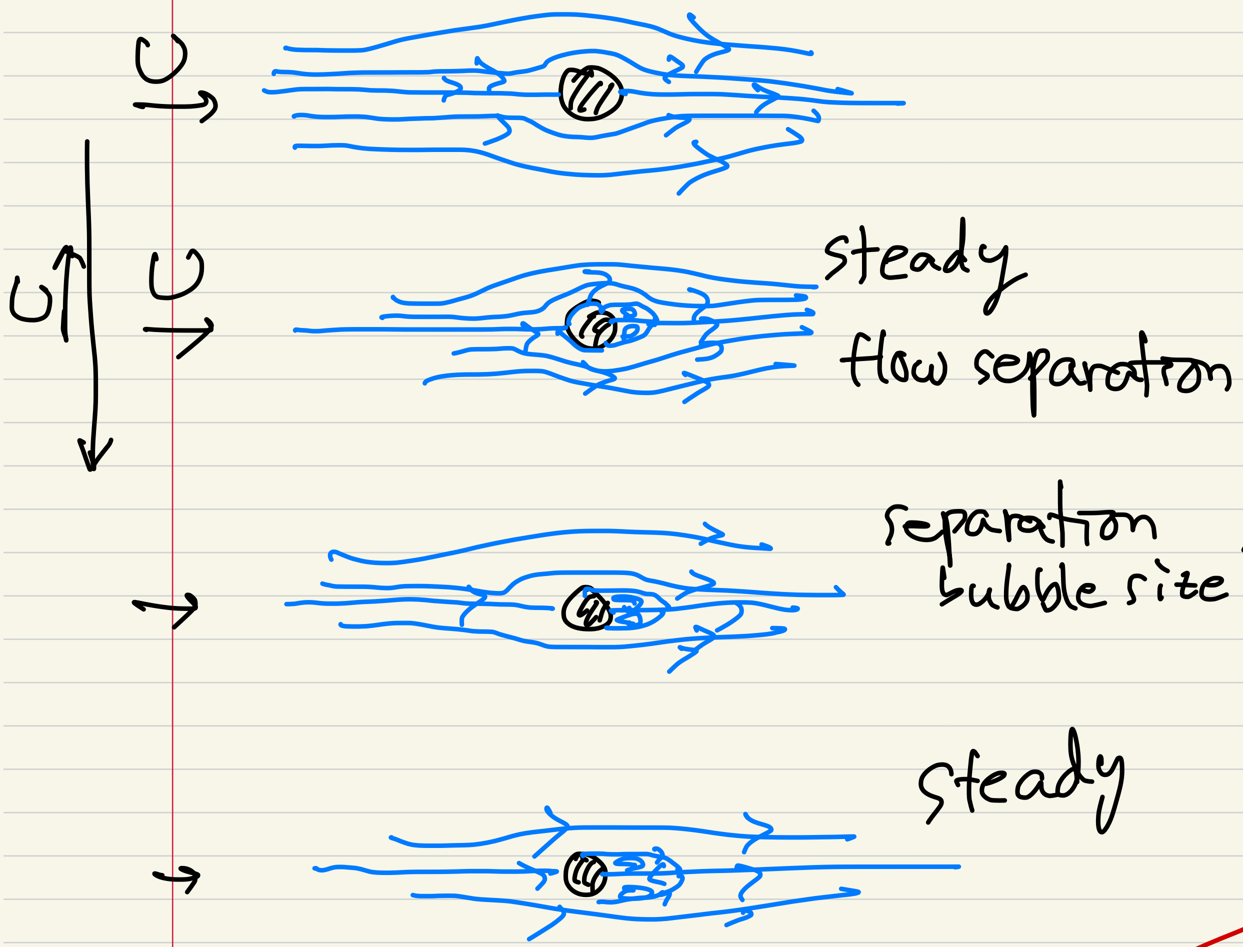
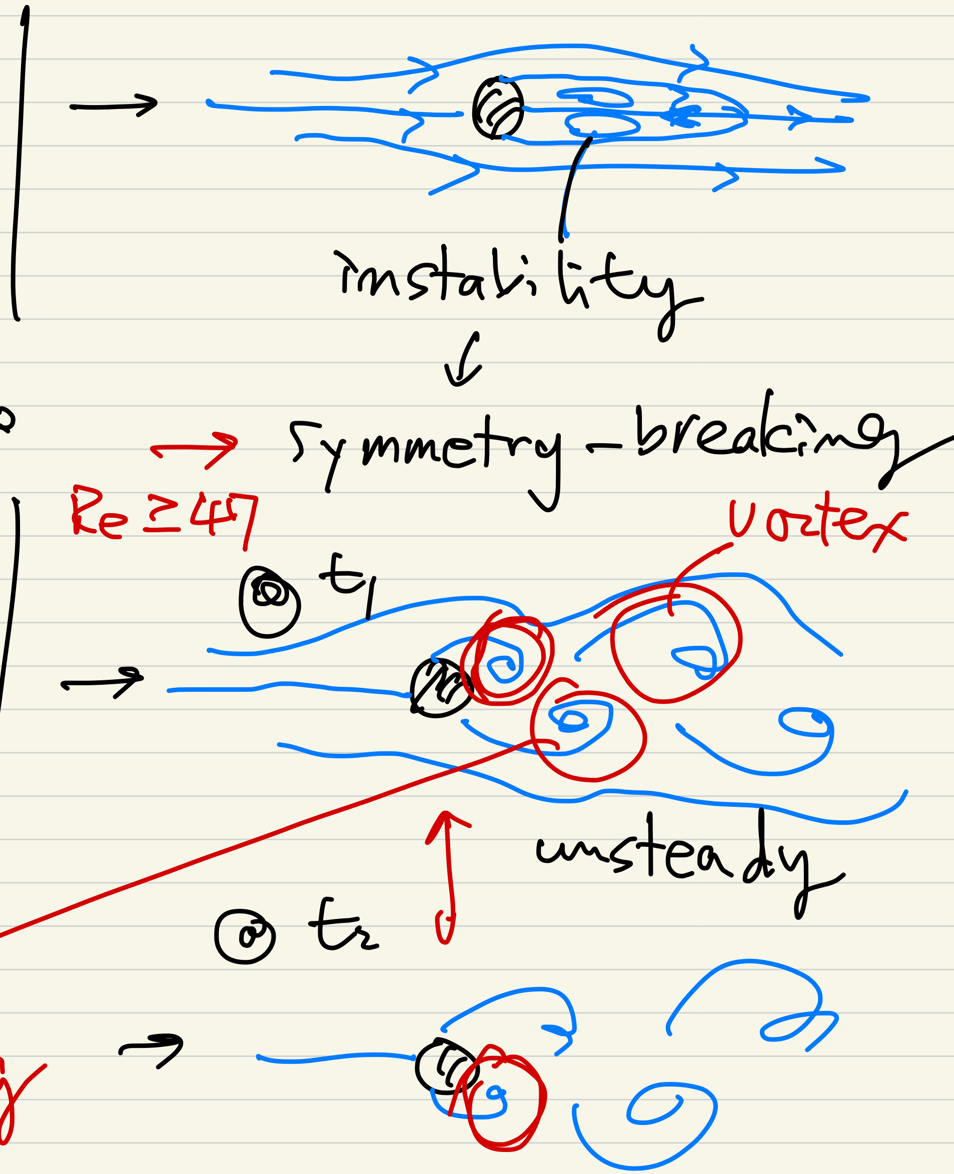
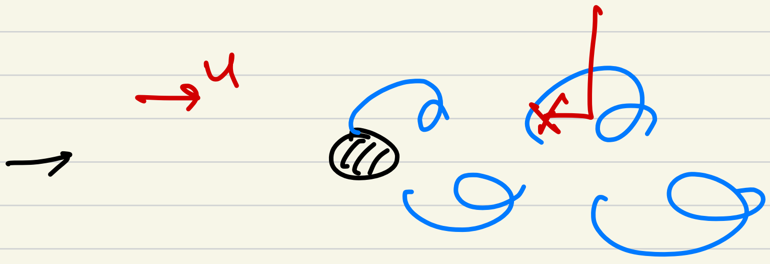
- Flow past a circular cylinder
  - ↳ a representative 2D bluff body.

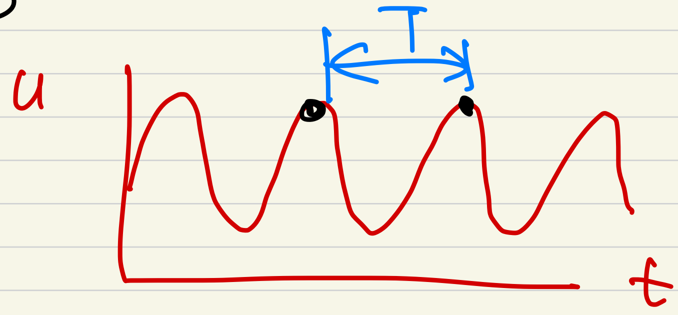




alternating Karman vortex shedding
와 흘림

$$Re = 47 = \frac{Ud}{\nu} = \frac{U \times 1.5 \times 10^{-2}}{1.5 \times 10^{-5}} \rightarrow U = 47 \times 10^{-3} = 47 \text{ mm/s}$$





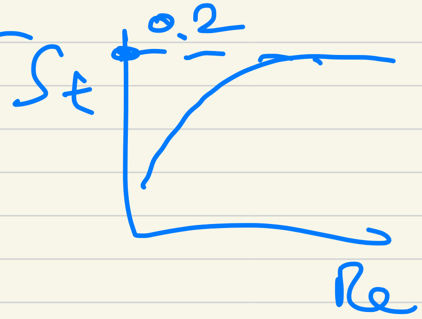
periodic

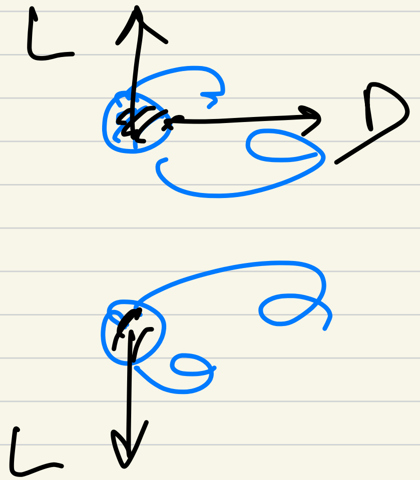
⊕ $Re = 100$

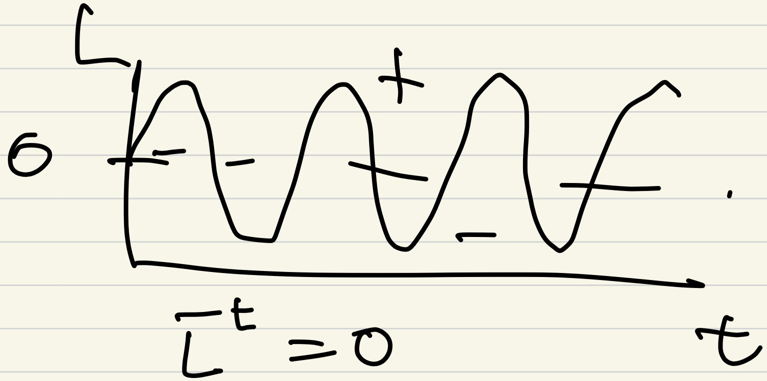
unsteady 2-D laminar flow

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

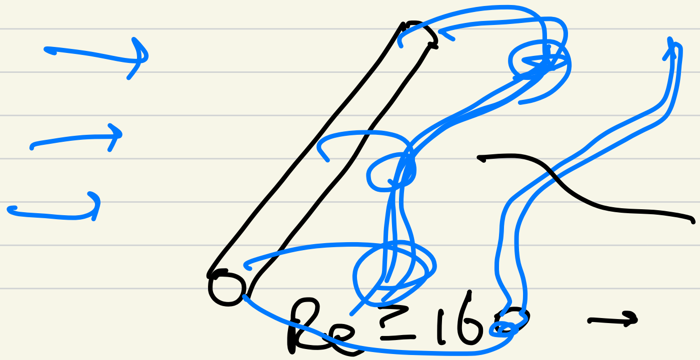
Strouhal number







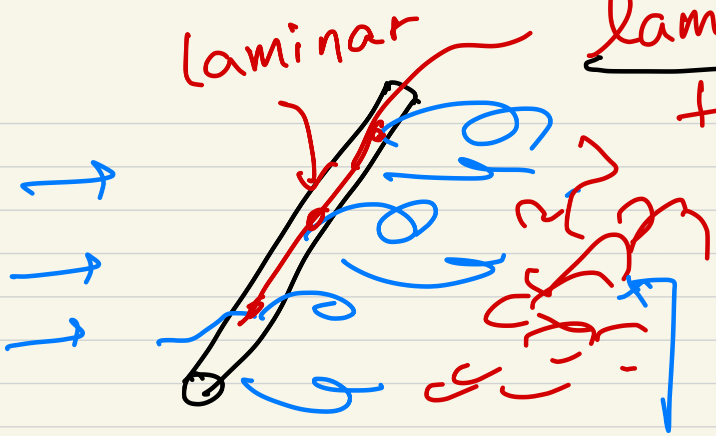
$$\bar{L}^t = 0$$



unsteady 3D laminar flow

unsteady 3D vortex shedding

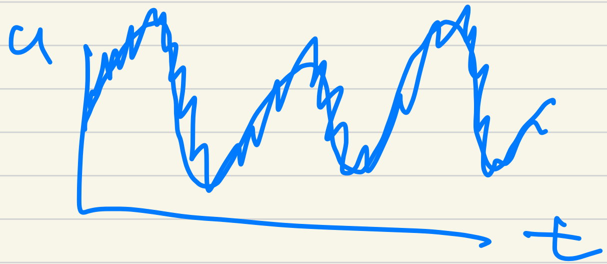
$Re \geq 160 \rightarrow$ 3D flow



laminar separation

turbulent

flow in wake

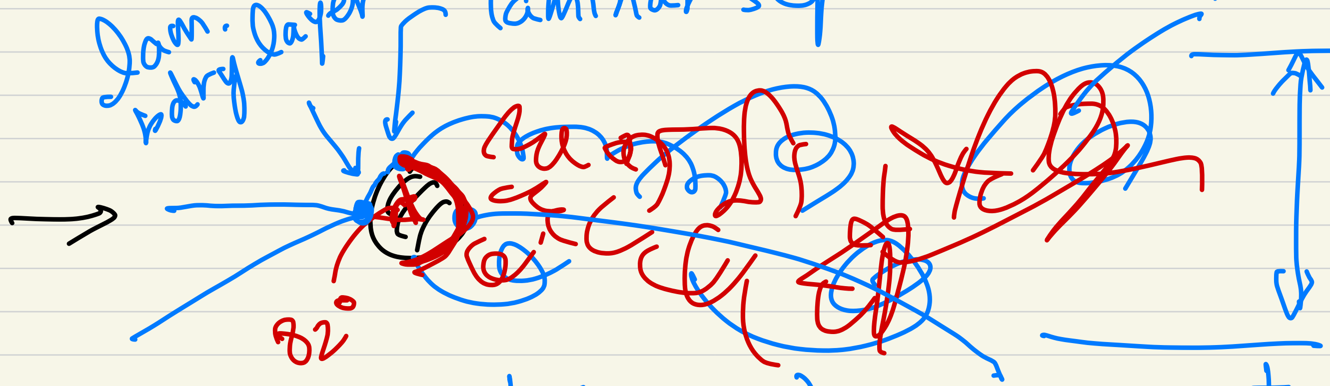


wake 후류

downstream 하류

Re = 1600

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



stagnation point (정체점)

" pressure

base point

" pressure ↓

$C_D = 1.2$

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

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

turbulent separation

narrow wake

separation delay

laminar

turbulent

$$Re_x = \frac{U \cdot \pi \frac{d}{2}}{\nu} = \frac{1}{2} \times 10^6 = 5 \times 10^5$$

$$C_D = 0.3 \sim 0.5$$

U, P_∞ →

$$C_p = \frac{P - P_\infty}{\frac{1}{2}\rho U^2}$$

pressure coeff.

압력계수

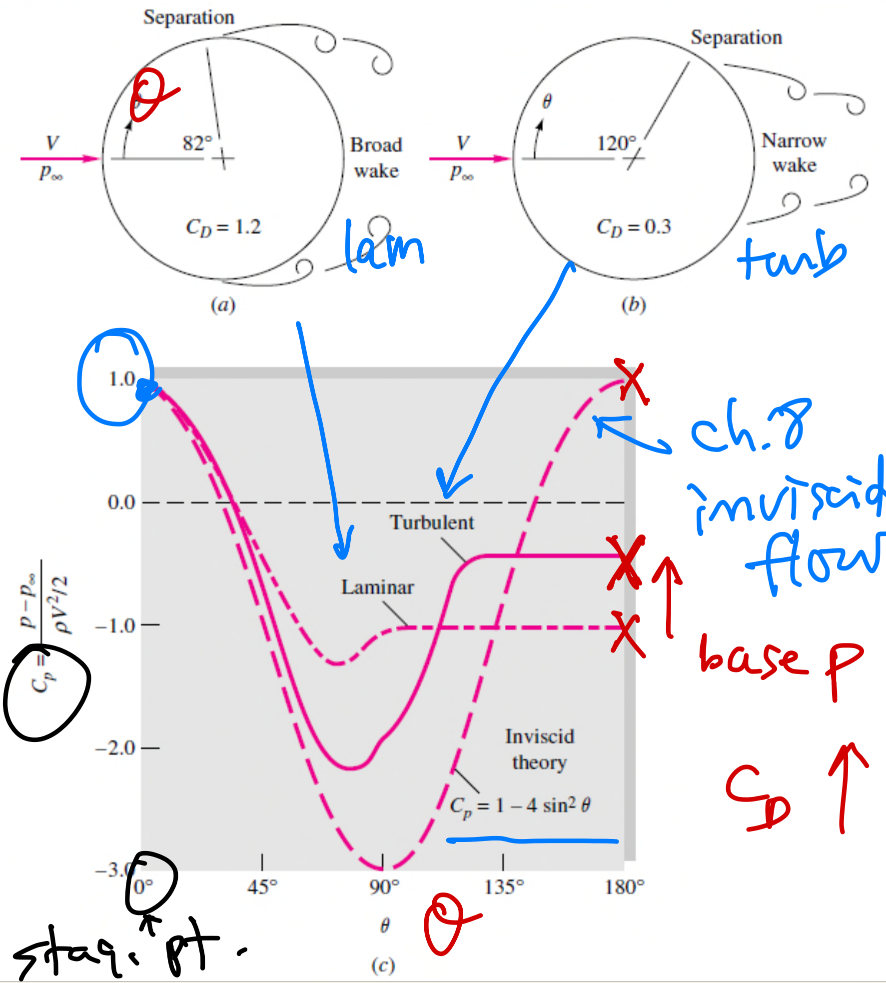


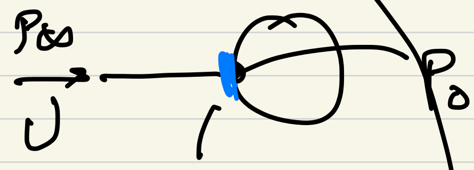
Fig. 7.13 Flow past a circular cylinder: (*a*) laminar separation; (*b*) turbulent separation; (*c*) theoretical and actual surface pressure distributions.

ch.8 inviscid flow

base p ↑

C_D ↑

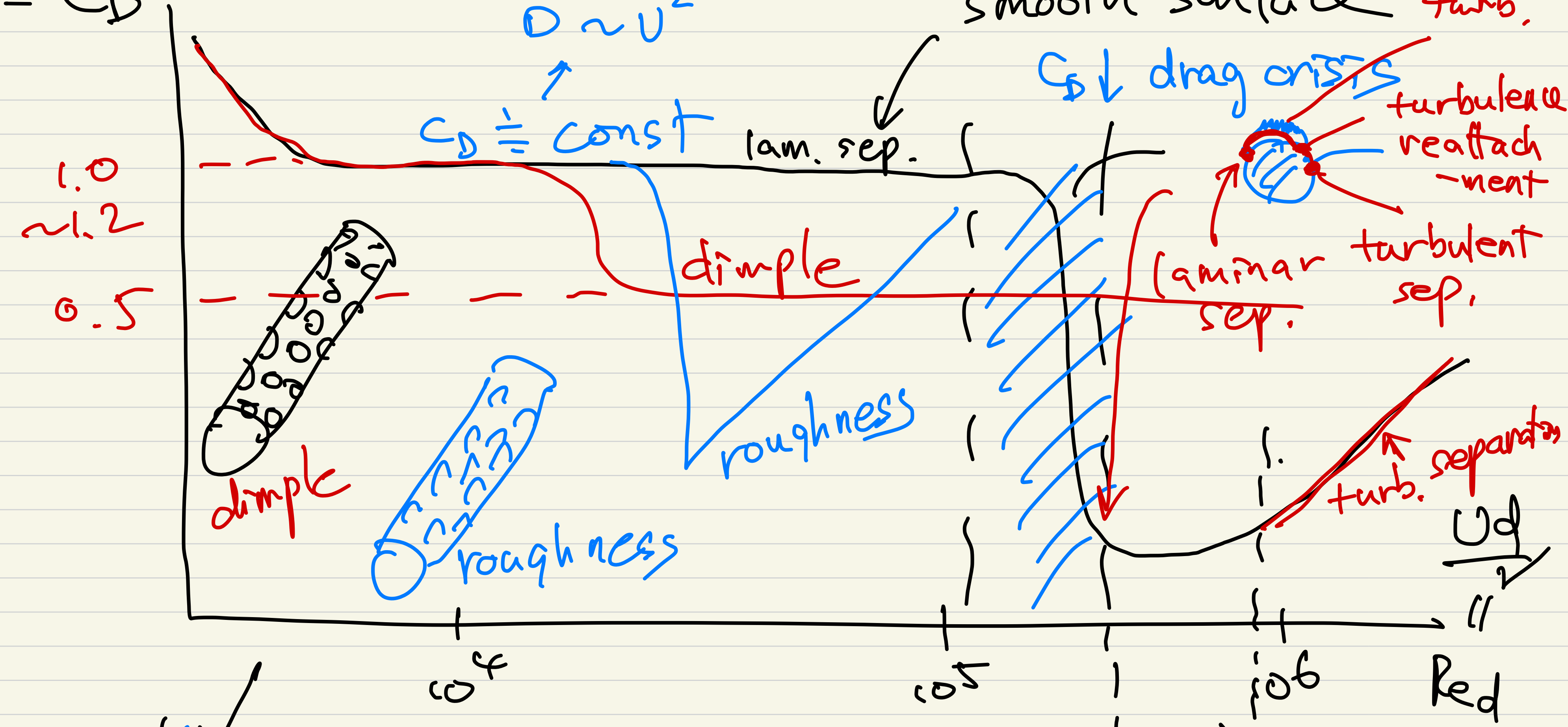
$$\frac{P_\infty}{\rho} + \frac{U^2}{2} = \frac{P_0}{\rho} + \frac{U^2}{2}$$

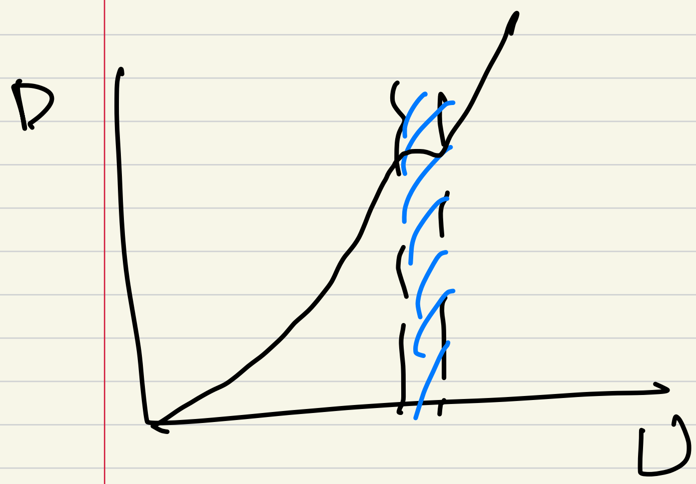


$$C_{p_0} = \frac{P_0 - P_\infty}{\frac{1}{2}\rho U^2} = \frac{\frac{1}{2}\rho U^2}{\frac{1}{2}\rho U^2} = 1$$

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

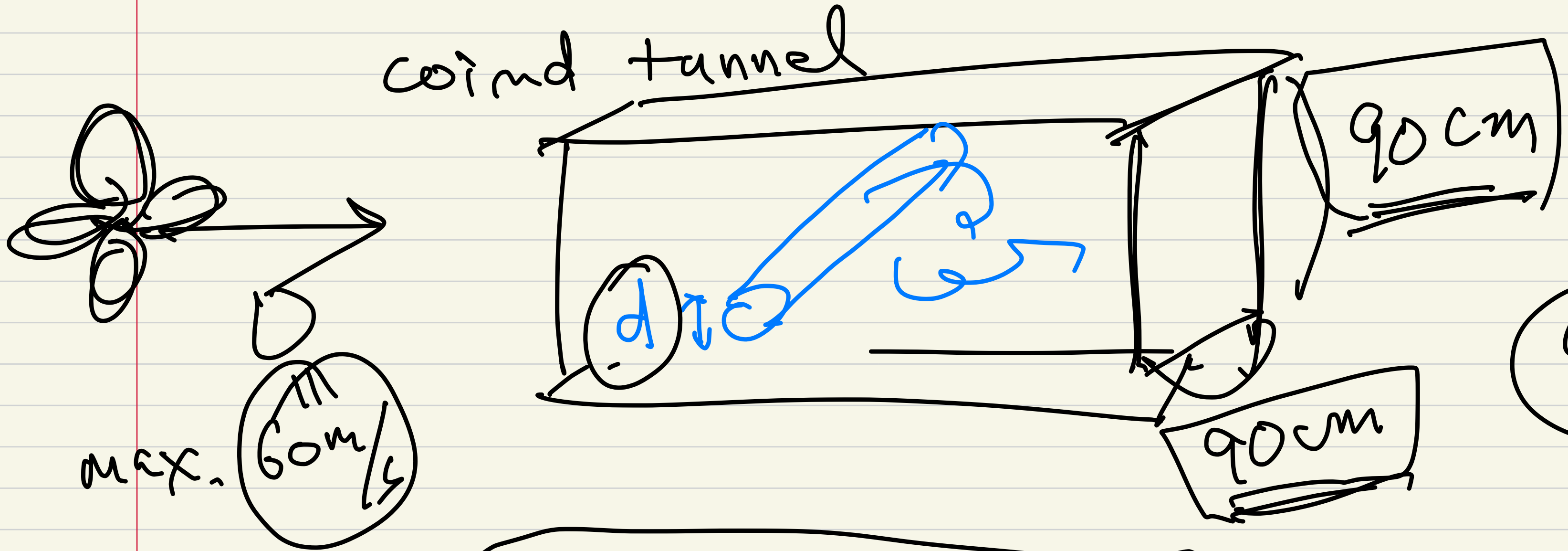
circular cylinder





$$Re = 10^6 = \frac{Ud}{\nu} = \frac{U \times 0.1}{1.5 \times 10^{-5}} = U \times 10^4 \rightarrow U = 100\ m/s$$

$d = ?$



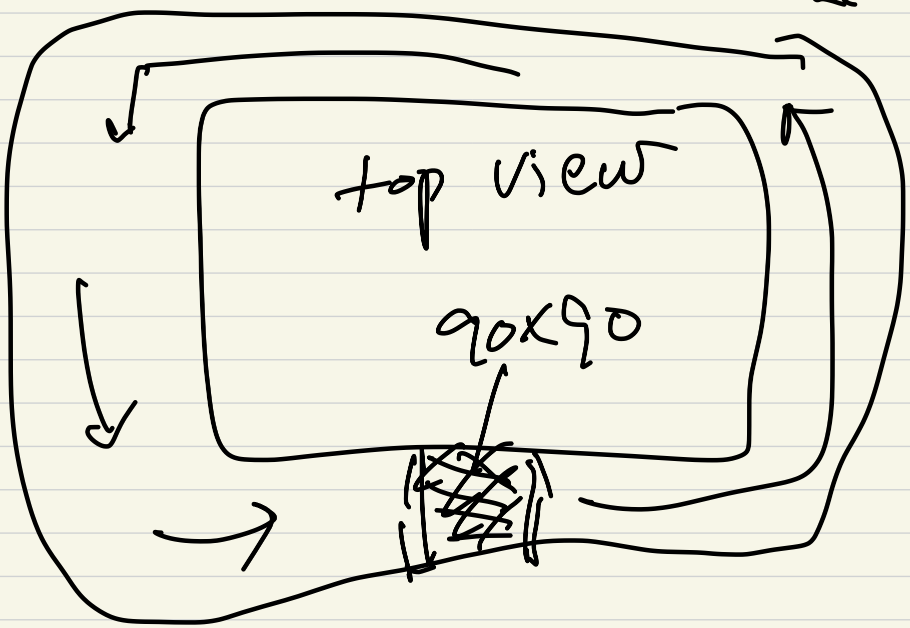
$d = 10\ cm$

44%

$d = 72\ mm$

$\phi = 4\%$ $\quad V = 140\ km/h$

$$Re = \frac{Vd}{\nu} = 1.87 \times 10^5$$



flow visualization

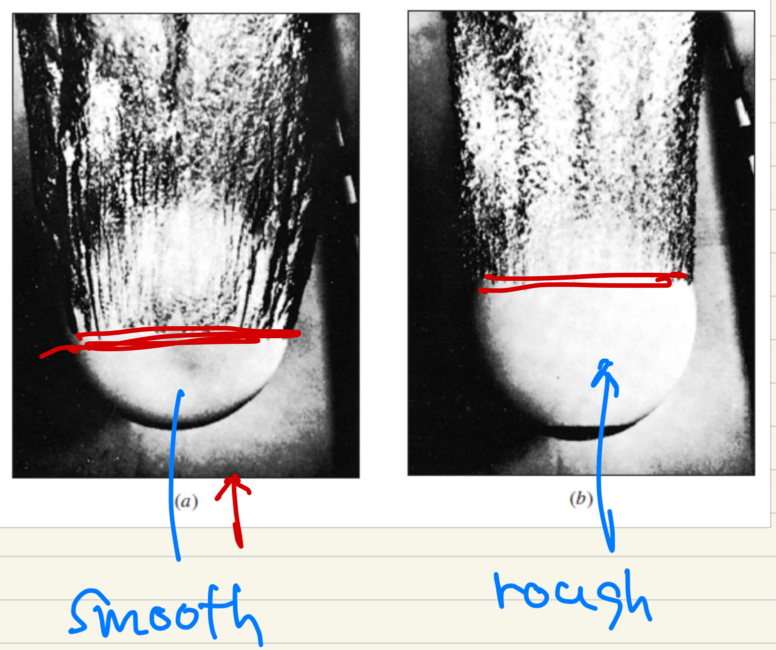
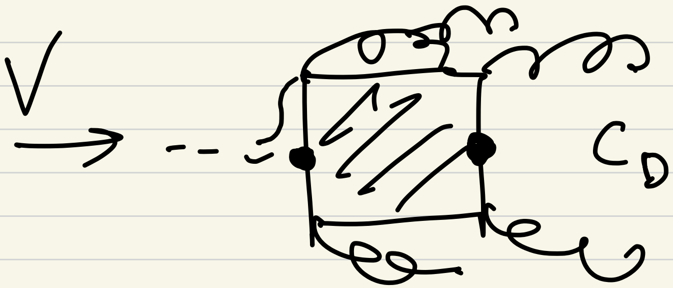
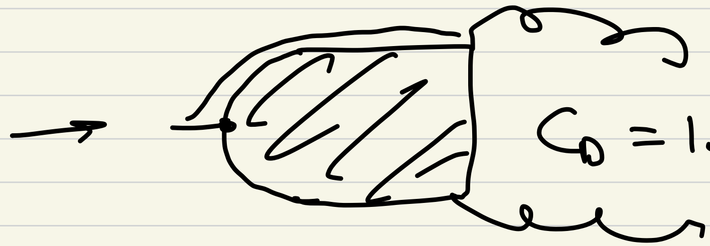


Fig. 7.14 Strong differences in laminar and turbulent separation on an 8.5-in bowling ball entering water at 25 ft/s: (a) smooth ball, laminar boundary layer; (b) same entry, turbulent flow induced by patch of nose-sand roughness. *(NAVAIR Weapons Division Historical Archives.)*

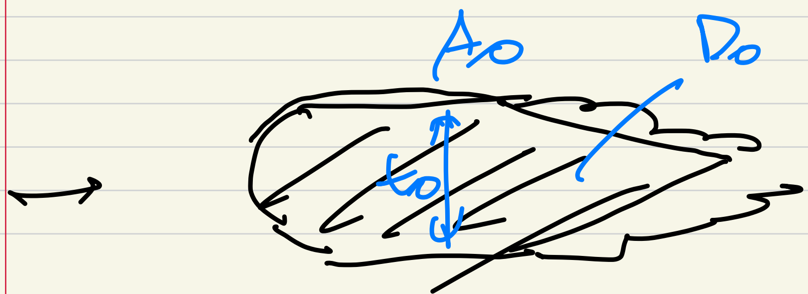
- Importance of streamlining



$C_D = 2.0$

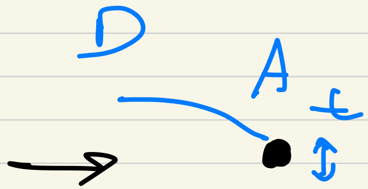


$C_D = 1.1$ 45% ↓



$C_D = 0.15$

85% ↓



$C_D = 1.2$

$D = D_0$: $t = \frac{1}{8} t_0$

$A = \frac{1}{300} A_0$

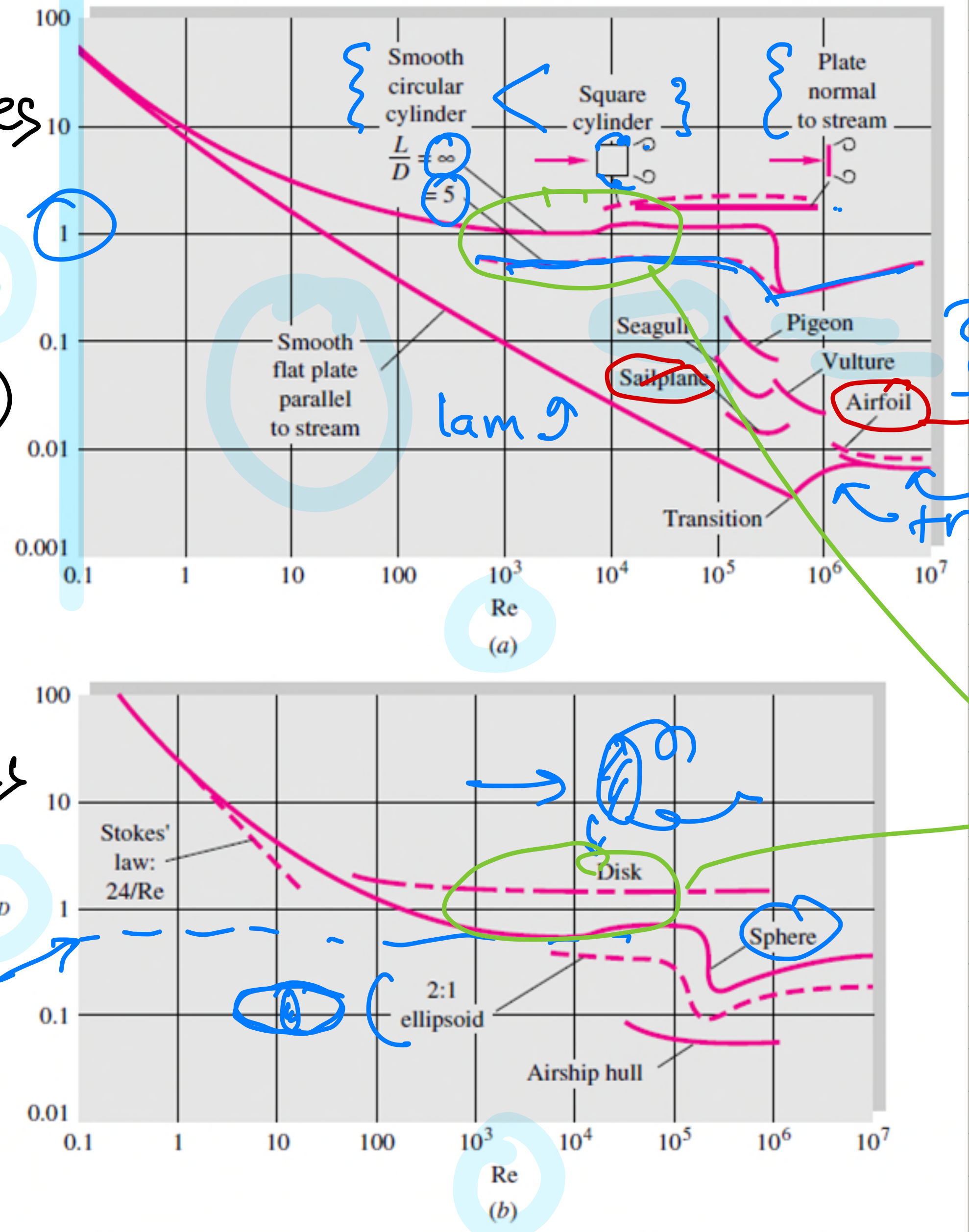
For high-performance vehicles and other moving vehicles, the name of game is drag reduction.

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

↑ planform area (except normal plate)

2-D bodies

3-D bodies



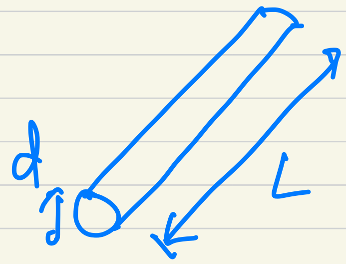


Fig. 7.16 Drag coefficients of smooth bodies at low Mach numbers: (*a*) two-dimensional bodies; (*b*) three-dimensional bodies. Note the Reynolds number independence of blunt bodies at high Re.

Table 7.2 Drag of Two-Dimensional Bodies at Re ≥ 10^4

2-D bodies ($Re \geq 10^4$)

$C_D \simeq$ const

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

↑ frontal area

Shape	C_D based on frontal area	Shape	C_D based on frontal area	Shape	C_D based on frontal area
Square cylinder:	2.1	Half cylinder:	1.2	Plate:	2.0
	1.6		1.7	Thin plate normal to a wall:	1.4
Half tube:	1.2	Equilateral triangle:	1.6	Hexagon:	1.0
	2.3		2.0		0.7

Shape	C_D based on frontal area							
Rounded nose section:	L/H:	0.5	1.0	2.0	4.0	6.0		
	C_D:	1.16	0.90	0.70	0.68	0.64		
Flat nose section:	L/H:	0.1	0.4	0.7	1.2	2.0	2.5	3.0	6.0
	C_D:	1.9	2.3	2.7	2.1	1.8	1.4	1.3	0.9

Elliptical cylinder:	Laminar	Turbulent
1:1	1.2	0.3
2:1	0.6	0.2
4:1	0.35	0.15
8:1	0.25	0.1

$C_D \downarrow$