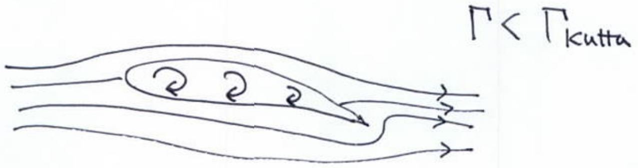
Chap. 11. Lift, Airfoils, Gliding and Soaring

§ Circulation and airfoils

- airfoil (Lanchester) : a device that can produce circulation
  in its vicinity without itself
  actually rotating

- Kutta condition



best simulates a real airfoil

$\Gamma \sim U$

$F_L \sim U^2$

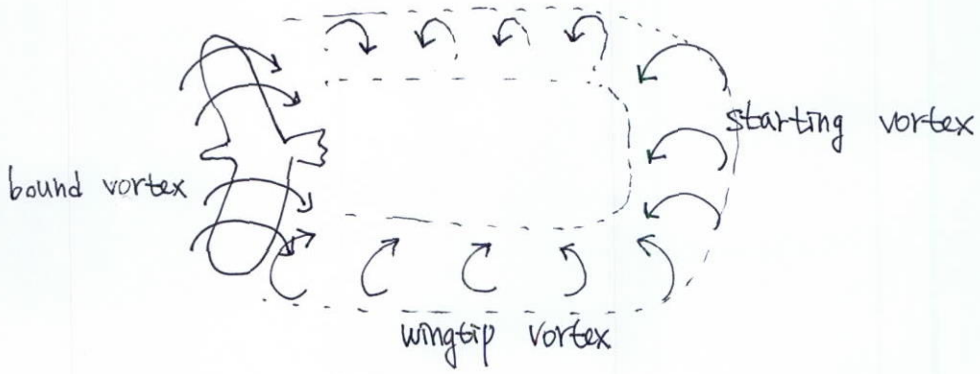
Fig. 11.2

* features of airfoil

- contour of upper surface more important than that of
  lower surface in lift producing
- flat lower surfaces work aerodynamically about as
  well as concave ones
- sharp trailing edge : crucial for lift generation
  and drag minimization

- rounded leading edge : discourages separation
- center of lift is relatively near the leading edge

* complete vortex ring around a gliding aircraft

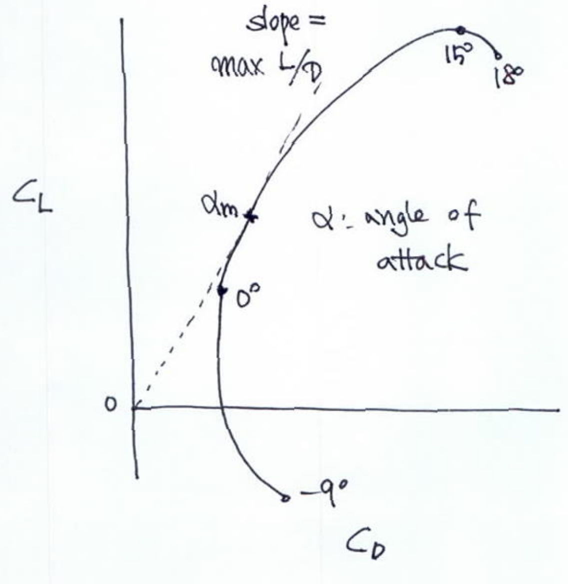


§ Lift coefficients and polar diagrams

$$C_L = \frac{F_L}{\frac{1}{2}\rho U^2 S} = fn\,(Re,\ shape,\ orientation)$$

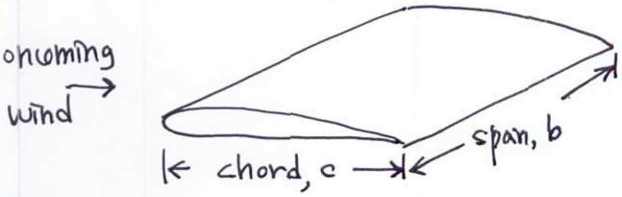
S : plan form area

- polar diagram (Fig. 11.4)



§ What determines airfoil performance ?

(1) Aspect ratio



$$AR \equiv \frac{b}{c}$$

for organisms,

$$= \frac{b^2}{area}$$

(area = bc)

high AR :

low AR :

2-D airfoil : AR → ∞

real wing : AR finite

~ poorer aerodynamically than 2-D airfoil

less life, more drag

: tip vortices

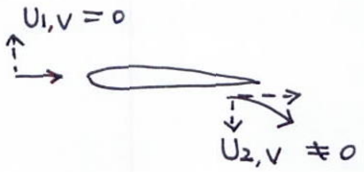
(2) The cost of life

- jet propulsion

Froude propulsion efficiency

$$\eta_f = \frac{P_{out}}{P_{in}} = \frac{\dot m U_1 (U_2 - U_1)}{\frac{1}{2}\dot m (U_2^2 - U_1^2)} = \frac{2U_1}{U_2 + U_1}$$

ideal fixed wing :



$\eta_F = 0.$

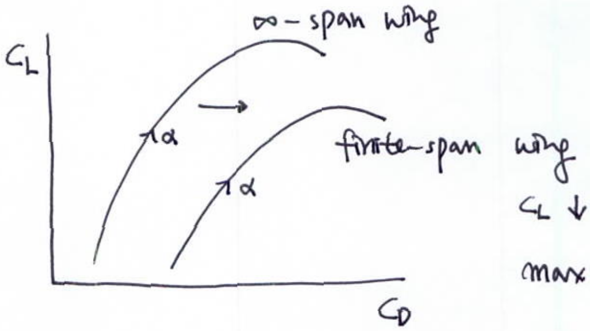
use no energy to stay aloft.

(3) Induced drag

- infinite-span wing.

- finite-span wing

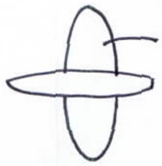
in polar diagram



$C_L \downarrow$, $C_D \uparrow$

max $L/D \downarrow$

for a given AR, to minimize induced drag



~ wings of low-speed aircraft

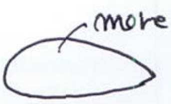
natural airfoils (lift + thrust)

: tapered + tips swept back

Fig. 11.6

(4) Body lift

bodies of many flying animals :



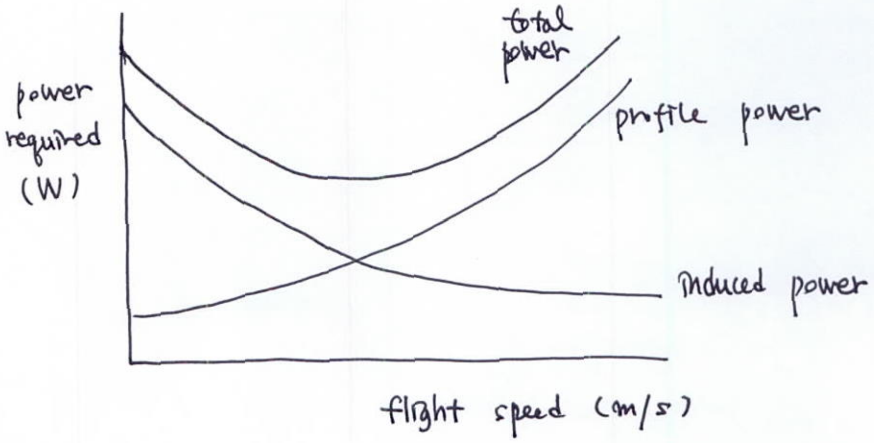
important for (swooping flight (wings folded, close to body)
(extending flight of ski jumpers

(5) profile drag = pressure drag + skin friction

profile drag $\propto$ angle of attack

U^2

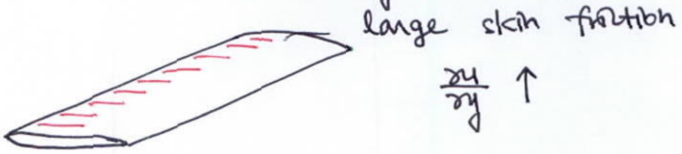
Fig. 11.7.



· for low Re (< 1000),

$C_D \uparrow$ as $Re \downarrow$ (increasing skin friction)

high AR

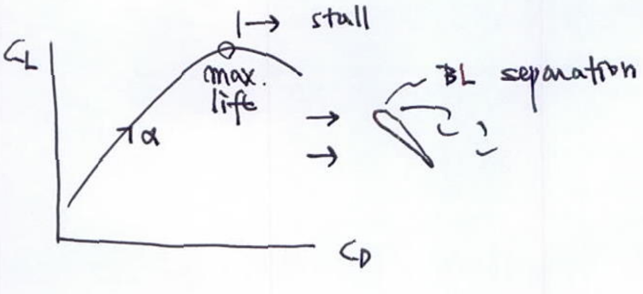


low AR

: small natural gliders (butterfly)

* All the kinds of drag in lift-producing systems

(6) stall



- devices for postponing stall for living fliers
  - alula
  - leading-edge barbs

(7) wing loading

lift control — changing α
adjustment of wing area
(during flapping cycle of virtually all birds and bats)

- wing loading $\equiv \dfrac{\text{weight of craft}}{\text{wing area}}$ $(\sim L^3)$ $(\sim L^2 U^2)$

slow craft (people-pedaled plane, 5~6 m/s)
: large wing ~ 20 N/m²

fast craft (B747, 240 m/s)
: small wing ~ 6000 N/m²

(8) The effects of Re

Re ↓ (effect of viscosity ↑)

: max L/D ↓
stall angle ↓

- possible (?) mechanism to improve aerodynamic performance

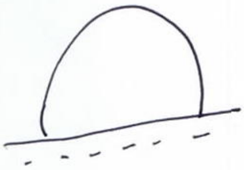
insect wings ~ corrugated (veins)
: greater stiffness to light structures
any effects on C_L, C_D ?

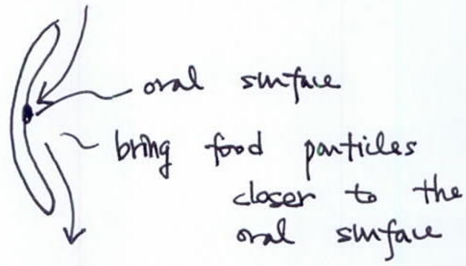
(9) The limits of circulation

for low Re, theory of circulation no longer valid

§ More on biological airfoils

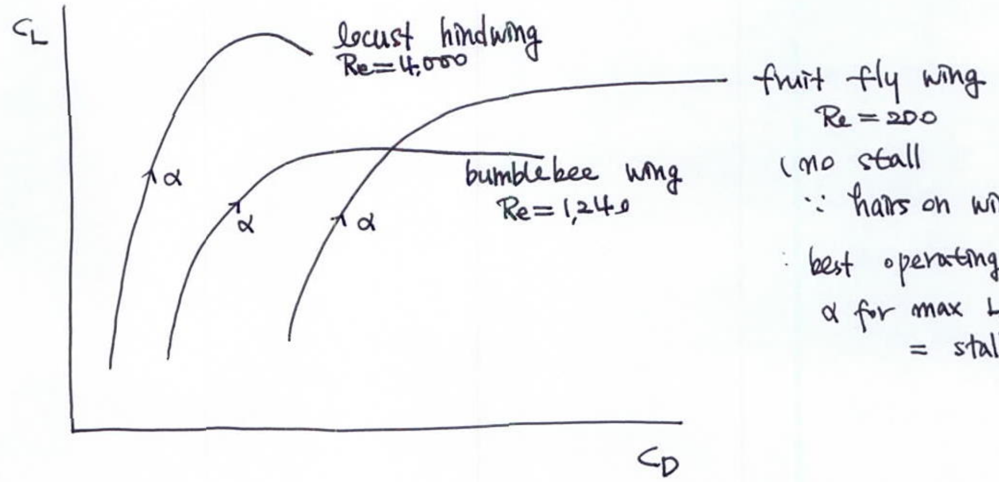
(1) A lift-producing sand dollar





(2) Wings.

Fig. 11. 9 polar plots for several insect wings



(no stall
∵ hairs on wings ?)

∴ best operating pt
α for max L/D
= stall pt.

as Re ↓ — C_D ↑ due to increased profile drag

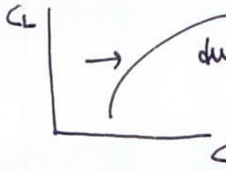
α for max L/D ↑

Table 11.1. : should be able to read the table

(3) Lifting bodies

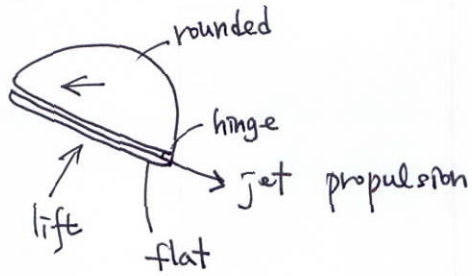
e.g. gliding phalanger (flying squirrel)

: very low AR



due to increased induced drag

e.g. scallops

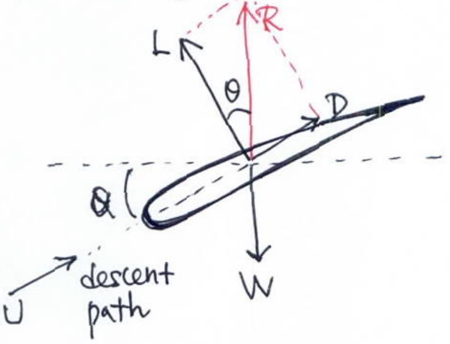


e.g. velella ~ sailboat

§ Gliding and soaring

: free ride from gravity and atmospheric motion

(1) How to glide



$\downarrow g$

$R = W$

glide angle θ. $\cot\theta = \frac{1}{\tan\theta} = \frac{L}{D} = \frac{C_L}{C_D}$

to minimize θ → maximize L/D

· how to obtain C_L & C_D on freely gliding birds.

θ, U, S (wing area), W

$\Rightarrow W\cos\theta = L$

$$\Rightarrow C_L = \frac{L}{\frac{1}{2}\rho U^2 S}$$

$\Rightarrow C_D = C_L \cdot \tan\theta$

· sinking speed U_s.

$$\sin\theta = \frac{U_s}{U}$$

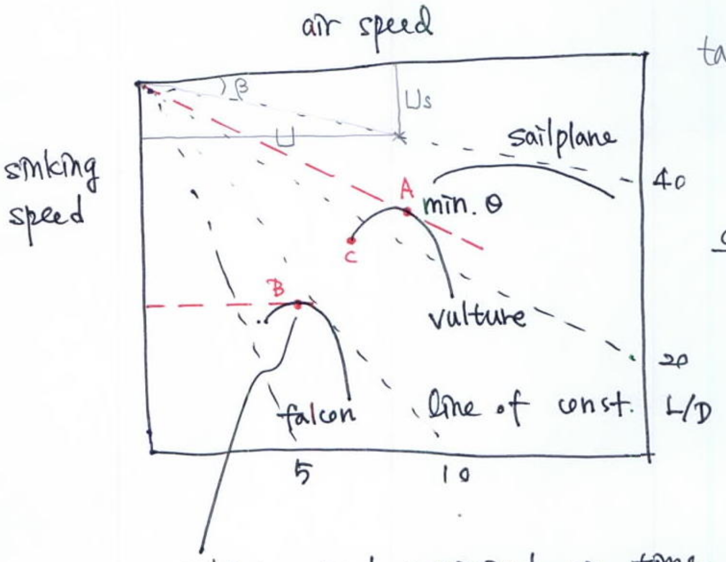
	albatross	phalanger	sailplane
$\cot\theta = \frac{L}{D}$	18	2	39

- high Re regime ~ AR ↑ – θ ↓ – L/D ↑

  : gliding animals are fairly large

(2) The glide polar

Fig. 11.12



$$\tan\beta = \frac{U_s}{U} = \sin\theta$$
$$= \sin\left(\cot^{-1}\frac{L}{D}\right)$$

$$\frac{C_L}{C_D} = L/D$$

sinking speed minimized → time aloft max.

pt. C : min. glide speed ~ U_{min}

$$C_{L,max} = \frac{L}{\frac{1}{2}\rho U_{min}^2 S}, \qquad L = W\cos\theta$$

$$U_{min} = \left(\frac{2L/S}{\rho C_{L,max}}\right)^{1/2}$$

(3) Gliding and parachuting

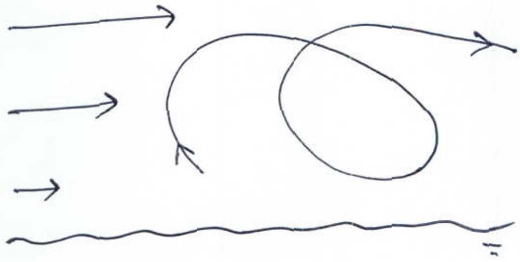
	$\theta < 45°$	$\theta > 45°$
e.g.	flying lizard	arboreal lizard
	flying frog	tree frog
	flying fish	

Fig. 11.13

(4) Soaring

i) static soaring (upward moving air)
- slope soaring
  e.g. hang-gliders
  petrels
  albatrosses
- thermal soaring
- sea anchor soaring
  e.g. petrels ~ kite

ii) dynamic soaring
(no upward air movement
(temporal or spatial velocity gradient in wind
from which an animal extracts the power necessary to stay aloft



Chap. 12. The thrust of Flying and Swimming

§ Thrust from flapping

(1) The origin of thrust

birds, bats, insects with "flapping" wings
≈ helicopter
≠ airplane

· propeller