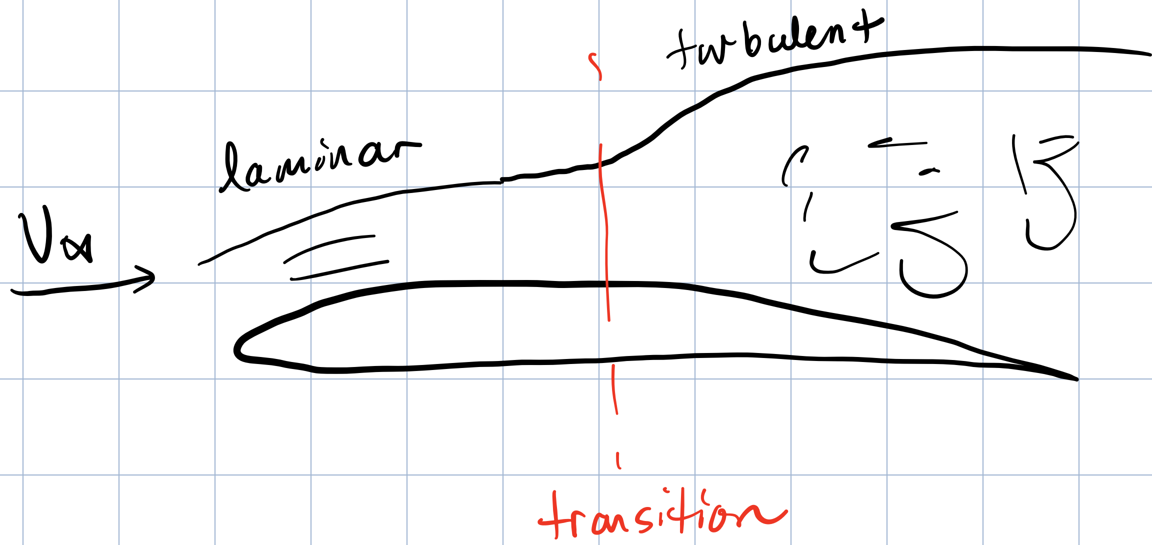
Relate BL properties to skin friction
Drag D_f

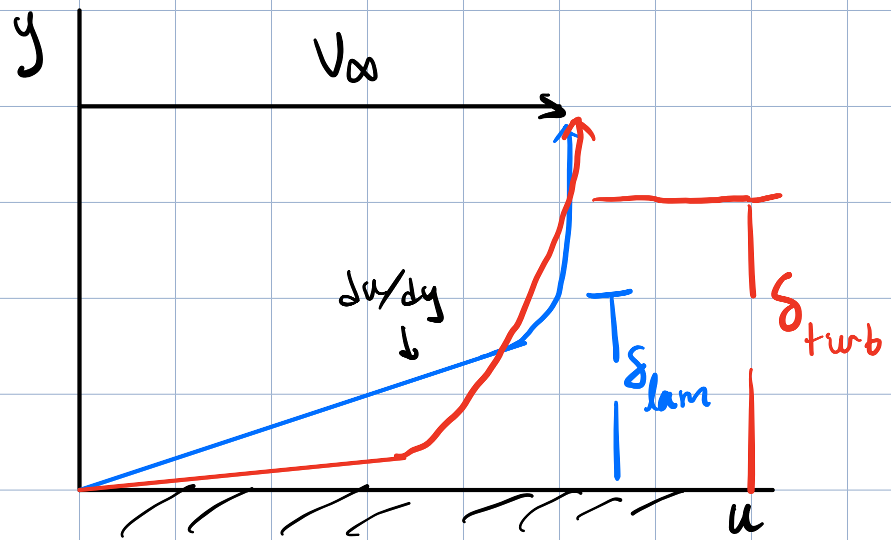
Recall shear stress
wall
$\tau_w = \mu \left(\frac{du}{dy}\right)_{y=0}$

$\mu \equiv$ dynamic viscocity, a fluid property, measures fluid's internal Resistance to flow

$\left.\frac{du}{dy}\right|_{y=0}$, what is it?, → depends on the BL type

type: Flow Regime





$$\tau_w = \mu \frac{du}{dy}\Big|_{y=0}$$

1. turbulent BL @ same position thicker than laminar one

2. turbulent BL has a fuller velocity profile near the wall

3. shear stress (skin friction)

$$\tau_{lam} < \tau_{turb}$$

Re characterizes the intertial effects in flow

$$Re = \frac{\rho V x}{\mu} \equiv \frac{\text{inertial forces}}{\text{viscous forces}}$$

if Re is large $\rightsquigarrow$ inertial effects dominate

→ turbulent

if Re small $\rightsquigarrow$ viscous effects dominate

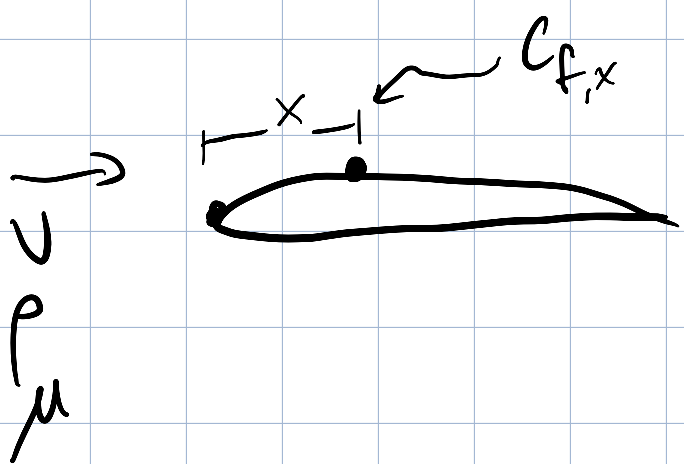
laminar

$$Re_{crit} = \frac{\rho V x_{crit}}{\mu}$$

x_{crit} is position where the flow transitions from laminar to turbulent for // flow to a flat plate,

$$Re_{crit} \sim 5 \times 10^5$$

skin friction



$C_{f,x} \equiv$ local skin friction coefficient @ x away from Leading edge

$$C_{fx} = \frac{\tau_{w,x}}{\frac{1}{2}\rho V^2} = \frac{\tau_{w,x}}{q}$$

$q \equiv$ dynamic pressure

for wings, tails assume skin friction properties similar to flat plates

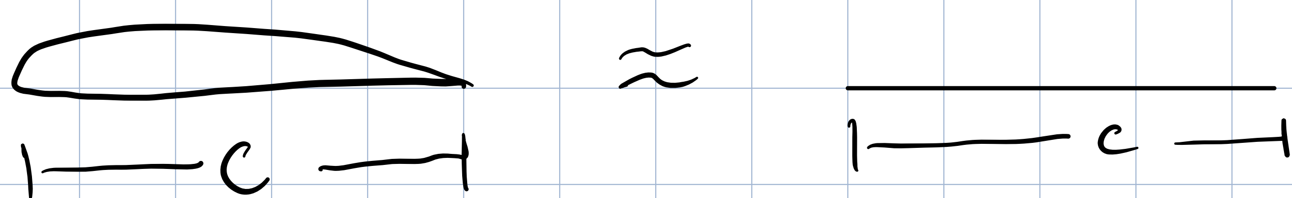
$$C_{f_x} = \frac{0.664}{\sqrt{Re_x}}$$ → laminar flow BL flat plate

$$Re_x = \frac{\rho V x}{\mu}$$

Integrate over surface to get

$C_f \equiv$ total skin friction coefficient

Skin friction



Skin friction Drag per unit span

$$D_f' = \int_0^c \tau_{w,x}\, dx$$

$$= \int_0^c c_{f_x} \cdot q \, dx$$

$$C_f \equiv \frac{D_f'}{q \cdot c} \equiv \frac{D_f}{qS}$$

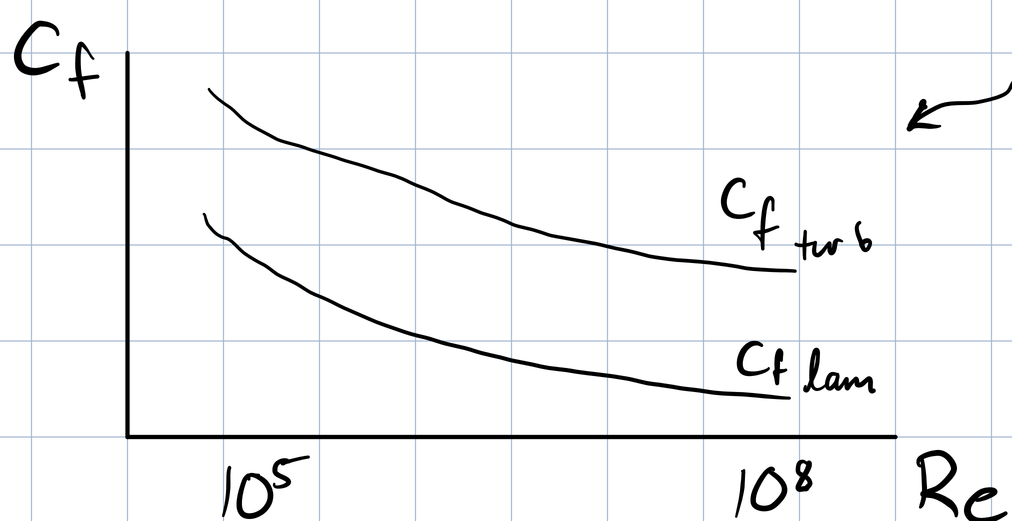
$$C_{f_{lam}} = \frac{1}{q \cdot c} \int_0^c \frac{0.664}{\sqrt{Re_x}} q \, dx$$

$$= \frac{1.328}{\sqrt{Re_c}}$$

Re @ chord length c

$$Re_c = \frac{\rho V c}{\mu}$$

$$C_{f_{turb}} = \frac{0.455}{(\log_{10} Re_c)^{2.58}}$$



Ch 10 shevell

$$D_f\,(\text{lbs}, N) = \underbrace{\tfrac{1}{2}\rho V^2}_{q} \cdot C_f \cdot S_{wet}$$

C_f depends on flow Regime

$S_{wet} \rightarrow$ area of exposed surface

for a wing

$$S_{wet} = 2 \cdot b \cdot c \cdot 1.02$$

S_{wet}: simple Rectangle

2: both sides (top & Bottom)

$b \cdot c$: S_{REF}, planform area

1.02: accounting for curvature

$$\text{Drag} = \tfrac{1}{2}\rho V^2 C_{D_{total}} \cdot S_{REF}$$

$C_{D_{total}}$: Drag coefficient

$$\underbrace{Drag_{total}}_{} = \underbrace{\overset{}{D_p}}_{q\,S_{REF}} + D_i + D_{compressibility}$$

D_p: D_f, D_B

$$C_{D_{total}} = \underbrace{C_{D_f} + C_{D_B}}_{C_{D_p}} + C_{D_i} + C_{D,c}$$

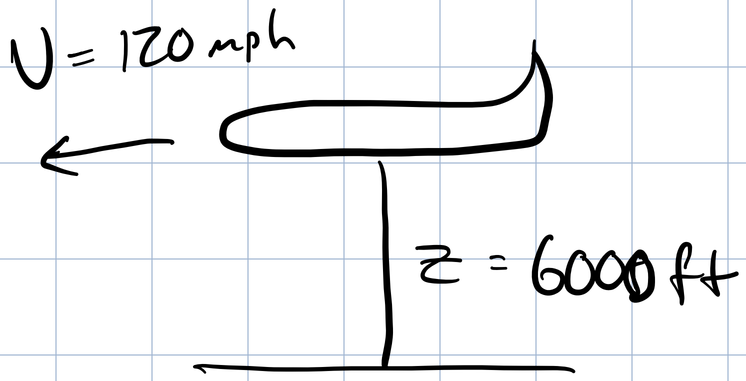
summation of coefficients only works if they are scaled to the same Reference area

$$C_{D_f} \neq C_f$$

$$C_{D_f} = \frac{D_f}{\frac{1}{2}\rho V^2 S_{REF}} = \frac{\cancel{\frac{1}{2}\rho V^2}\, S_{wet} \cdot C_f}{\cancel{\frac{1}{2}\rho V^2}\, S_{REF}}$$

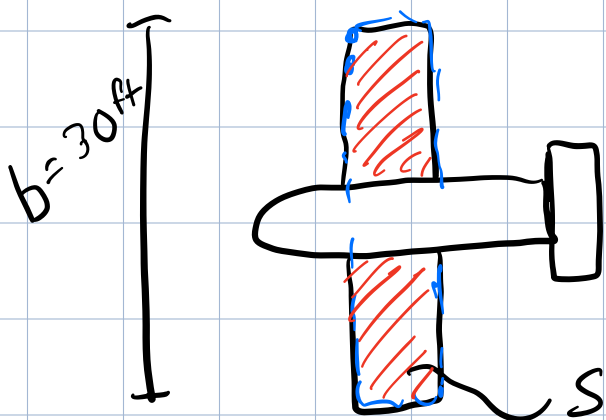
$$C_{D_f} = \frac{S_{wet}}{S_{REF}} \cdot C_f$$

Example: calculate D_f for an aircraft's Rectangular wing



true airspeed
$V = 120\,mph$

assume turbulent flow everywhere



assume wing is 85% exposed

$S_{REF} = 160\,ft^2$

$$C_f = \frac{0.455}{(\log_{10} Re_c)^{2.58}} \qquad Re_c = \frac{\rho V c}{\mu}$$

$$c = \frac{S_{REF}}{b} = \frac{160\,ft^2}{30\,ft} = 5.3\,ft$$

Rectangular wing

$z = 6000\,ft$, $\rho = 0.001987\,\frac{slug}{ft^3}$

$\mu = 3.62\times10^{-7}\,\frac{slug}{ft\,s}$

$V = 120\,mph \rightarrow 176\,\frac{ft}{s}$

$Re_c = 5$ million

$\hookrightarrow C_{f_{turb}} = 0.00335$

$$D_f = \frac{1}{2}\rho V^2 \cdot S_{wet} \cdot C_f$$

$$2 \cdot \underbrace{b \cdot c}_{S_{REF}} \cdot 1.02 \cdot 0.85$$

$S_{wet} = 277 \text{ ft}^2$

$D_f = 28.6$ lbs $\rightarrow$ skin fric drag on wing