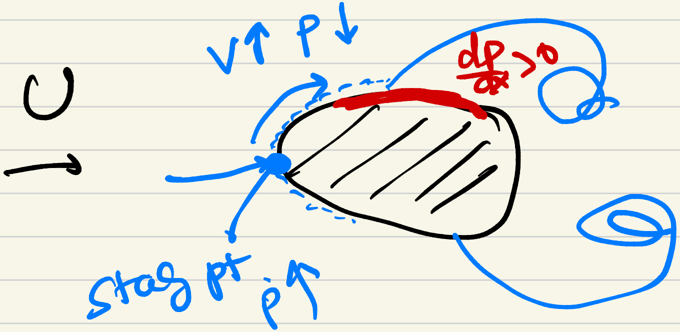
7.6 Experimental external flows



sep. occurs

→ bdry layer approx ✗
theory fails.

⇓

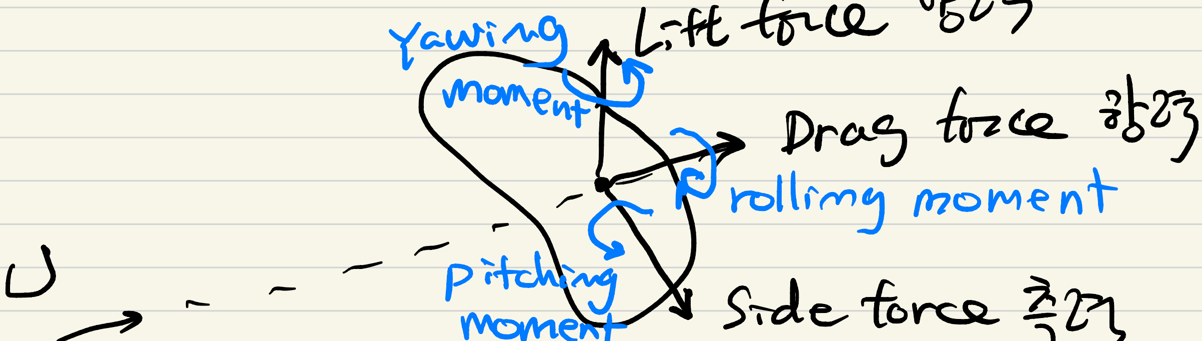
No theory

⇓

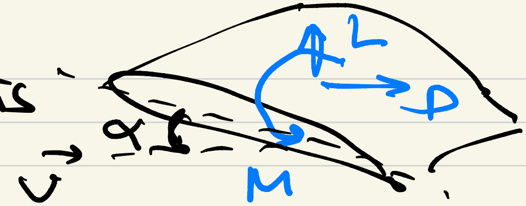
experiment or CFD

- Drag of 2D & 3D bodies

Performance of lifting bodies → drag, lift



Symmetry about the lift-drag axis



→ side force, yawing & rolling moment = 0

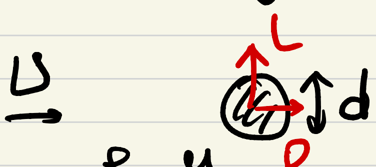
α : angle of attack
영각

drag, lift, pitching moment ≠ 0

Two planes of symmetry

→ drag ≠ 0 $L(t) \neq 0$, $\bar{L} = 0$

- Similarity (geometric, kinematic, dynamic)
  [L]   [L, T]   [L, T, M]



$\text{Drag} = f(U, d, \rho, \mu)$

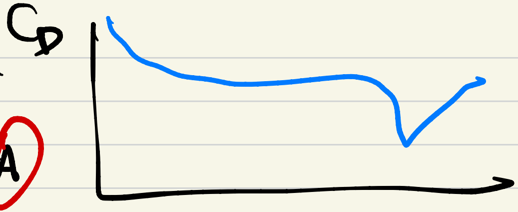
dimensional analysis

$\rightarrow C_D = f(Re)$ $Re = \frac{Ud}{\nu}$

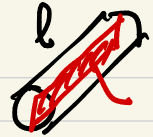
$= \frac{D}{\frac{1}{2}\rho U^2 A}$: drag coeff.

?

$C_D = \frac{D}{\frac{1}{2}\rho U^2 A}$

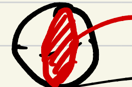


Re →



l, d → $A = ld$ →

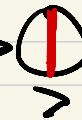
A



$A = \frac{1}{4}\pi d^2$

bluff bodies : A ← frontal area

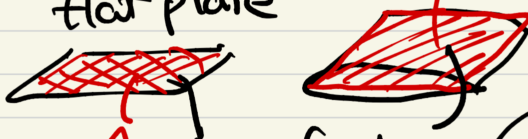
↳ form drag (press)



P_1 → ← P_2, >

$\frac{D_{total}}{\frac{1}{2}\rho U^2 A}$

→ flat plate



A, A

↑ skin friction

planform area

streamlined bodies

Total drag = Friction drag + Form drag + (wave drag)

A ! A

Surface ship ← Skin friction

A : wetted surface area

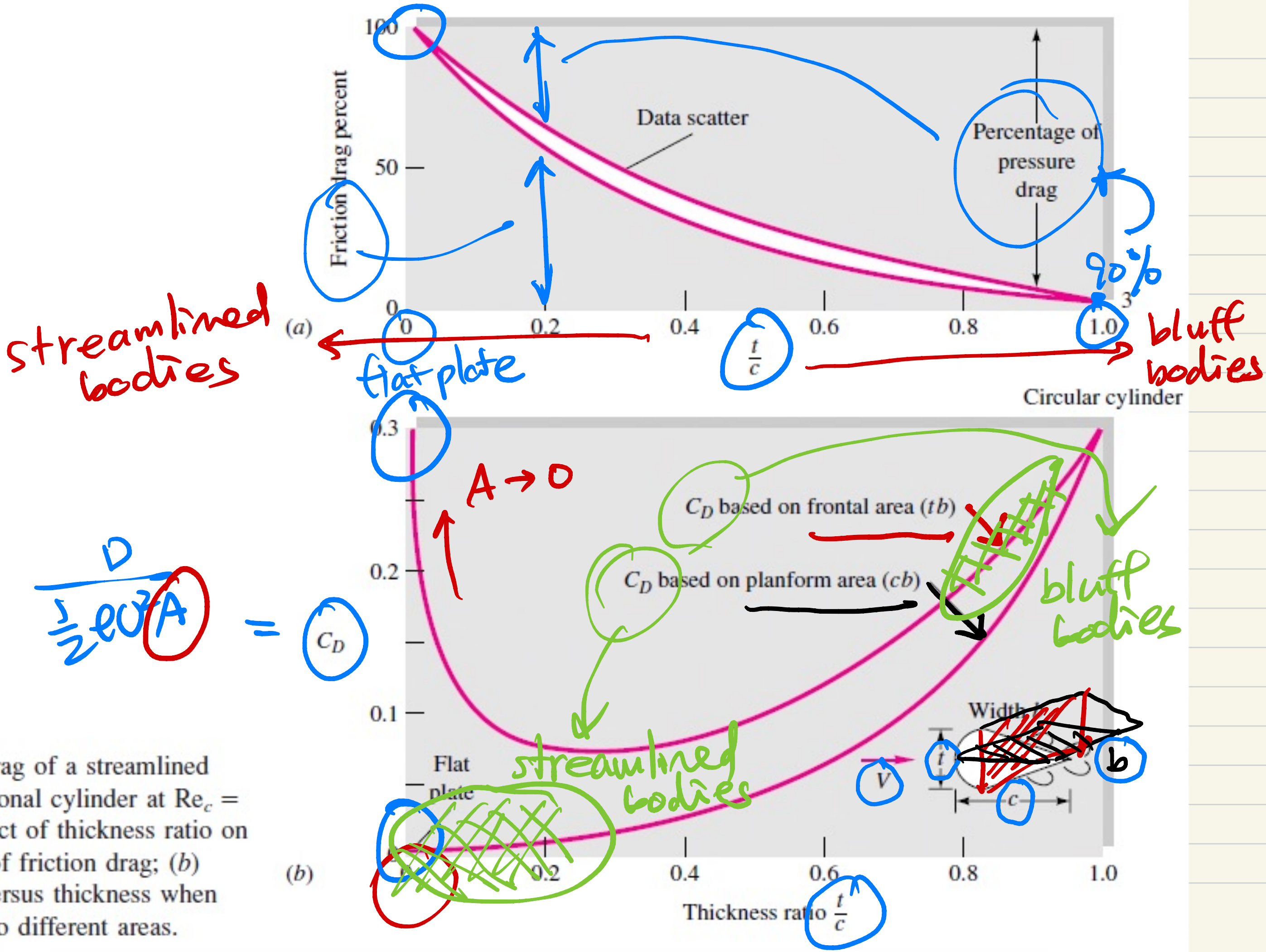
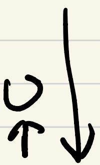


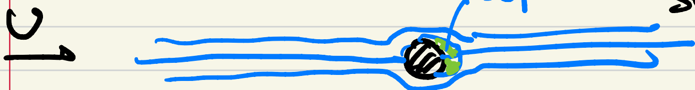
Fig. 7.12 Drag of a streamlined two-dimensional cylinder at $Re_c = 10^6$: (*a*) effect of thickness ratio on percentage of friction drag; (*b*) total drag versus thickness when based on two different areas.

- Flow past a circular cylinder

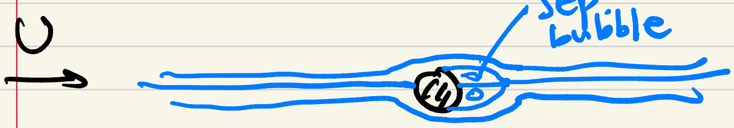
↳ a representative 2D bluff body



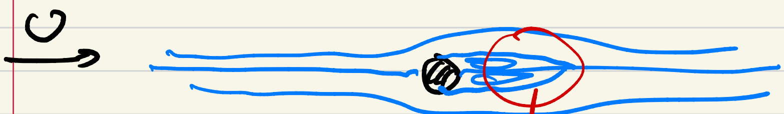
no separation
steady, 2D flow



separation
steady, 2D flow



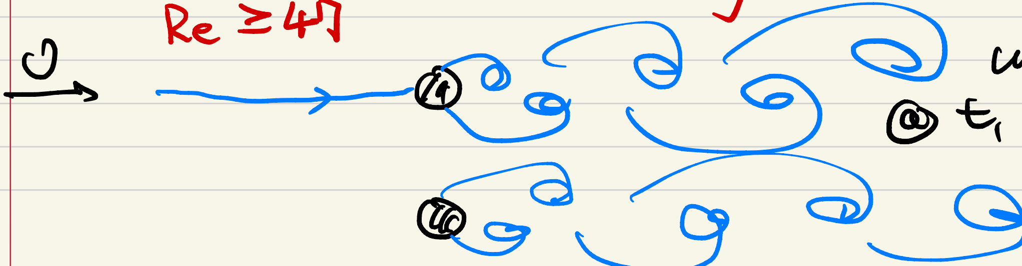
sep. bubble size ↑ as Re ↑ (U)
steady, 2D flow



"

instability occurs ⇒ symmetry-breaking

Re ≥ 47

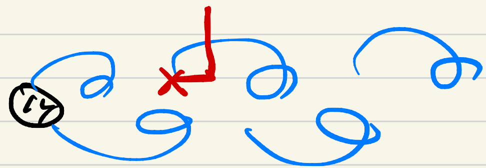


unsteady, 2D flow

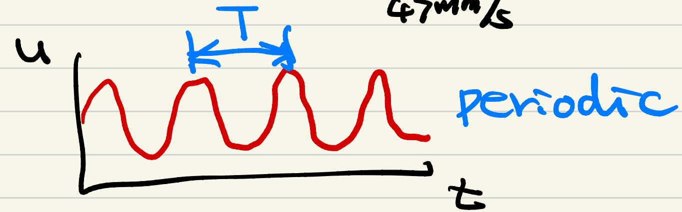
@ t_1

alternating Karman vortex shedding
와 흘러

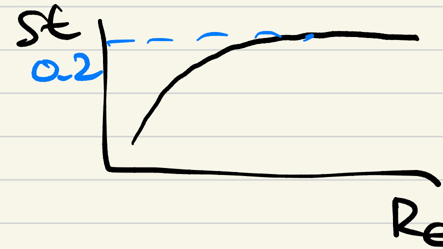
$Re = 47 = \frac{Ud}{\nu} = \frac{U \times 1.5\times10^{-2}}{1.5\times10^{-5}} \rightarrow U = 47\ mm/s$ ← (cyl) 1.5cm, 47mm/s



@ Re=100



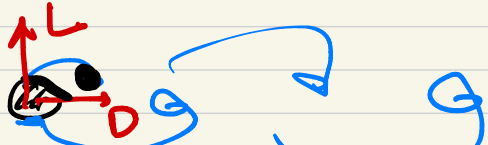
unsteady 2D laminar flow



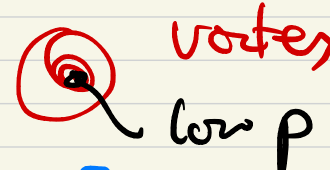
$St = \frac{fd}{U} = \frac{d}{UT} \quad (f = \frac{1}{T})$

strouhal number (스트롤 수)

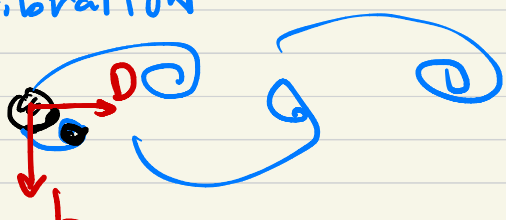
@ t_1

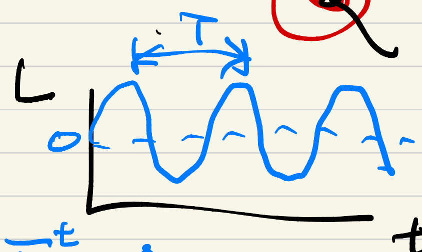


vibration

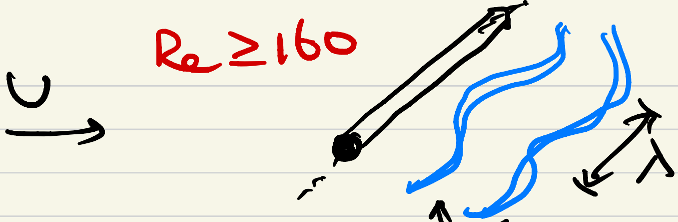


@ t_2





$\bar{L}^t = 0$



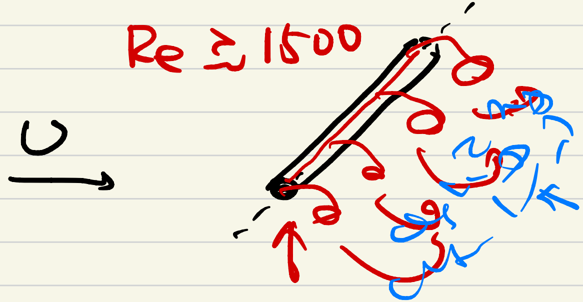
unsteady 3D laminar flow

3D vortex shedding

HW2 $Re \simeq 300$ ⇒ 3D simulation! ×8~30

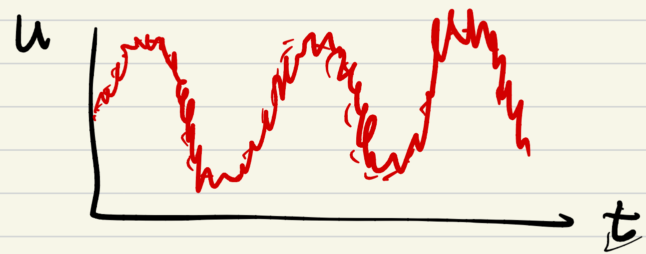
↓

HW: 2D simulation



wake: $\frac{1}{6}\frac{2}{\pi}$

downstream: $3+\frac{2}{\pi}$

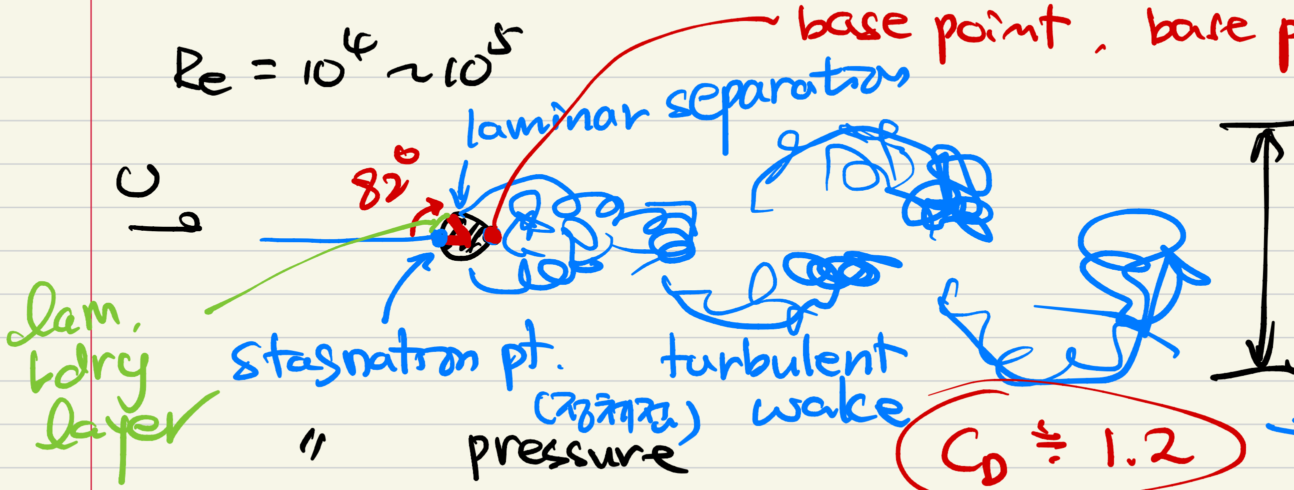


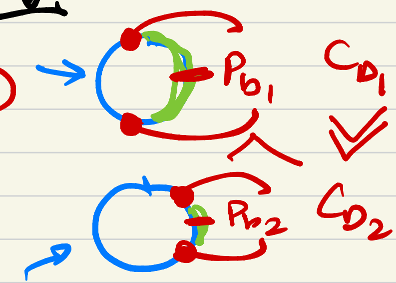
3D turbulent flow

↑

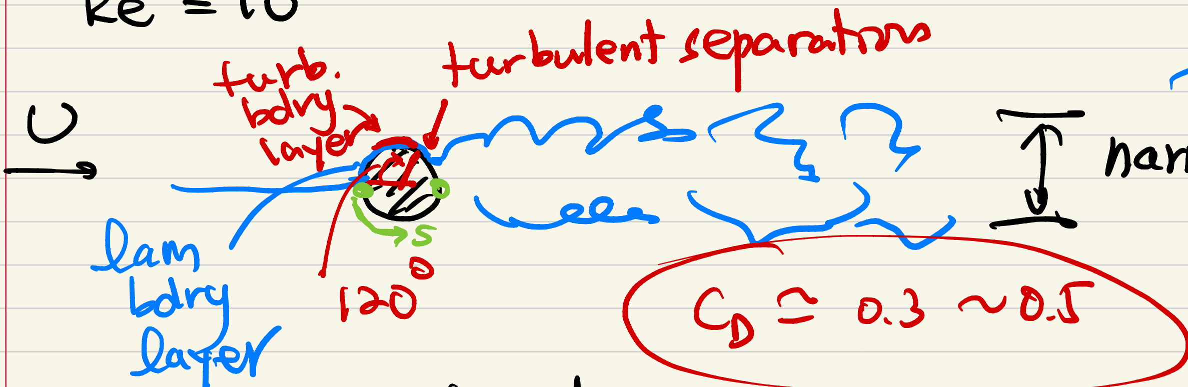
unsteady

$Re = 10^4 \sim 10^5$





$Re = 10^6$



$Re = 10^6 = \frac{Ud}{\nu}$

$Re_s = \frac{US}{\nu} = \frac{U \cdot \pi d/2}{\nu} = \frac{Ud}{\nu} \cdot \frac{\pi}{2} \fallingdotseq 1.5\times10^6 >$

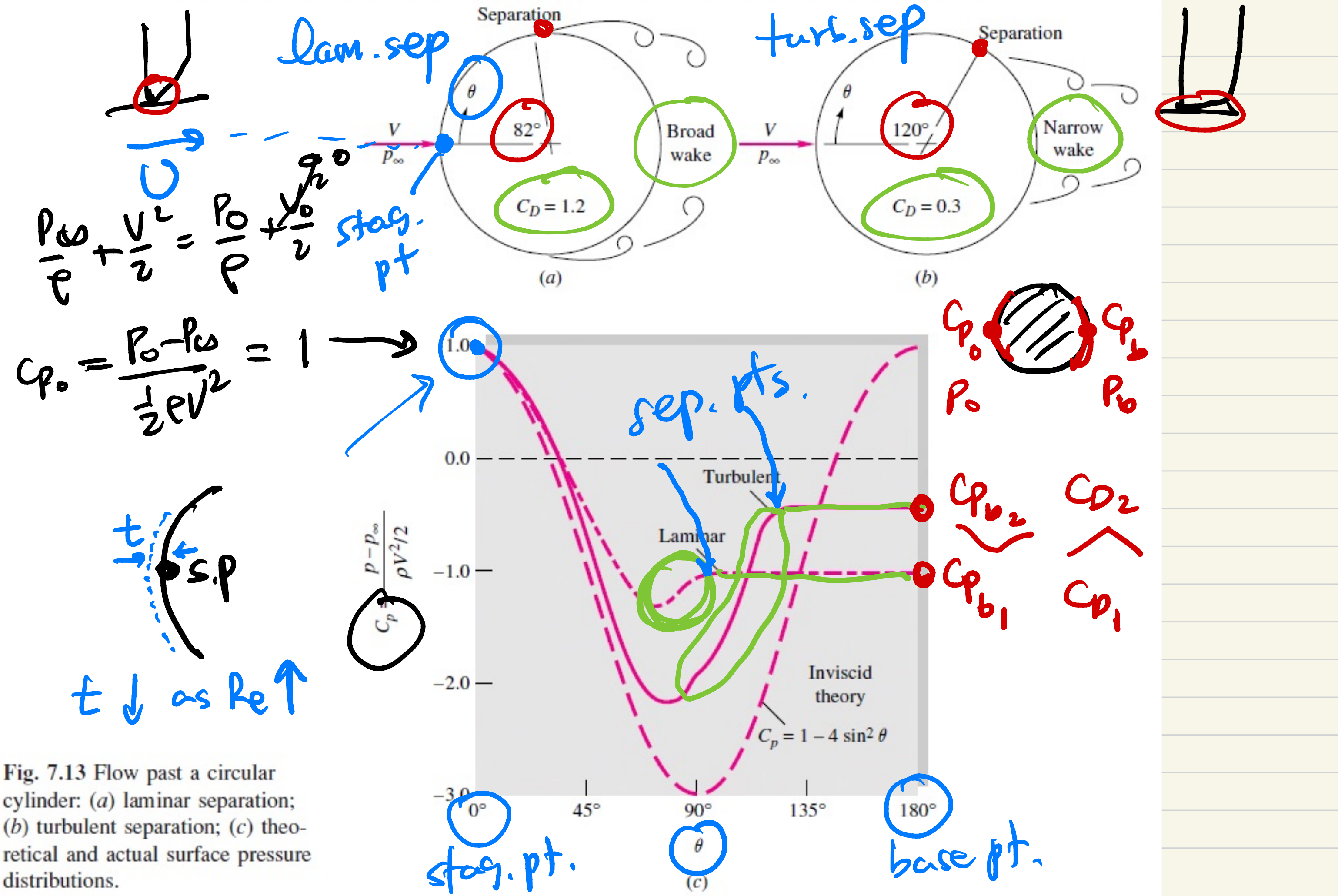


Fig. 7.13 Flow past a circular cylinder: (*a*) laminar separation; (*b*) turbulent separation; (*c*) theoretical and actual surface pressure distributions.