Chap. 7. Shape and Drag : Motile Animals

· streamlining : continuously facing into oncoming current, definite, noncompliant shape) → animals (swimmers, flyers)

§ Streamlining and the comparison of drag coefficients

* converting drag coefficients from one reference area to another

i) sphere

$$C_{D,\,frontal} = \frac{F_D}{\frac{1}{2}\rho U^2(\pi R^2)} \sim \frac{1}{\pi R^2}$$

$$C_{D,\,plan\ form} = \text{"}$$

$$C_{D,\,wetted\ area} = \frac{F_D}{\frac{1}{2}\rho U^2(4\pi R^2)} \sim \frac{1}{4\pi R^2}$$

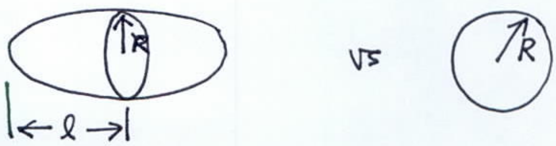
$$\frac{C_{D,w}}{C_{D,f}} = \frac{1}{4}$$

$$C_{D,\,V^{2/3}} = \frac{F_D}{\frac{1}{2}\rho U^2(\frac{4}{3}\pi R^3)^{2/3}} \sim \frac{1}{2.6\,R^2}$$

$$\frac{C_{D,V^{2/3}}}{C_{D,f}} = \frac{\pi}{2.6} = 1.208$$

ii) cylinder

iii) prolate spheroids



plan form area for sphere : πR^2

p.s. $(l : R = 2:1)$: $\pi l R = 2\pi R^2$

$$\frac{C_{D,p.s.}}{C_{D,s}} = \frac{1}{2}$$

⇢ Table 7.1.

* quality of streamlining

streamlining ~ prevents separation

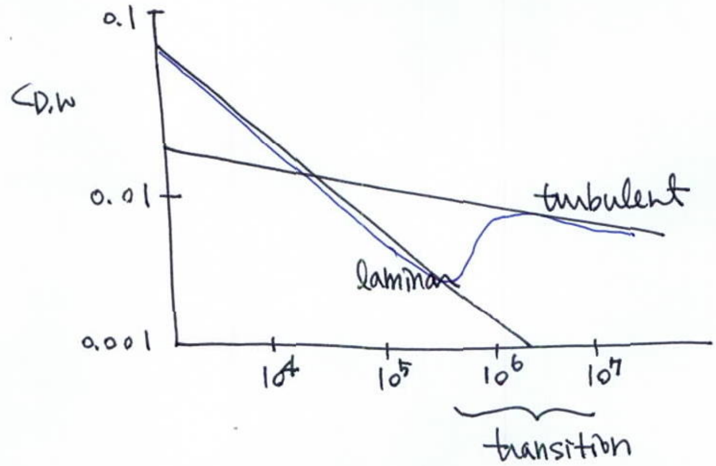
ideal nonseparating flow ~ flow across a flat plate parallel to the flow.

- for flat plate,

$$C_{D,w} = 1.33\ Re_L^{-0.5} \quad (\text{laminar})$$

$$C_{D,w} = 0.072\ Re_L^{-0.2} \quad (\text{turbulent})$$

L-T transition : $\sim 5\times10^5 \sim 1\times10^7$

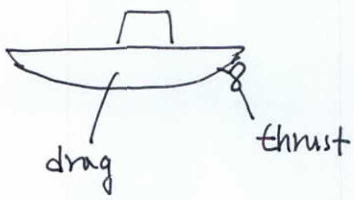


§ Drag and thrust

- drag = thrust in steady speed
  horizontal motion
  otherwise still medium

- separation bet. thrust-generating and drag-sustaining structures.

e.g.



in biological systems, the separation is imperfect.

- non-thrust-producing structures are subjected to
  - simple and smooth oncoming flow
  - complex and temporally varying flow from wings or legs
- some fish / invertebrate larvae with ciliated region
  - ~ whole body participates in propulsion

e.g. ciliated microorganism

flow with the cilia beating

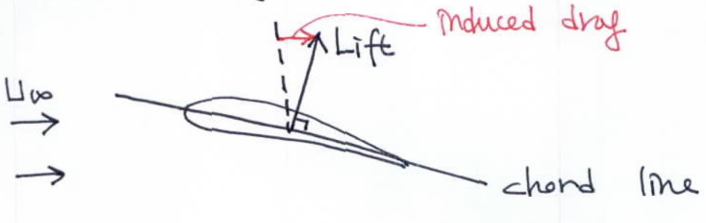
≠ flow around the creature falling under gravity at the same speed

· Types of drag

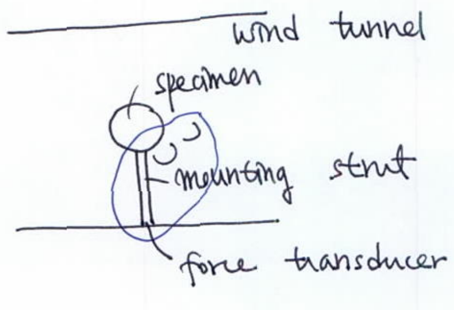
① parasite drag (when thrust-producing appendages involved)

: combined drag of all non-thrust-producing structures (external drag that the thrust producer has to offset)

② induced drag



③ interference drag

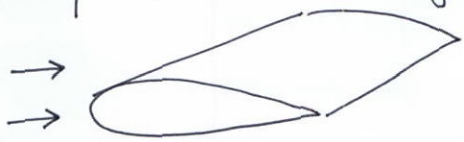


④ added mass

· simple way to get (sometimes) drag figures for
swimming / flying animals
∵ they don't swim / fly continuously
~ "gliding" is quite a normal event.

§ Looking for streamlined struts (2-D)

· relatively uncommon among organisms.



e.g. mayfly nymph legs (living in rapid stream)
crab legs (walk around or stand erect in water currents)
hammerhead sharks

cf.)

water/air interface → chap. 17
e.g. skimmer bill, fishing bat toe

§ A diversity of streamlined bodies (3-D)

· 3-D streamlined body ~ hallmark of virtually every competent swimmer or flyer

Fig. 7. 3.

* Smallish arthropods

· reduction of maximum travel range by resistance (air drag)
baseball : 19%
golf ball : 36%
jumping locust : 16%, generic flea : 83%

- For small insects, drag becomes more important relative to gravity
  - ∵ area ~ L^2
  - volume ~ L^3. $L \downarrow$ ~ $\frac{V}{A} \downarrow$

Fig. 7.4.

- drag coeff. of small arthropods : both spheres and plates

* several undistinguished swimmers
  - e.g. frogs, crabs, ducks underwater
    - ~ high C_D.

* Fish

* Birds
  - : feather increases C_D

* Penguins
  - : lowest cost of transport (energy expenditure per unit mass and distance) in all aquatic endotherms (온혈동물)

* Marine mammals

§ Tricks for reducing drag – hope and reality

- well documented ways organisms minimize drag
  1. extreme flexibility in flow
  2. streamlining
  3. growth to great length in oscillating flow
  4. staying close to a solid surface
  5. expulsion of water through opercula in ram ventilation in fish

other schemes

: mostly describe ways organisms, largely large swimming animals, can get body drag down below that of a flat plate with turbulent flow.

cf) $C_{D,turb} \approx 3.4\ C_{D,laminar}$ at $Re = 10^6$.

* compliant surfaces

e.g cetacean 

mechanism : damping of incipient turbulence

* Mucus secretions (점액)

e.g fish, dolphin

mechanism : adding long-chained polymers to a flow, especially if they're added in the velocity gradients at surfaces, can reduce drag

skeptism : (1) rate of polymer secretion for good effect > rate fish can reasonably manage

(2) cost of producing such secretions > benefit of drag reduction

cf. snail indeed uses mucus secretion for locomotion

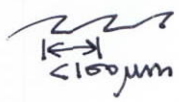
* surface heating e.g : cetacean

mech : μ_{water} ↓ as T ↑

drag on hot surface < drag on cold surface

* surface morphology

e.g. ridging characteristics of dermal scales of sharks



mechanism : reduction of skin friction
not postponement of separation

physical evidence : riblets 
on racing yachts, airplane wings.

* Drag - based locomotion e.g. mammals, birds, arthropods

- appendage moving back and forth
  - drag in power stroke > drag in recovery stroke
- drag reduction in recovery stroke
  - : appendage folded or twised
    - ~ close to body, parallel to flow
  - setae lie back
- drag increase in power stroke
  - : appendage (setae) stick out