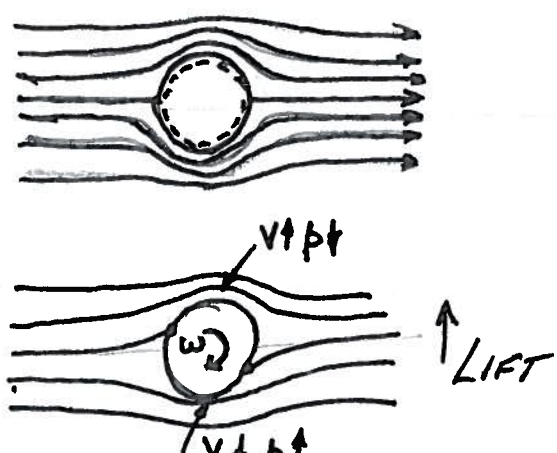
LIFT

Property called circulation

Integral of tangential velocities around a surface - If any asymmetry, then "circulation"

If circulation, slight imbalance of pressure force ⇒ lift

LIFT



AS WITH DRAG

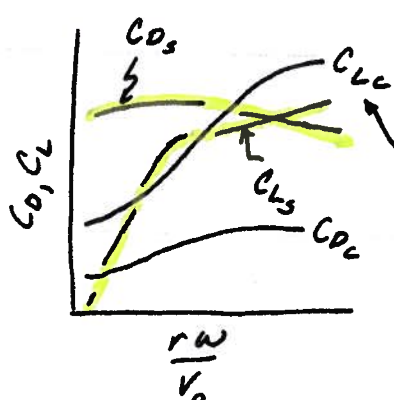
$$C_L = \frac{F_L}{A\left(\frac{\rho V_0^2}{2}\right)}$$

REFERENCE AREA (USUALLY PROJECTED AREA)

AREA 'PROJECTED' AS SHADOW.

object

FOR SPINNING CYLINDERS/SPHERES ω MATTERS



LIFT C_L ABOVE C_D FOR CYLINDERS

EXAMPLE 11.6 p 425 GOOD ILLUSTRATION HOW TO USE CHARTS

AIRFOILS (AND PROPELLER BLADES)

WHEN INTEGRATE, OBTAIN ASSYMETRIC

TANGENTIAL V, HENCE LIFT.

AIRFOIL THEORY ELABORATE, NOTICE ~~the~~ SIGNIFICANT ESTIMATOR OF LIFT & DRAG ARE ANGLE OF ATTACK

Terminal Velocity (Stokes Flow)

$F_B = \gamma_w \forall$

$F_D = C_D A_p \rho \frac{V^2}{2}$

$W = \gamma_s \forall$

Force balance

$$F_D + F_B = W$$

$$\frac{C_D A_p \rho}{\forall}\frac{V^2}{2} + \forall\gamma_w = \gamma_s \forall$$

← SOLVE FOR V

$$C_D A_p \rho \frac{V^2}{2} = (\gamma_s - \gamma_w)\forall$$

$$\frac{V^2}{2} = \frac{(\gamma_s - \gamma_w)\forall}{C_D A_p \rho}$$

$$V = \left[\frac{2(\gamma_s - \gamma_w)\forall}{C_D A_p \rho}\right]^{1/2}$$

$$A_p = \frac{\pi d^2}{4}$$

$$\forall = \frac{\pi d^3}{6}$$

$$V = \left[\frac{2(\gamma_s - \gamma_w)\frac{\pi d^3}{6}}{\frac{\pi d^2}{4} C_D \rho} \right]^{1/2}$$

$$V^* = \left(\frac{(\gamma_s - \gamma_w)(4/3)\, d}{C_D \rho} \right)^{1/2}$$

$$C_D \propto \underbrace{\frac{V_0 d}{\nu}}_{Re}$$

i.e. FOR VALUES IN EXAMPLE 11.4

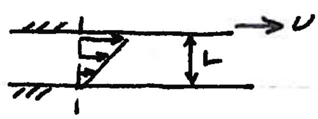
THEN BUILD TABLE

V	Re	C_D	V^*
1 m/s	20,000	0.456	0.413
0.413	8264	0.406	0.438
⋮	⋮	⋮	⋮

LAMINAR FLOW & BOUNDARY LAYERS
CHAPTER 9

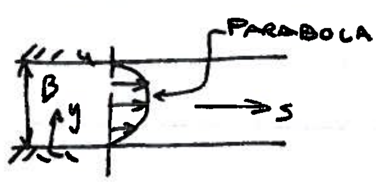
p 326-327

Couette Flow



$\tau = \mu \frac{U}{L}$ (WE DID SIMILAR ANALYSIS BACK IN CHAP. 3)

Hele-Shaw Flow



$$u = -\frac{1}{2\mu}(By - y^2)\frac{d(p+\gamma z)}{ds}$$

(GOOD APPROXIMATION FOR POROUS FLOW)

$$\bar{V} = \frac{2}{3} u_{max}$$

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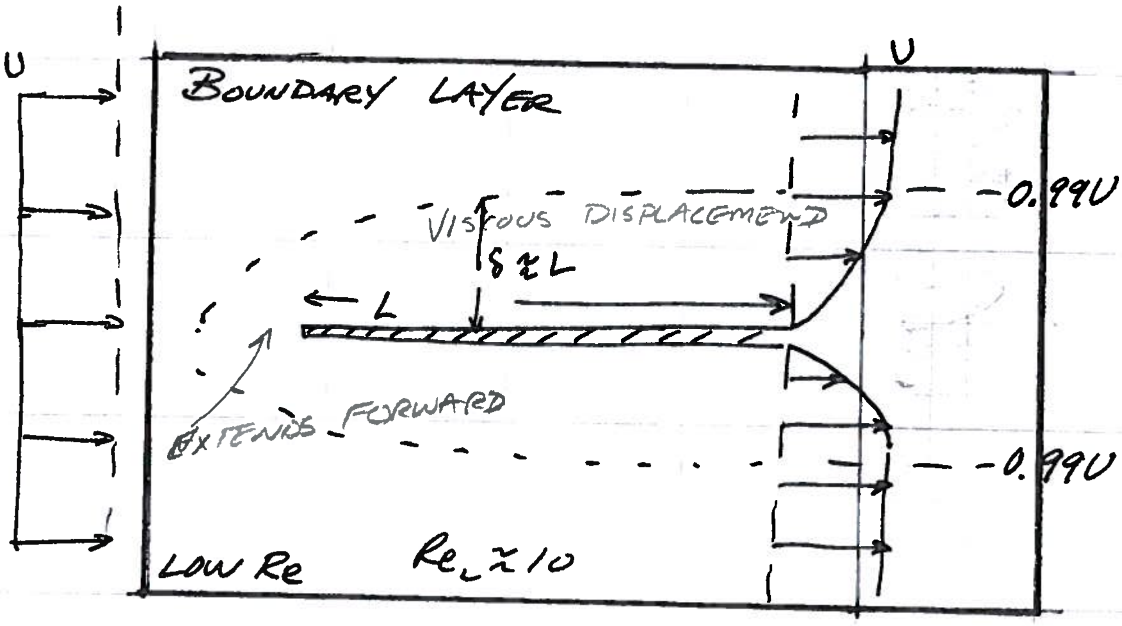
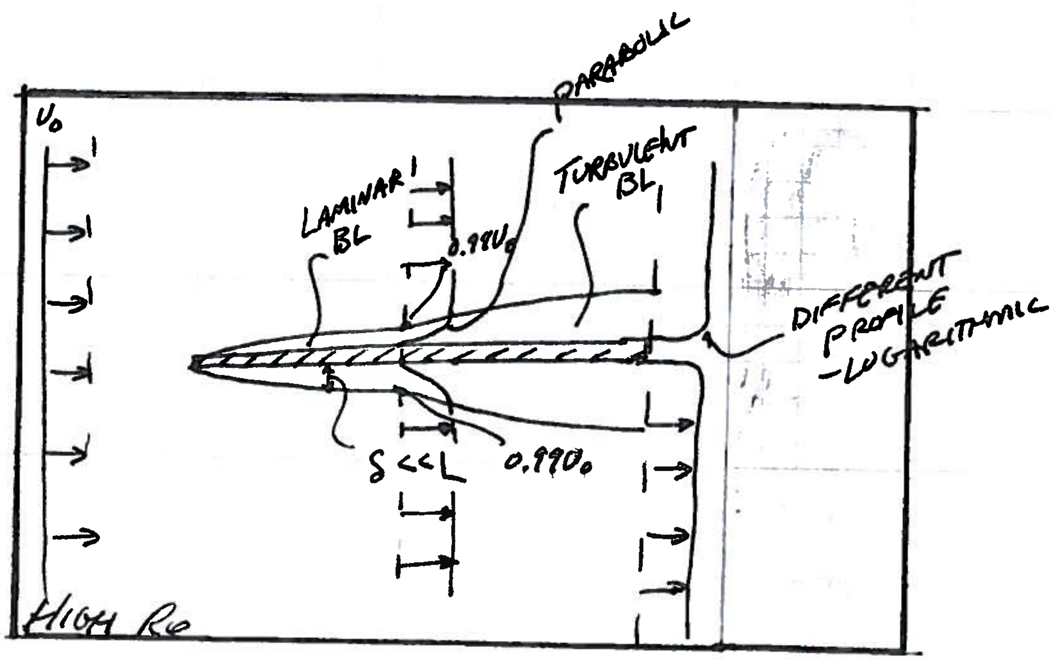
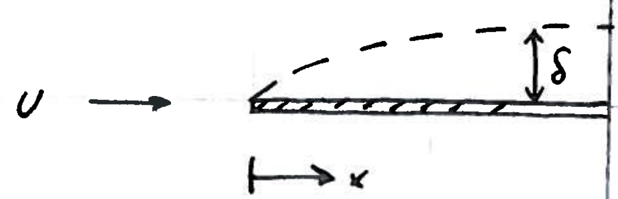

U
BOUNDARY LAYER
U
0.99U
VISCOUS DISPLACEMENT
δ ≈ L
L
EXTENDS FORWARD
0.99U
LOW Re
$Re_L \approx 10$


PARABOLIC
U_0
TURBULENT BL
LAMINAR BL
$0.99U_0$
DIFFERENT PROFILE -LOGARITHMIC
δ << L
$0.99U_0$
HIGH Re

Blasius' approximation for BL thickness



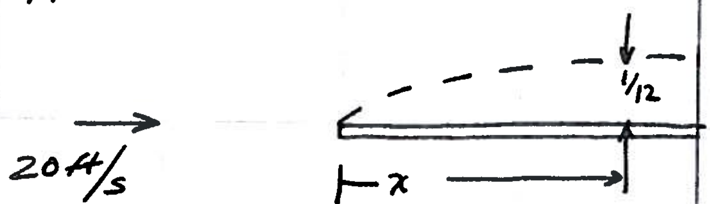
Laminar

$$\delta = \frac{5x}{Re_x^{1/2}} \qquad (Re_x < 10^6)$$

Turbulent

$$\delta = \frac{0.16x}{Re_x^{1/7}} \qquad (Re_x > 10^6)$$

Suppose situation below:



$$\nu = 1.09 \cdot 10^{-5}\ ft^2/s$$

$$x = ?$$

$$\delta = 1\ in.$$

Assume laminar

$$Re_x = \frac{Ux}{\nu}$$

$$\frac{U}{\nu} = \frac{20\ ft/s}{1.09 \cdot 10^{-5}\ ft^2/s} = 1.84 \cdot 10^6\ ft^{-1}$$

$$\delta = \frac{5x}{\sqrt{1.84 \cdot 10^6 x}}$$

SOLVE FOR x

$\delta = 1/2$

$$\delta^2 = \frac{25x^{\cancel{2}}}{1.84 \cdot 10^6 \cancel{x}}$$

$$\frac{1.84 \cdot 10^6 (1/12)^2}{25} = 511 \text{ ft}$$

Check Re_x

$Re_x = 1.84 \cdot 10^6 \cdot 511 \text{ ft} = 9.4 \cdot 10^8 > 10^6$

$\therefore$ NOT LAMINAR, USE TURBULENT MODEL (EQ 9.33)

$$\delta = \frac{0.16\, x}{(Re_x)^{1/7}}$$

$$\delta = \frac{0.16 \quad x}{(1.84 \cdot 10^6\, x)^{1/7}}$$

$$\delta^7 = \frac{(0.16)^7 (x)^7}{1.84 \cdot 10^6\, x} = \frac{(0.16)^7 (x)^6}{1.84 \cdot 10^6}$$

$$\frac{\delta^7\, 1.84 \cdot 10^6}{(0.16)^7} = x^6$$

$$x = \left[\frac{\delta^7 (1.84 \cdot 10^6)}{(0.16)^7} \right]^{1/6}$$

$$= \left[\frac{(\frac{1}{12})^7 (1.84 \cdot 10^6)}{(0.16)^7} \right]^{1/6} = 5.17 \text{ ft}$$

$$Re_x = \frac{(20)(5.17)}{1.09 \cdot 10^{-5}} = 9.5 \cdot 10^6 > 10^6 \text{ TURBULENT}$$

$\therefore$ AT GIVEN CONDITIONS,
B.L. = 1 in AT 5.17 ft from leading edge.

Utility of BL is to estimate shear force on plate.

Once shear force is known drag from plate can be approximated. Used for guiding experiments, forcing layer transition to control drag

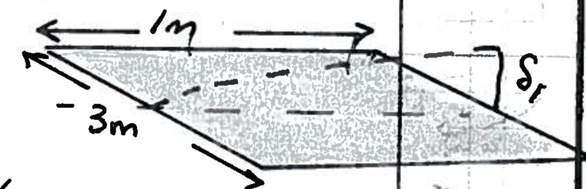
Shear force (one side) drag

$$C_f = \frac{F_s}{A\left(\frac{\rho V_0^2}{2}\right)}$$

$$C_f = \frac{1.33}{Re_x^{1/2}} \quad (\text{LAMINAR})$$

$$C_f = \frac{0.032}{Re_x^{1/2}} \; (Re < 10^7); \; \frac{0.523}{\ln^2(0.06 Re_x)}$$

Consider plate



$V = 2 m/s$

$\rho = 1.23 kg/m^3$
$\nu = 1.46 \cdot 10^{-5} m^2/s$

FIND δ AT TRAILING EDGE

FIND DRAG ON ONE SIDE OF PLATE

$$Re_L = \frac{(2.0)(1.0)}{1.46 \cdot 10^{-5}} = 137{,}000 < 10^6$$

LAMINAR.

$$C_f = \frac{1.33}{(137{,}000)^{1/2}} = 0.0036$$

$$F_s = C_f A \left(\frac{\rho V_0^2}{2} \right)$$

$$= (0.0036)(3)(1)(1.23)(2)^2\left(\tfrac{1}{2}\right) = 0.0265 N$$

m m kg/m³ m/s

$$\frac{kg\, m^4}{m^3 \cdot s^2} = \frac{kg\, m}{s^2} = N$$

$$\delta = \frac{5 \cdot L}{(Re_L)^{1/2}} = \frac{5(1)}{(137{,}000)^{1/2}} = 0.0135$$

$$= 13.5\,mm$$