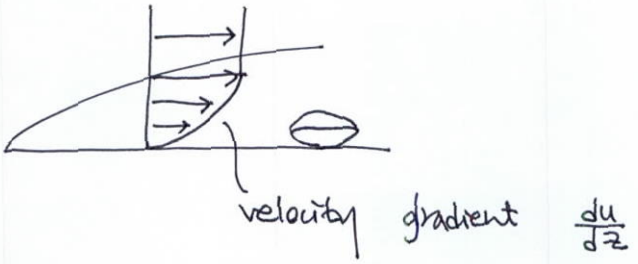
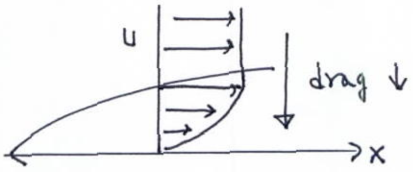
Chap. 9. Life in Velocity Gradients



good	bad
· hiding place from drag	· barrier to exchange of materials and energy
· insulation	· impede heat loss (overheating) : leaves
· mechanical protection from the impact of material carried by flow	· detrimental deflection of edible particles around the filter
	· flow-dispersed seeds, spores, and spiderlings travel less far

§ Drag in boundary layer



linear approximation of $u(z)$

$$\frac{u}{U} = 0.32\, z \sqrt{\frac{\rho U}{x\mu}} \qquad (8.4)$$

$$u \sim U^{3/2}$$

for bluff body at moderate Re.

$$F_D \sim u^2 \sim U^3$$

· speed-specific drag $\frac{F_D}{U^2} = U^{1.0} = E.$

* The torrential fauna

: inhabitants of streams where $U \gtrsim 0.5$ m/s

Fig. 9.1. in general, dorso-ventrally flattened

~ need to consider drag / life together

↓ ↓

e.g. significant separation behind mayfly nymph, freshwater limpet)

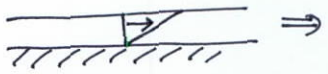
→ life ↓ despite increase of drag.

* Analogs of torrential fauna

- ectoparasites of fast swimmers such as whales.
  (barnacles, whale lice)
  이
- feather mites of some large seabirds
  진드기

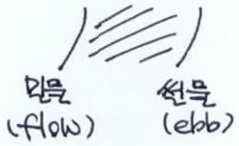
* Sheets of water with really extreme gradients

- on beach / rock face



- Beach : swash-riding

e.g. clam 대합조개 (Donax variabilis) : intertidal



(swash ~ carried upbeach in chaotic flow
(back wash ~ move down the beach without significant tumbling

: severe separation / downward life

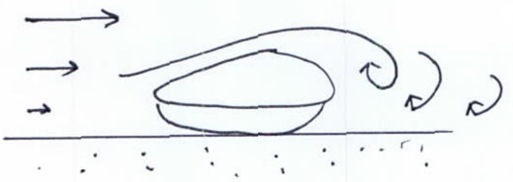


Fig. 9.2

§ Settling down in a velocity gradient

* Larval recruitment

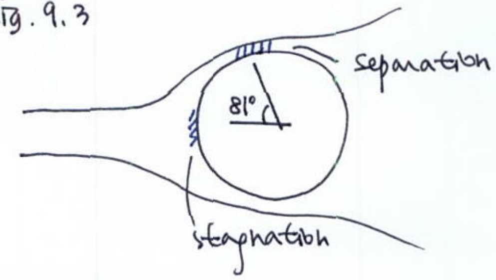
- selection of attachment site : free-stream velocity irrelevant

  e.g. barnacle cyprid : shear rate $50\ s^{-1} \sim 400\ s^{-1}$

  $100\ s^{-1}$: optimal

  e.g. black fly larvae : greatest velocity gradient along the lengths of their bodies

Fig. 9.3



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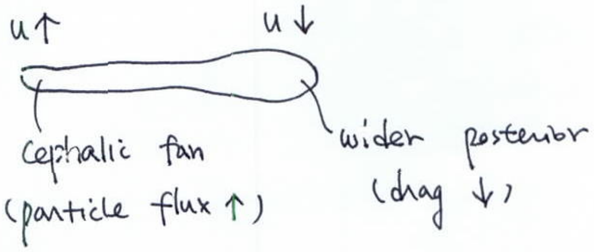


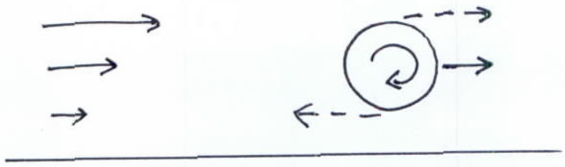
- a larva explores surface before attachment

  settlement rate ↑ as (roughness ↑

  $\frac{U_{settling}}{U_{shear}}$ ↑)

§ More direct effects of shear

- velocity gradient ~ make an object rotate



e.g. off-axis blood cells rotate as flowing along in small vessels

rapid rotation of cells / eggs ~ centrifugal disruption

§ Suspension feeding and local currents

* why suspension feeding in velocity gradient.

(1) u ↓ near the surface to facilitate attachment

u ↑ farther away to provide ample supplies of food

(2) maximizing rates of fluid processing

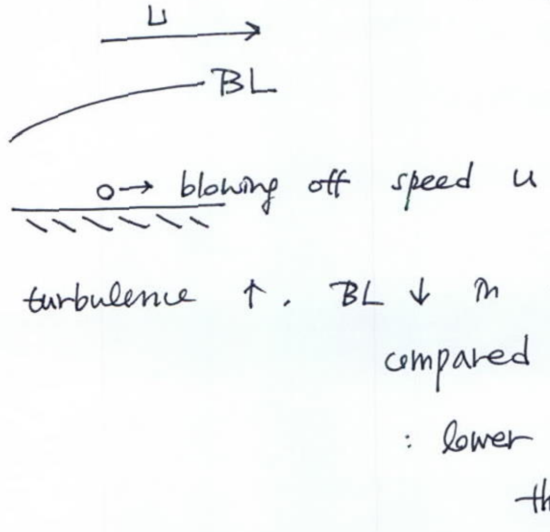
preventing processed. fluid from reentering the separator

~ jet

§ Dispersal and velocity gradients as barriers

* requirements for passive dispersal of propagules (spores, pollen, seeds)

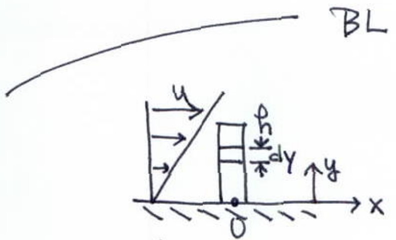
- low sinking rate (high drag)
- life production
- upcurrent detection
- density reduction
- crossing velocity gradient (getting liberated into the current ↗
  alighting on a surface ↘



$U \gg u$

turbulence ↑, BL ↓ in nature compared to wind tunnel

: lower U required than ideal situation (unperturbed)



$$+\circlearrowright \ \Sigma M_o = \int_0^h f_d \, w \, y \, dy$$

f_d : drag force per area $= fn(u)$

$$\xrightarrow{+} \ \Sigma F_i = \int_0^h f_d \, w \, dy$$

elasticity

$q = EI\, v'''' = f_d$

shear force $V = -EI\, v'''$

" at the clamped end : $V(y=0)$

stresses σ / τ → Mohr circle ...

* Ballistic mechanisms for wind-dispersal of seeds or spores

- aerodynamic specialization of projectiles
  : stability in flight
  limiting tumbling
  low drag along the flight direction
  → streamlining (paper introduced)

* Settling mechanisms for effective dispersal by ambient fluid motion

- aerodynamic specialization
  : high drag for slow settling
  ← small size, low density

* shooting a spore (microprojectile) experiencing severe drag

$\frac{F_{Drag}}{F_{gravity}} \uparrow$ — $\alpha \downarrow$ for greater horizontal range

e.g. fungus, Sordaria . Fig. 9.6

§ Diffusion across the velocity gradients at surfaces

* In every transport phenomenon (heat, momentum, mass, ...)

$$q \sim \frac{k}{\delta_T}\Delta T$$

$$\tau \sim \frac{\mu}{\delta_M}\Delta u$$

$$J \sim \frac{D}{\delta_c}\Delta c$$

· if diffusion alone, $\delta \sim \sqrt{Dt}$: too slow

$$\delta_M \sim \delta_T \sim \delta_c$$

$$\frac{\delta_M}{x} \sim \frac{1}{Re_x^{\,n}}$$

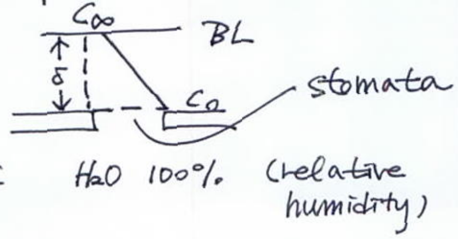
as $Re_x \uparrow$ ~ $\frac{\delta_M}{x} \downarrow$ ~ $\left(\begin{array}{l} \frac{q_{conv}}{q_{cond}} \uparrow \\ \frac{\tau_{conv}}{\tau_{diff}} \uparrow \\ \frac{J_{conv}}{J_{diff}} \uparrow \end{array} \right.$

(convection)

stirring effect.

§ Will diffusion across a velocity gradient limit a process

e.g. transpirational water loss from leaves



$$\dot{m} \approx \frac{D}{\delta}(C_0 - C_\infty)$$

· when stomata are open :

$U_{wind} \uparrow \; - \; \delta \downarrow \; - \;$ water less ↑

· when stomata are closed ,

stomata resistance $\gg$ BL resistance

$\uparrow$

" rate-limiting process "

U_{wind} has little effect

· further consideration .

H_2O vaporization $\propto T$

$U_{wind} \uparrow \; - \left(\begin{matrix} \delta \downarrow \\ T \downarrow \end{matrix} \right.$ if this is more significant, transpiration reduced.

§ The minute currents that matter in water

* diffusion coefficients of small molecules

D in water $\sim 10^{-4} \cdot D$ in air

e.g. alveolus in lung
(hollow cavity, primary site of gas exchange with blood)

→ diameter of alveolus ≃ (100) diameter of pulmonary capillary

$A_{alv} \approx 10^4 A_{cap}$

$J_{gas} \sim A D \Delta C$

* Cutaneous respiration in amphibians

: submerged for long periods

external velocity gradient ~ significant resistance

eg) in still water, bullfrogs do spontaneous, undirected motion

e.g. salamenders (도롱뇽).

in low flow rate ~ reduce their metabolic rates

§ The "unstirred layer"

≈ laminar boundary layer near a surface

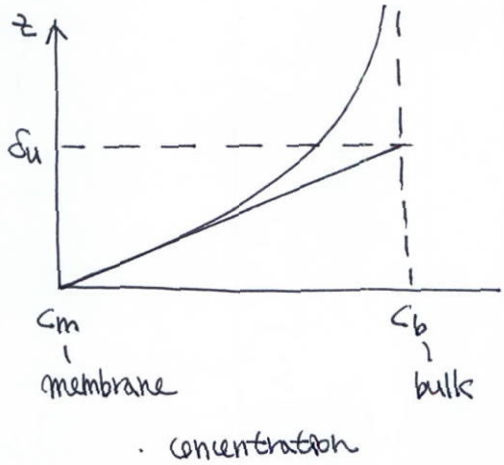


Fig. 9.8

thickness of unstirred layer $\delta_u = \dfrac{C_b - C_m}{(dC/dz)_m}$.

for Blasius boundary layer ⇐ eq (8.4)

$\delta_u \simeq 0.6\ \delta_{99\%}$.