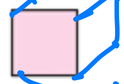
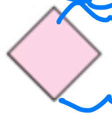
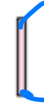
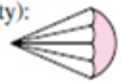
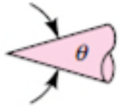
Table 7.3

3-D bodies @ $Re \geq 10^4$

Body		C_D based on frontal area
Cube:		1.07
		0.81
Cup:		1.4
		0.4
Disk:		1.17
Parachute (Low porosity):		1.2
Streamlined train (approximately 5 cars):		$C_D A \approx 8.5\ m^2$
Bicycle:		Upright: $C_D A \approx 0.51\ m^2$; Racing: $C_D A \approx 0.30\ m^2$

$C_D A$ 40% ↓

Cone: 

θ:	10°	20°	30°	40°	60°	75°	90°
C_D:	0.30	0.40	0.55	0.65	0.80	1.05	1.15

Short cylinder, laminar flow: 

L/D:	1	2	3	5	10	20	40	∞
C_D:	0.64	0.68	0.72	0.74	0.82	0.91	0.98	1.20

Porous parabolic dish [23]: 

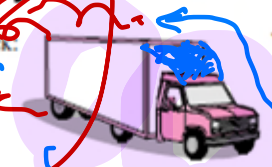
Porosity:	0	0.1	0.2	0.3	0.4	0.5
← C_D:	1.42	1.33	1.20	1.05	0.95	0.82
→ C_D:	0.95	0.92	0.90	0.86	0.83	0.80

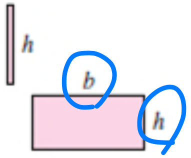
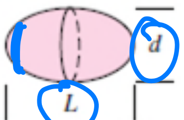
Average person: 

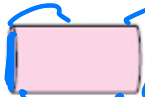
→ $C_D A \approx 9\ ft^2$ ↑ $C_D A \approx 1.2\ ft^2$

Pine and spruce trees [24]: 

U, m/s:	10	20	30	40
C_D:	1.2 ± 0.2	1.0 ± 0.2	0.7 ± 0.2	0.5 ± 0.2

Tractor-trailer truck:  Without deflector: 0.96; with deflector: 0.76

Body		Ratio		C_D based on frontal area	
Rectangular plate:		b/h	1	1.18	
			5	1.2	
			10	1.3	
			20	1.5	
			∞	2.0	
				Laminar	Turbulent
Ellipsoid:		L/d	0.75	0.5	0.2
			1	0.47	0.2
			2	0.27	0.13
			4	0.25	0.1
			8	0.2	0.08

Body		Ratio		C_D based on frontal area
Flat-faced cylinder:		L/d	0.5	1.15
			1	0.90
			2	0.85
			4	0.87
			8	0.99
Buoyant rising sphere [50], $135 < Re_d < 1E5$				$C_D \approx 0.95$

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

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

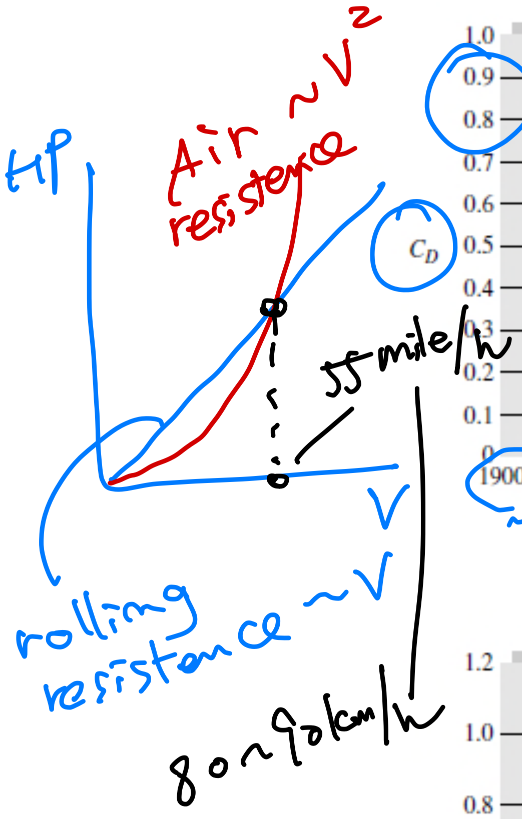
$$C_D A = 9\ ft^2 = 9 \times 0.3048^2\ m^2 \simeq 0.81\ m^2$$

$$U = \frac{100\ m}{10\ s} = 10\ m/s$$

$$D = C_D A \cdot \tfrac{1}{2}\rho U^2 = 0.81 \times \tfrac{1}{2} \times 1.2 \times 10^2 \simeq 50\ N$$

splitter plate

$C_D = 1$ $\quad C_D \simeq 0.5 \sim 0.8$



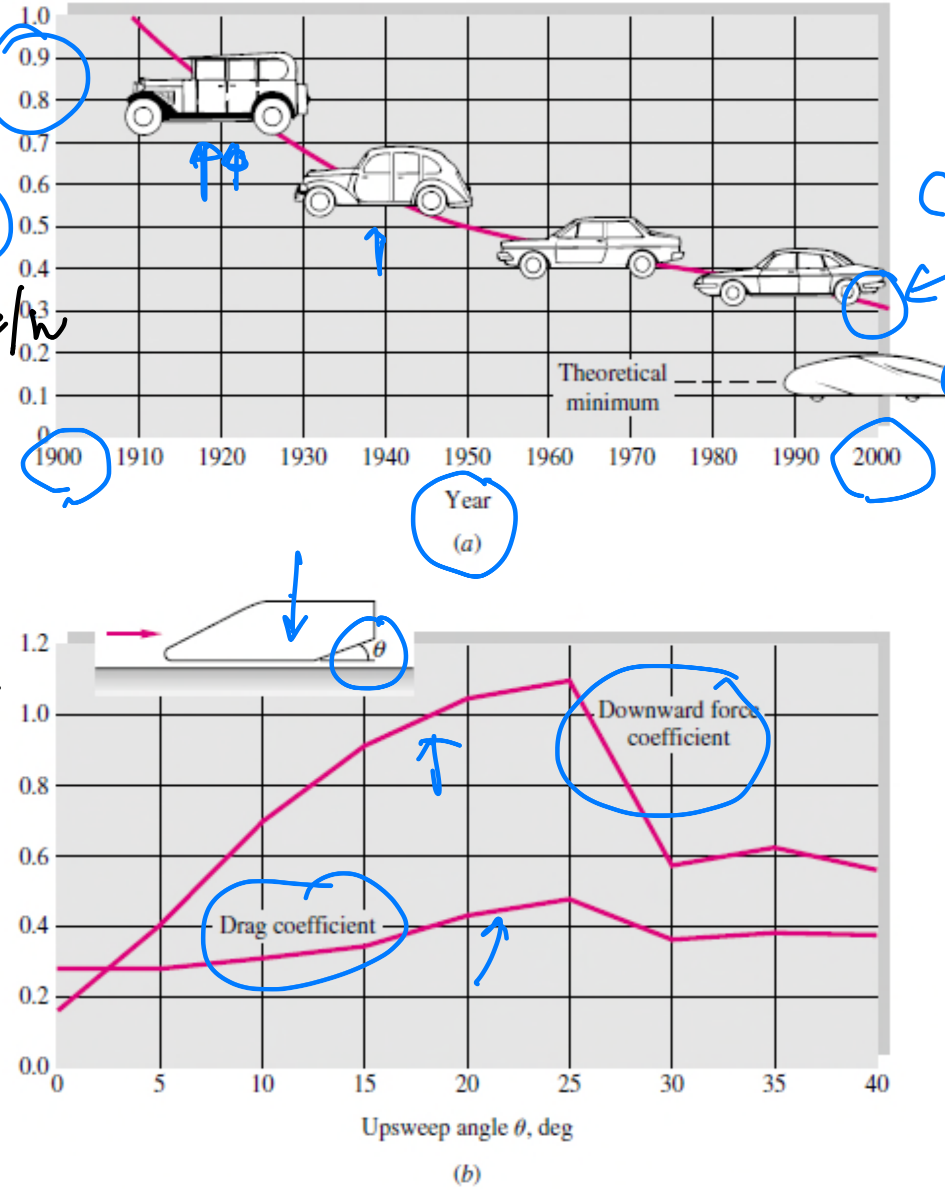


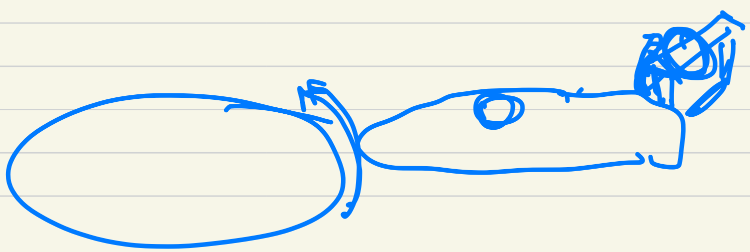
Fig. 7.17 Aerodynamics of automobiles: (*a*) the historical trend for drag coefficients (from Ref. 21); (*b*) effect of bottom rear upsweep angle on drag and downward lift force (from Ref. 25).

	C_D
Sonata NF	0.30
Genesis	0.29
Benz E350	0.28
Lexus GS350	0.28
SUV	0.35
Ferari F50	0.37
GM EV1	0.195
Bionic car (Benz concept car)	0.19

생체모방공학

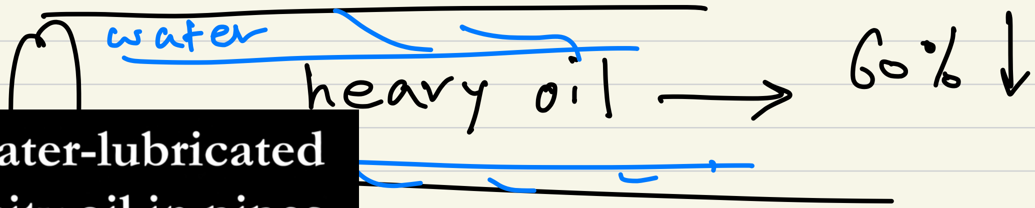
Boxfish (거북복)

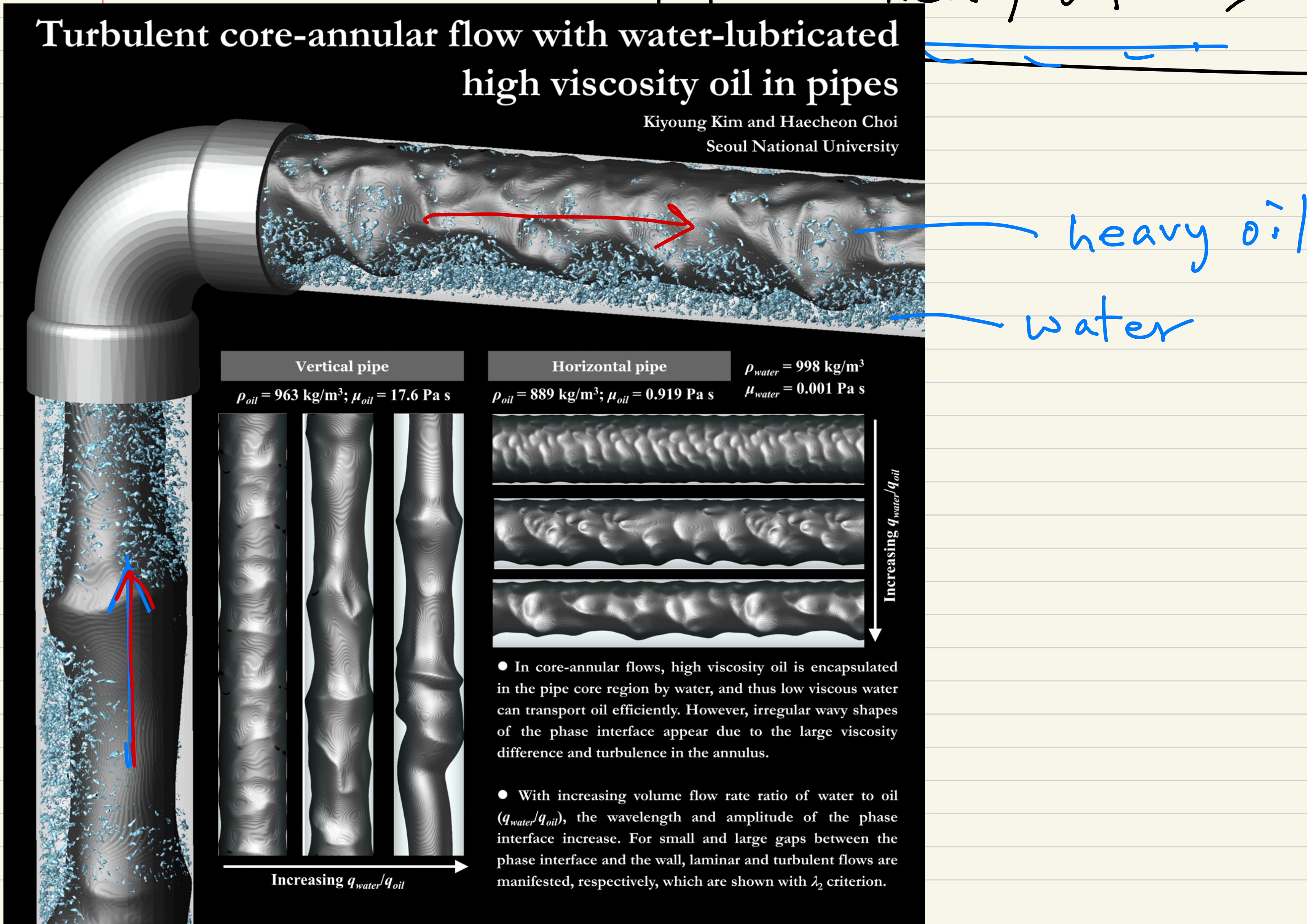
Side mirror 1개 → $\Delta C_D = 0.01$



· Other methods of drag reduction

① oil + water



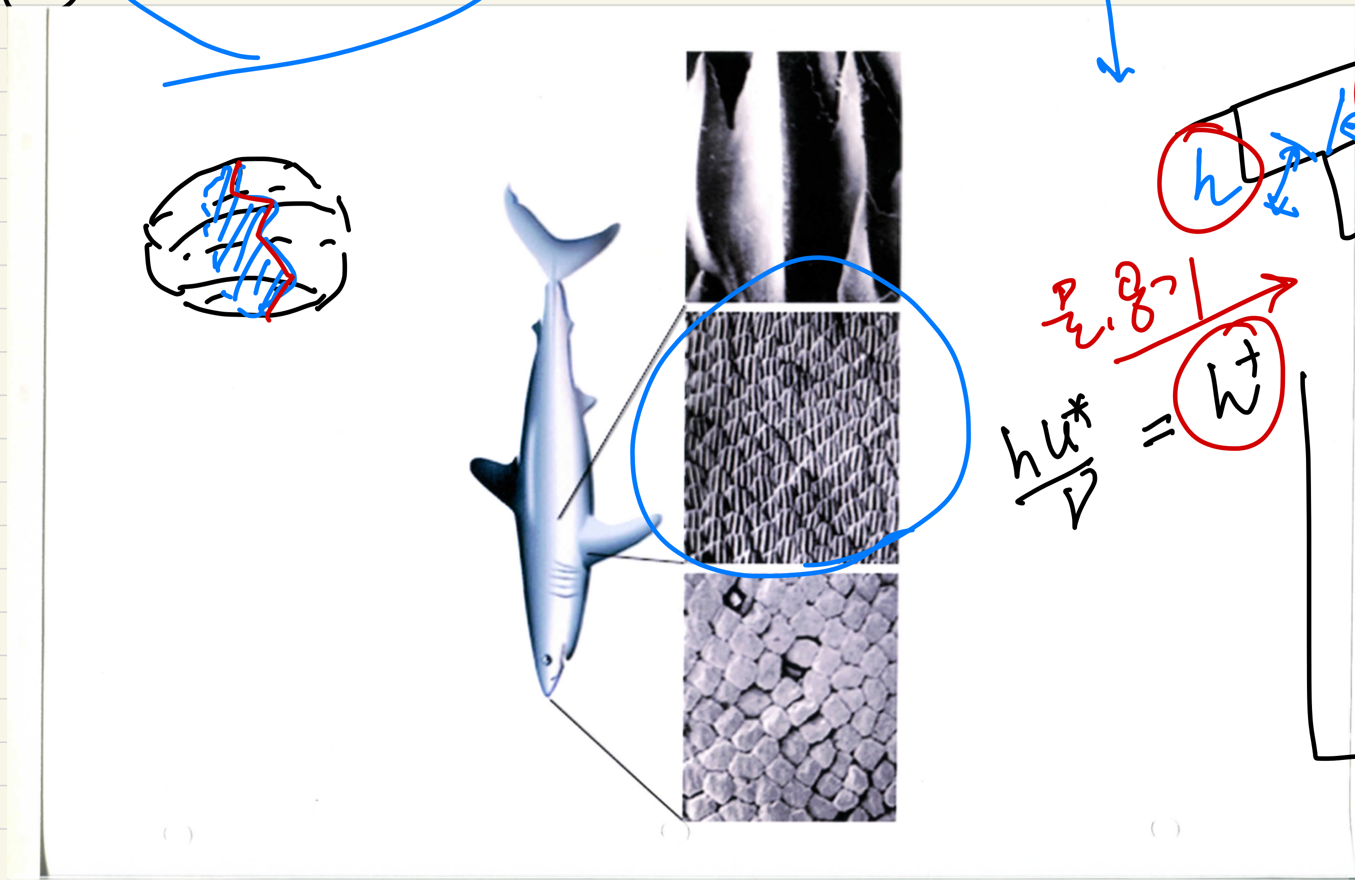


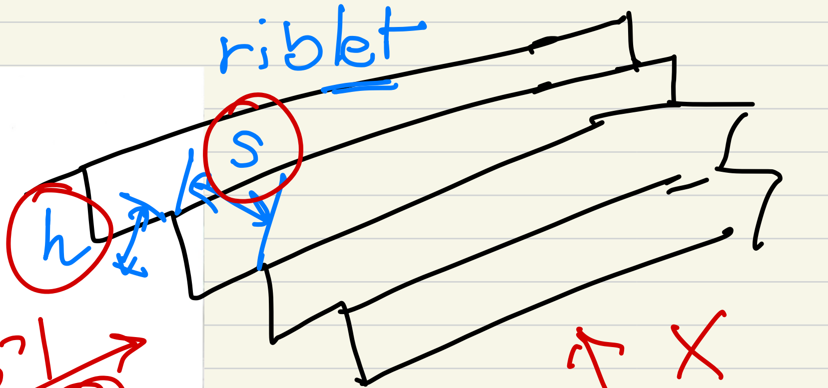
② water + polymer : polymer additives
oil pipe (ppm)

light oil + polymer (ppm) 80% ↓

Min et al. (JFM)

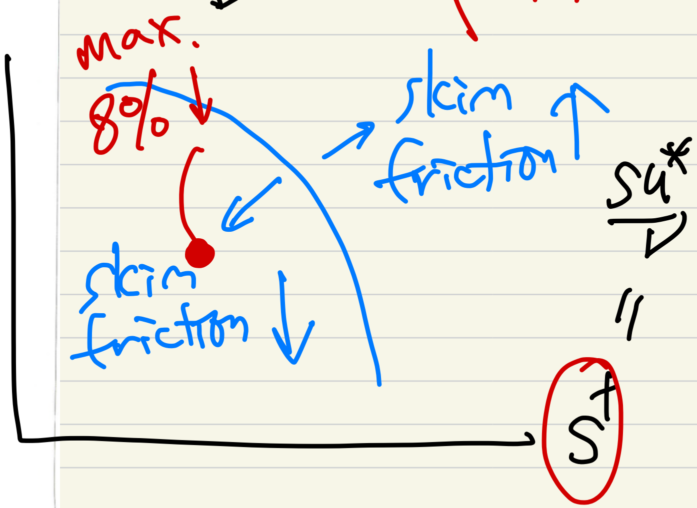
③ riblets – Walsh (1980)





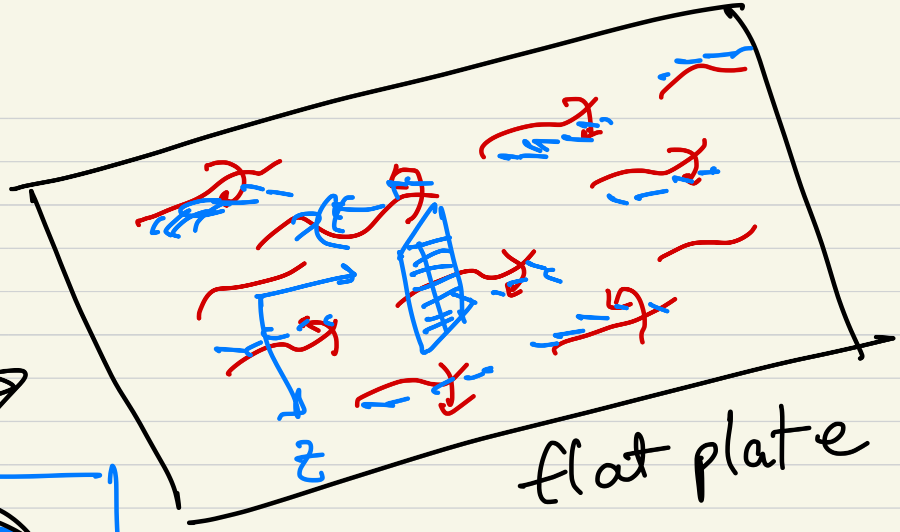
올리기

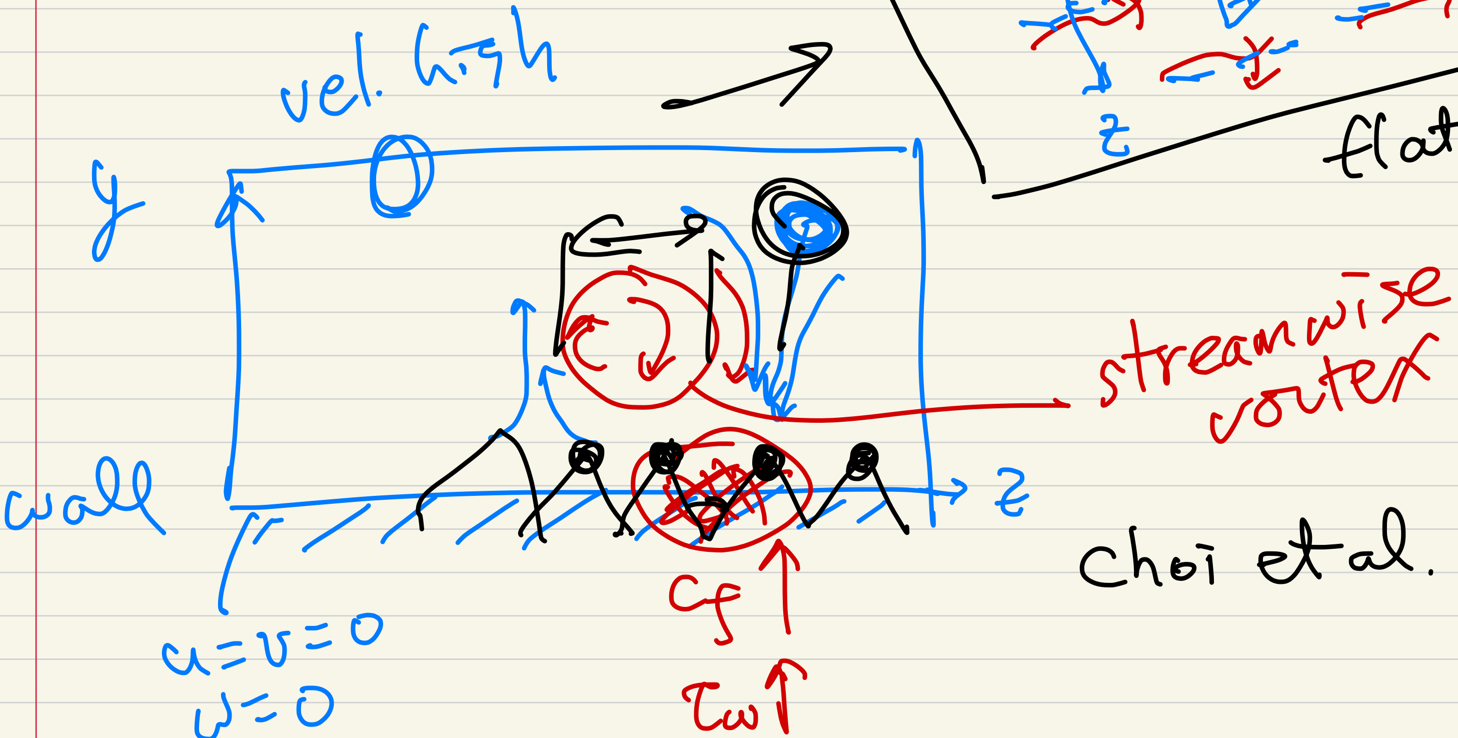
$$\frac{h u^*}{\nu} = h^+$$



mechanism?

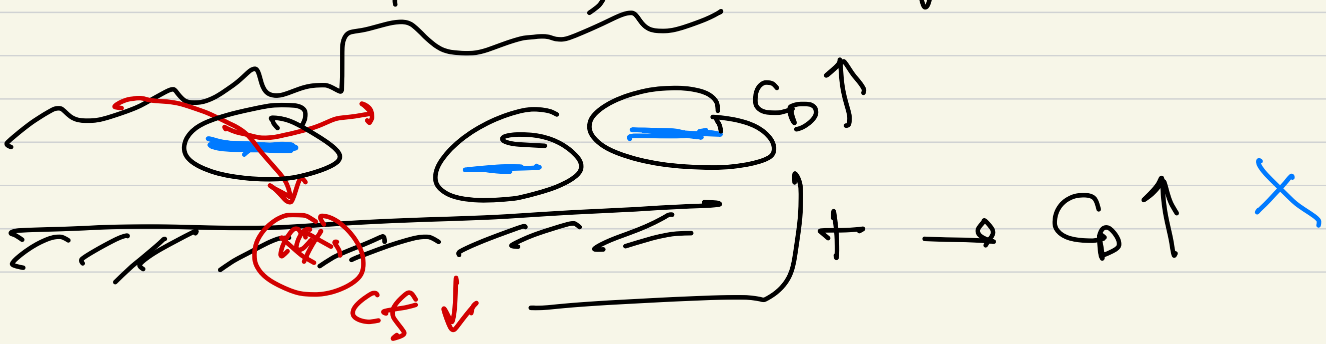
eq?





Choi et al. (JFM, 1993)

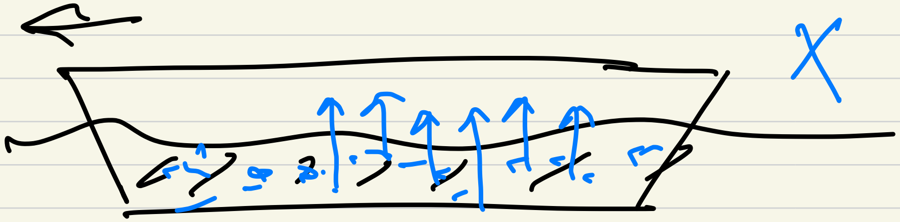
④ LEBU (large eddy break-up) device



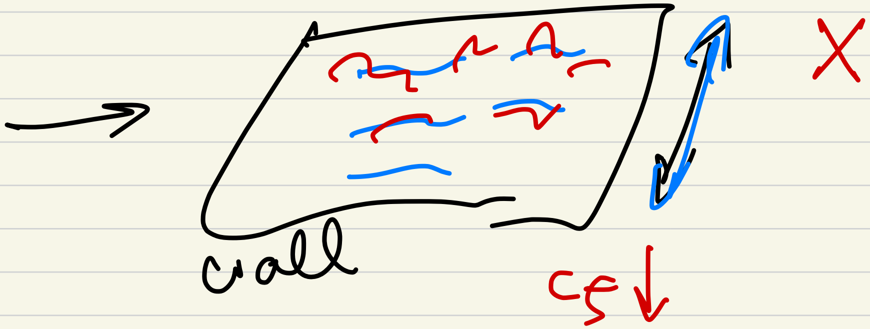
⑤ micro bubble drag reduction

water + bubble
(air)

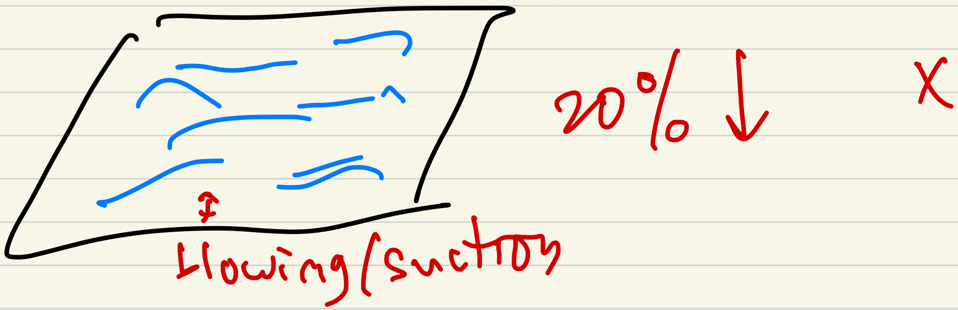
$\mu_w >> \mu_a$



⑥ spanwise wall oscillation



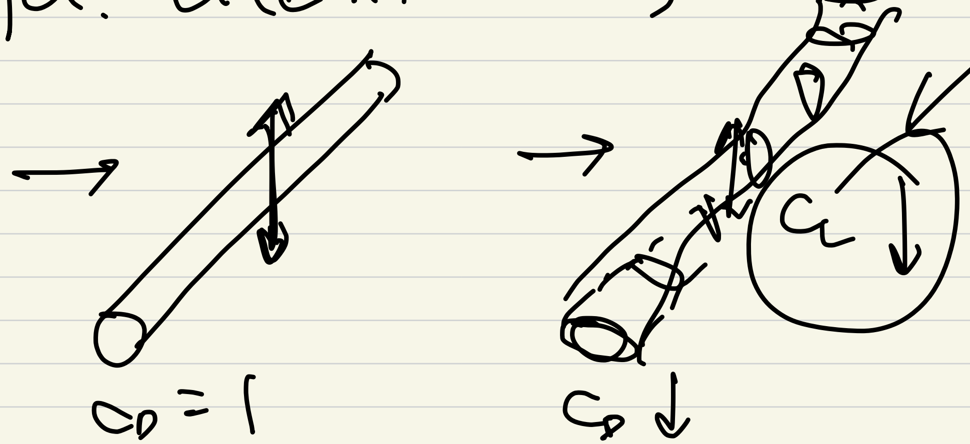
⑦ active flow control – opposition control (Choi et al. JFM 1994)



⑧ biological drag reduction

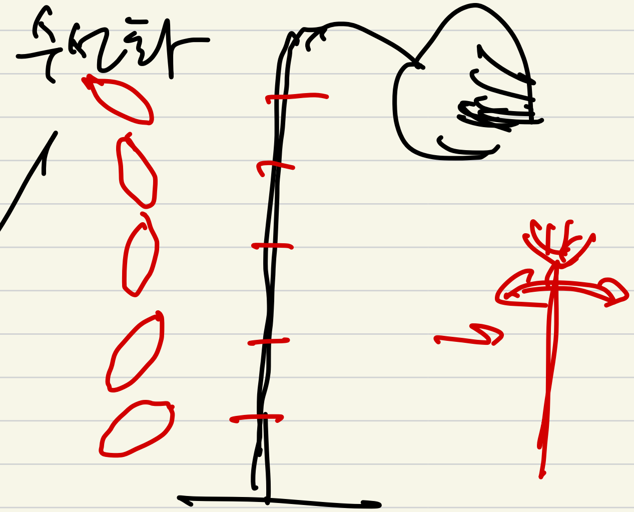
– biomimetic flow control

S. Vogel. "Life in moving fluids"



$C_D = 1$

$C_D \downarrow = 0.8$



Drag on surface ships

$C_{D,\,wave}$

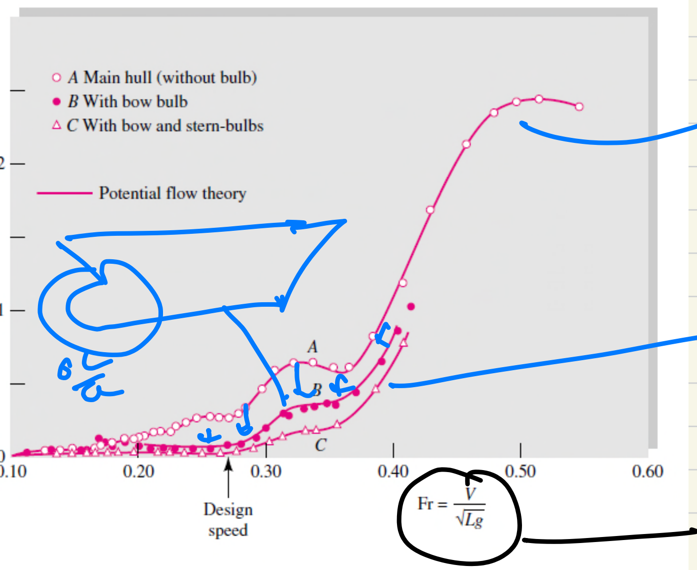
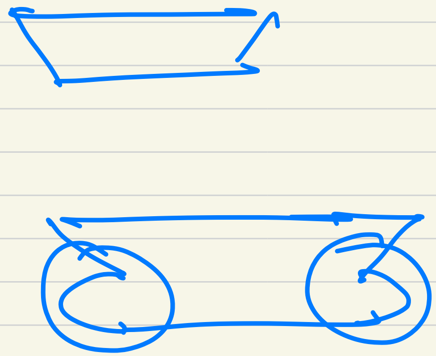


Fig. 7.19 Wave-making drag on a ship model. (*After Inui [27].*)
Note: The drag coefficient is defined as $C_{DW} = 2F/(\rho V^2 L^2)$.

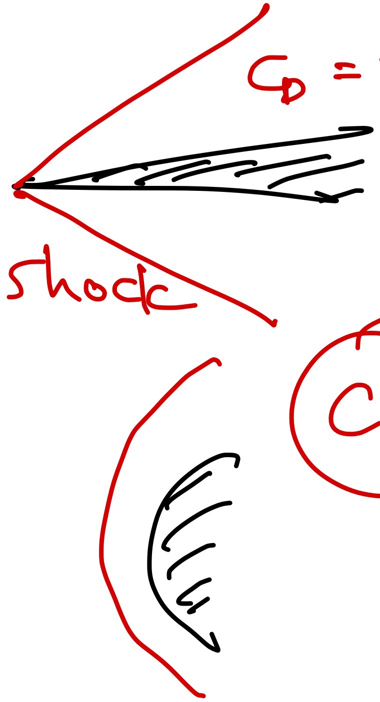


$$Fr = \frac{V}{\sqrt{Lg}}$$

Effect of Mach

Ma > 1

$C_D = f(Re, Ma)$



Ch.9

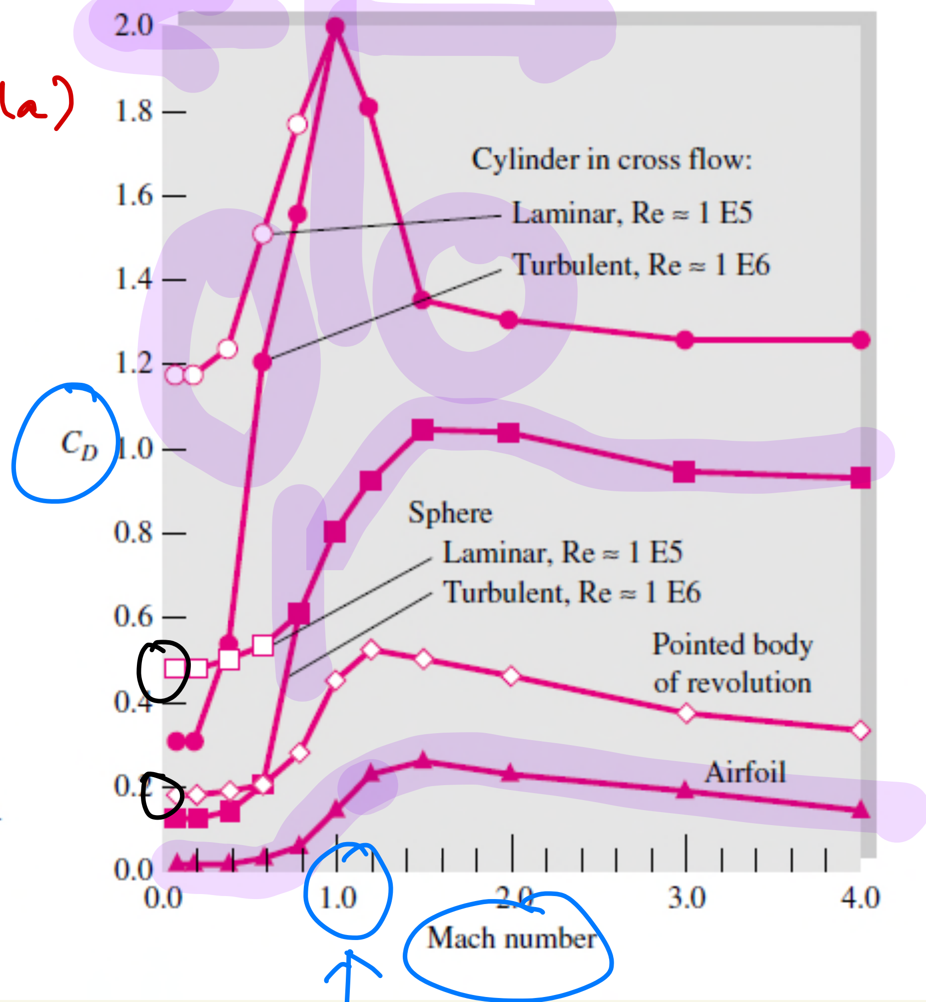


Fig. 7.20 Effect of the Mach number on the drag of various body shapes. (*Data from Refs. 23 and 29.*)