8d. Aquatic & Aerial Locomotion

Newton's Laws of Motion

First Law of Motion

The law of inertia: a body retains its state of rest or motion unless acted on by an external force.

Second Law of Motion

F = M*a*. (Force = Mass * acceleration). A force gives a body acceleration in the direction of the force.

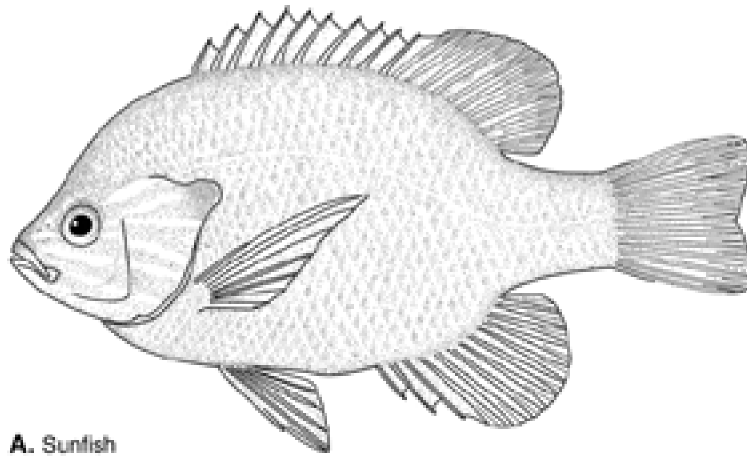
Third Law of Motion

For every action there is an equal and opposite reaction. If one body exerts force on another body, the second body exerts an equal but opposite force on the first.

Forces acting on a Fish in Water

Weight
(pull of gravity)

Drag
(friction or pressure)



A. Sunfish

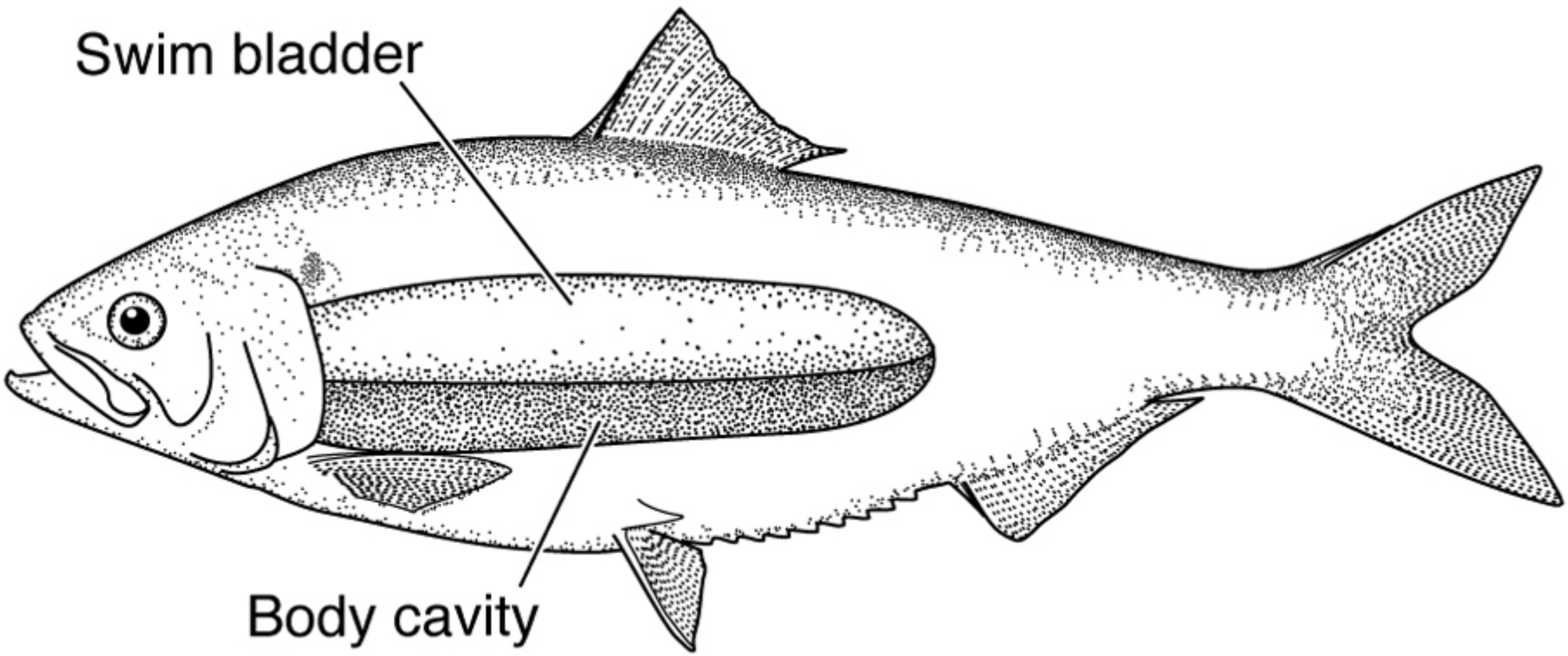
Thrust
(generated by animal)

Buoyancy
(lift of water)

Mass and buoyancy operate all the time.

Thrust is generated by the animal to move. Drag arises when the animal is in motion.

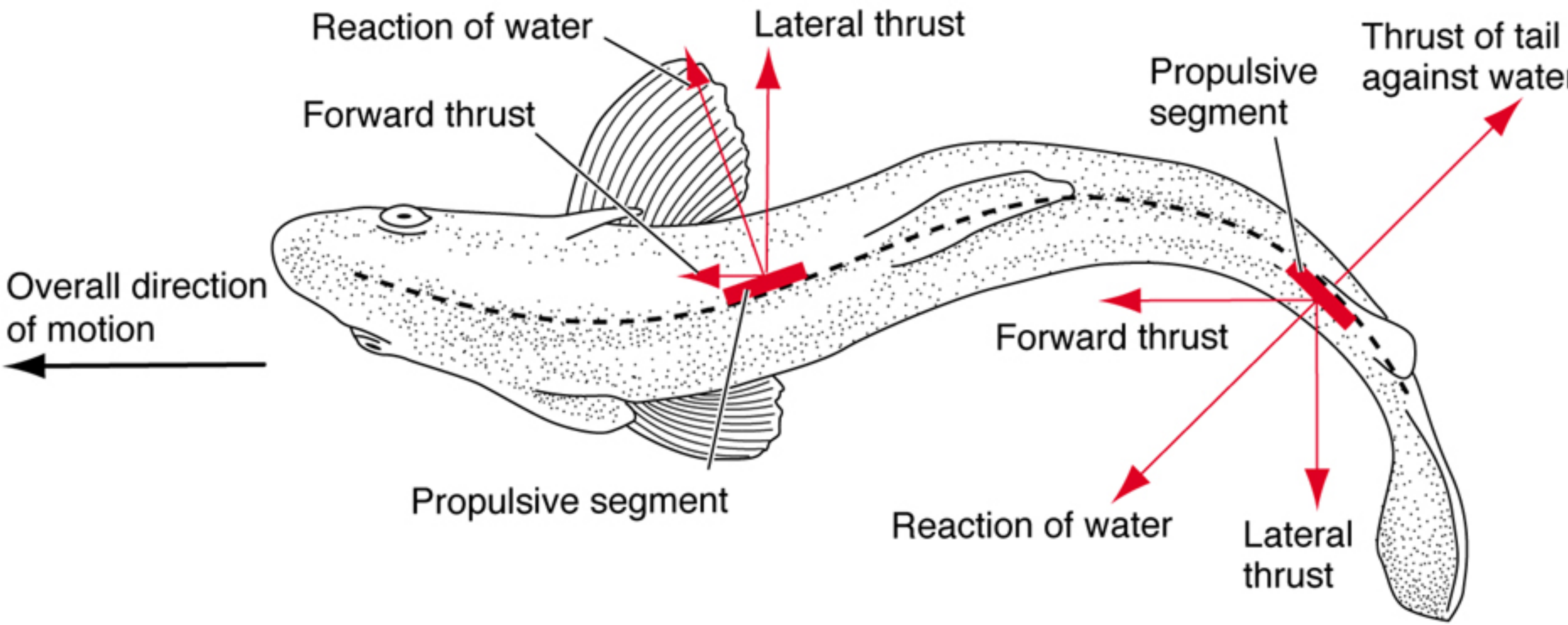
Regulation of Buoyancy in Fishes with Swim Bladders/Lungs



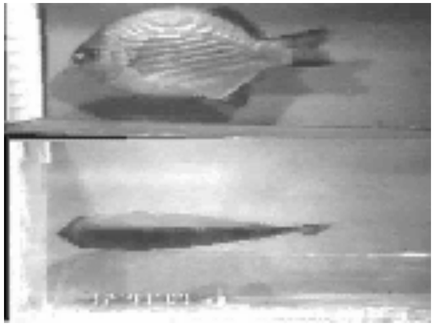
“Flesh” is slightly denser than water, so without generating any lift, a fish will sink. Most living fishes (except chondricthyans) have swim bladders or lungs to regulate buoyancy (by controlling the amount of gas inside).

Neutral buoyancy = having the same average density as water so that animal does not sink or float in the water column.

Generation of force via lateral undulation

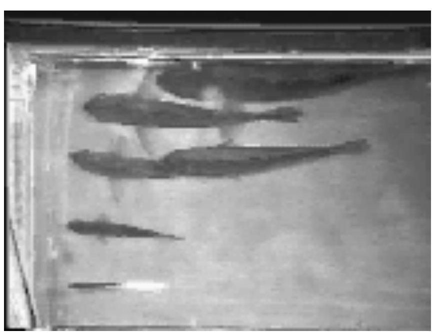


Generating Thrust: Oscillatory and Undulatory movements



Pectoral Fin Oscillation

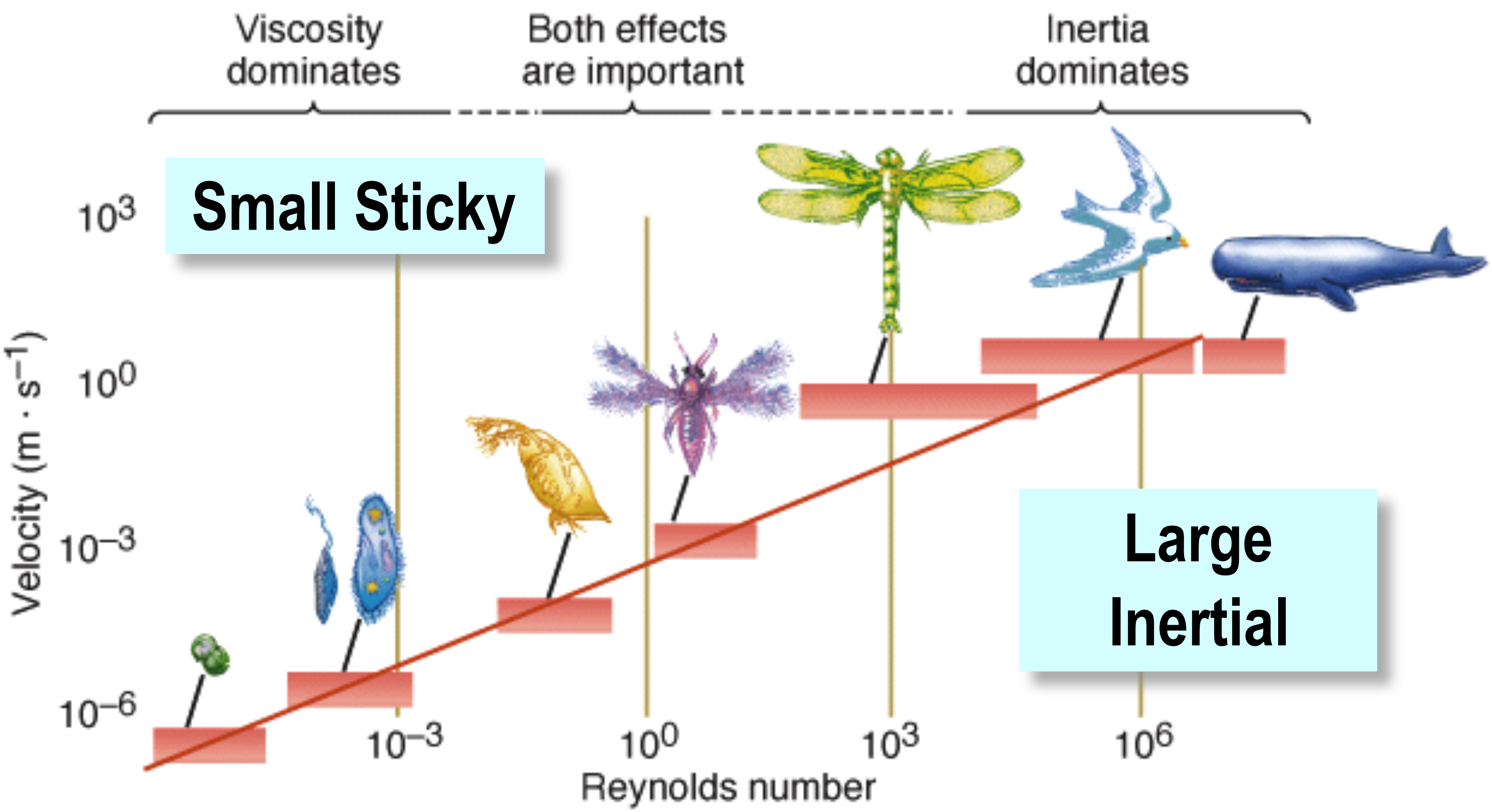
Pectoral Fin Oscillation +
Lateral Undulation



Size, Speed and Swimming Effort

Novel Worlds: Body Size and Media

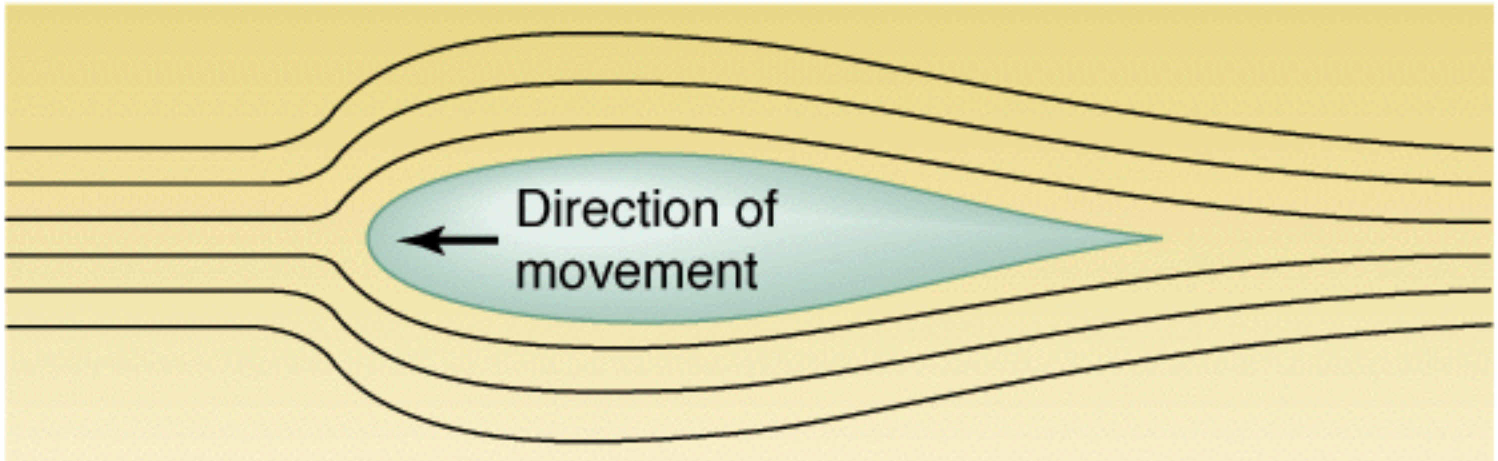
Reynolds Number = density * length * velocity / viscosity



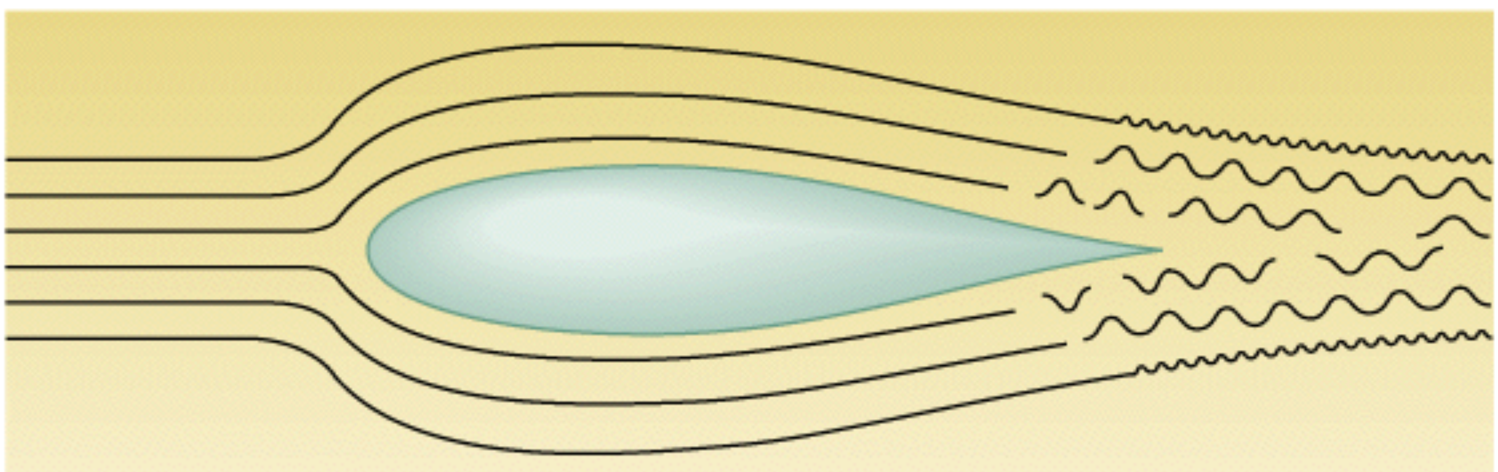
Ratio of inertial forces to viscosity forces or: Re tells us *how important is viscosity*?

The transition from laminar to turbulent flow occurs at an Re of 2000 (Re is a dimensionless number)

Laminar vs Turbulent Flow



Low velocity — laminar flow



High velocity — turbulent flow

Laminar vs. Turbulent Flow

Friction Drag

- Boundary layer of water surrounds moving fish.
- Innermost layer moves at same speed as fish, but outer layers move more slowly, eventually moving same speed as surrounding water.
- Shear forces between adjacent boundary layers cause friction drag.

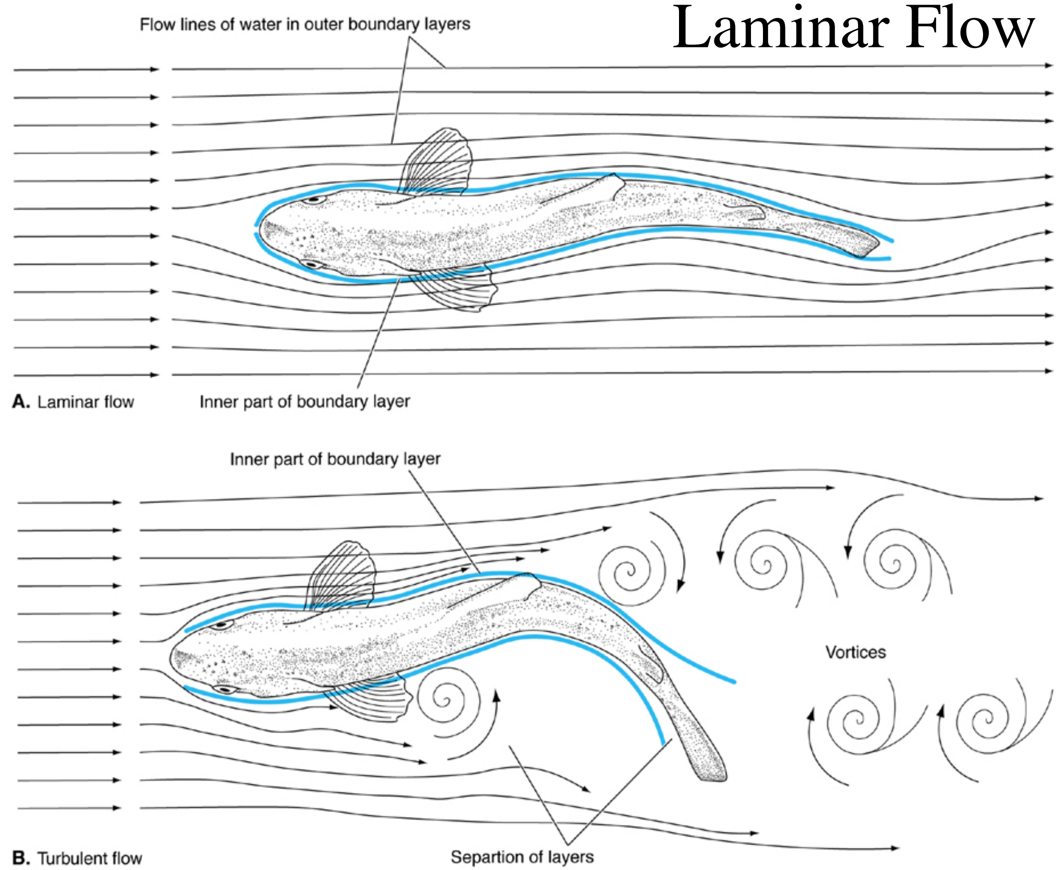
Pressure Drag

- Result from differences in water pressure between front and rear of fish. (often high in front, lower behind -- creates vacuum).

Body Shape and Drag tradeoffs

- Sphere: high pressure drag, low friction drag
- Long, thin body: low pressure, high friction.
- Fusiform shape is best compromise.

Laminar Flow



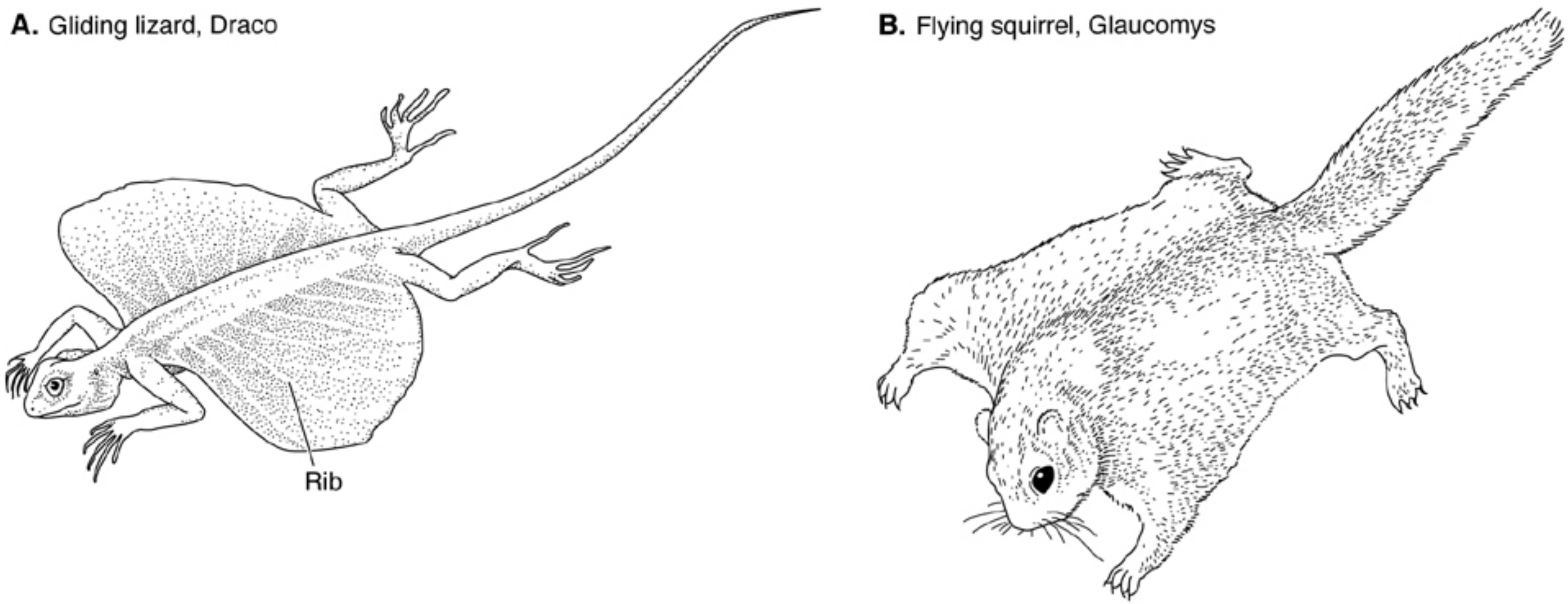
Turbulent Flow

Wake visualization: looking at fluid vortices

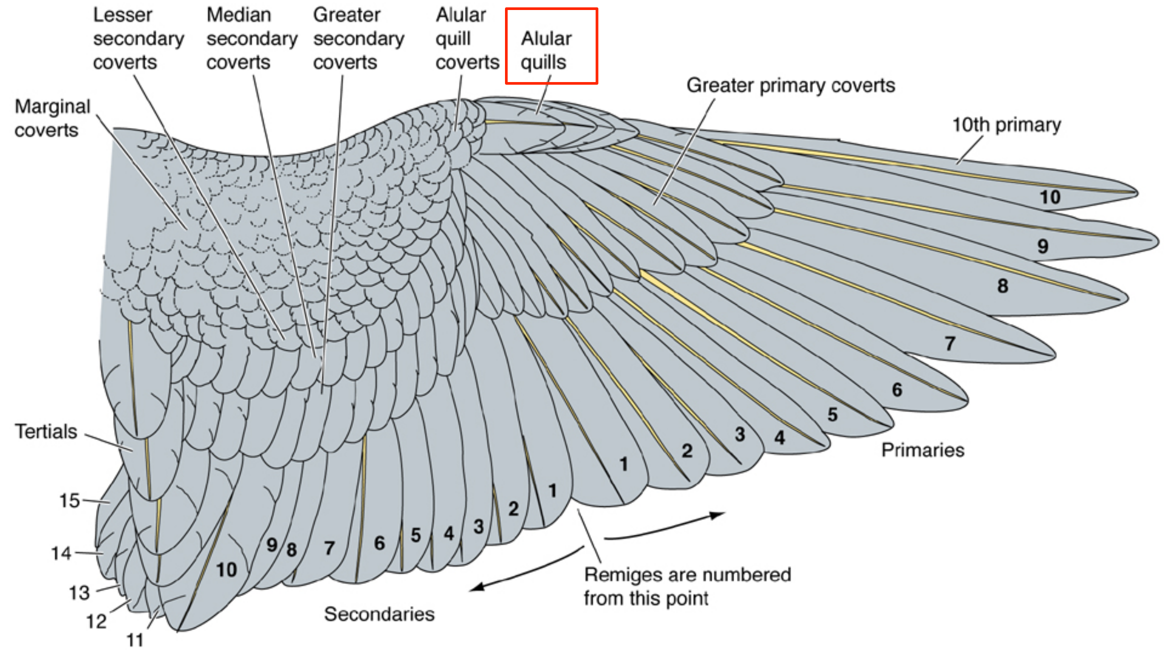
Digital Particle Image Velocimetry

Flight: Swimming through the Air

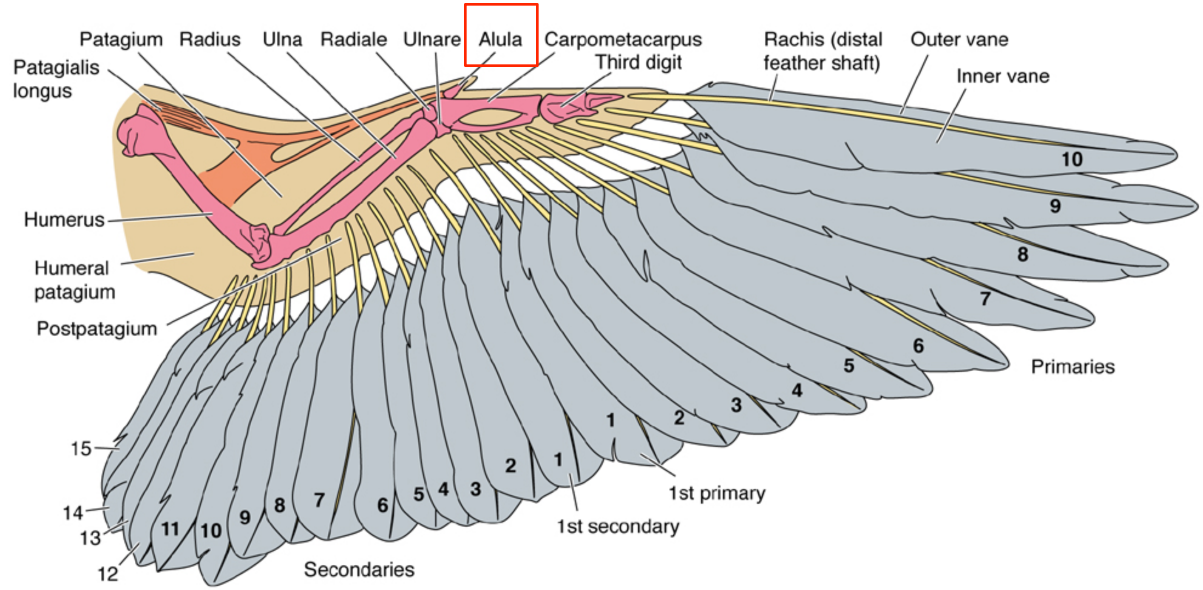
Vertebrate Airfoils: Gliders



Vertebrate Airfoils: Wing for Powered Flight

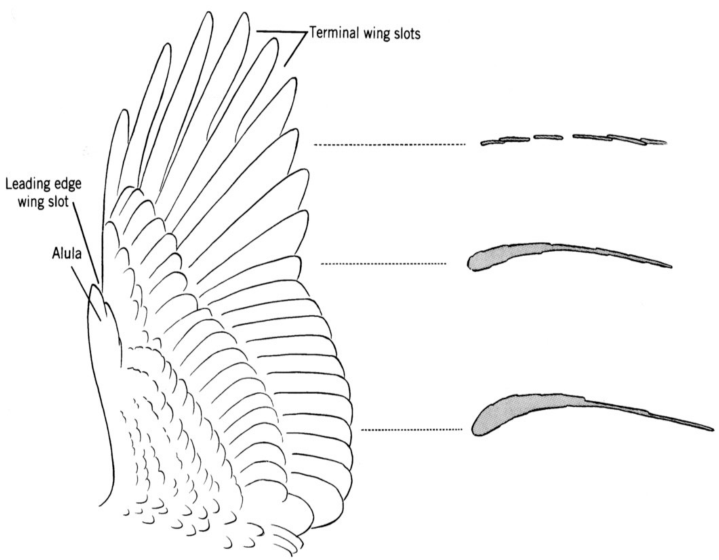


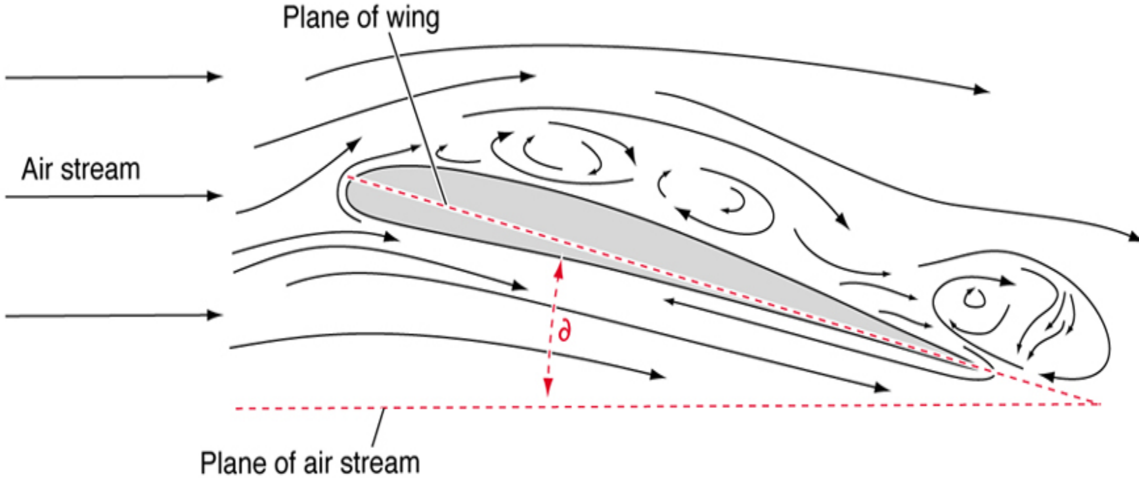
A. Dorsal view of wing surface showing coverts, alular quills and flight feathers (= remiges)



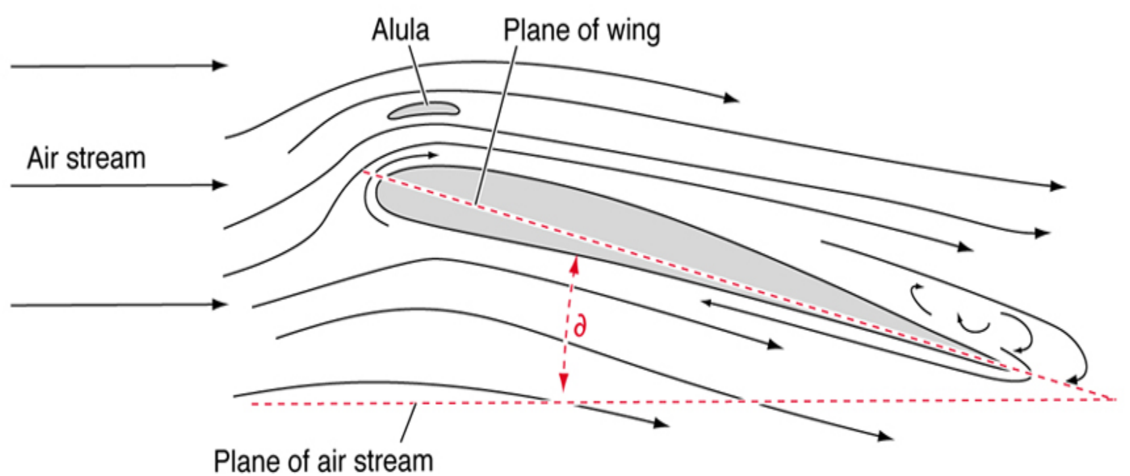
B. Ventral view of wing after removal of covert feathers

Lift and Turbulence





A. A high angle of attack (∂) produces greater lift but also causes lift-reducing turbulence above wing



B. Adding a slot at the front of the wing increases airspeed above the wing and reduces turbulence

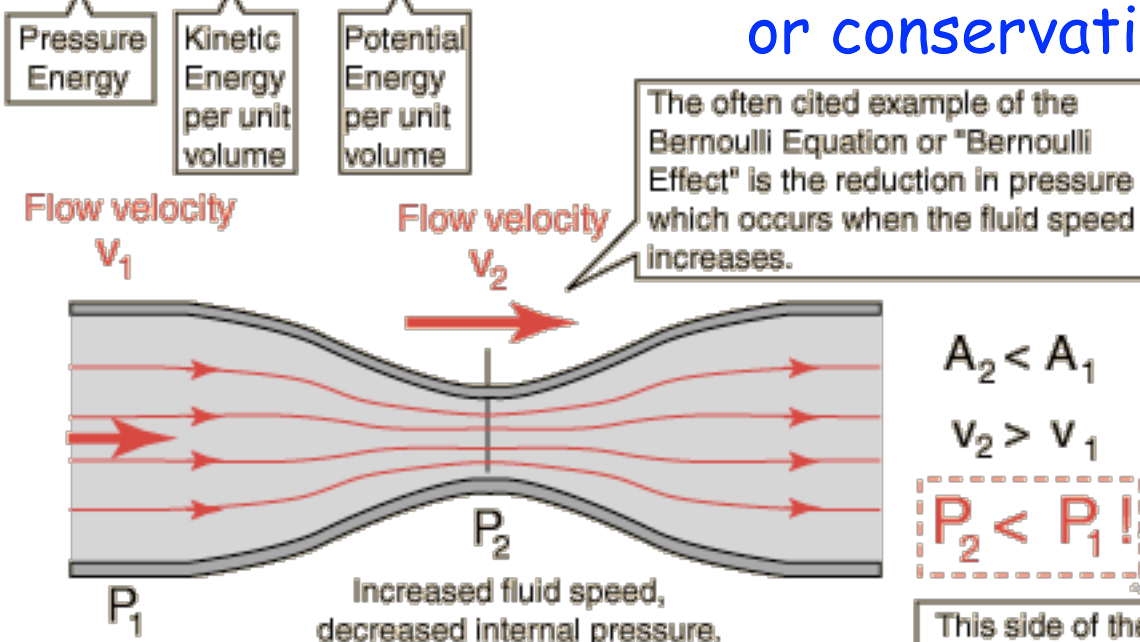
Bernoulli Effect

Bernoulli's Principle states that as the speed of a moving fluid increases, the pressure within the fluid decreases.

Energy per unit volume before = Energy per unit volume after

$$P_1 + \frac{1}{2}\rho v_1^2 + \rho g h_1 = P_2 + \frac{1}{2}\rho v_2^2 + \rho g h_2$$

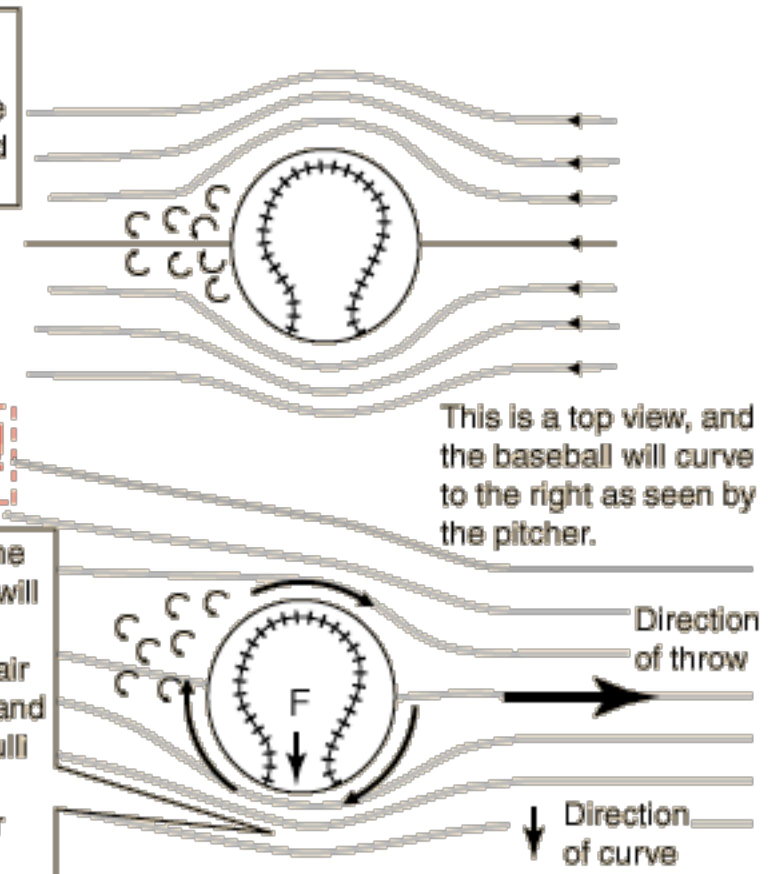
or conservation of energy in fluids!



$A_2 < A_1$

$v_2 > v_1$

$P_2 < P_1$!

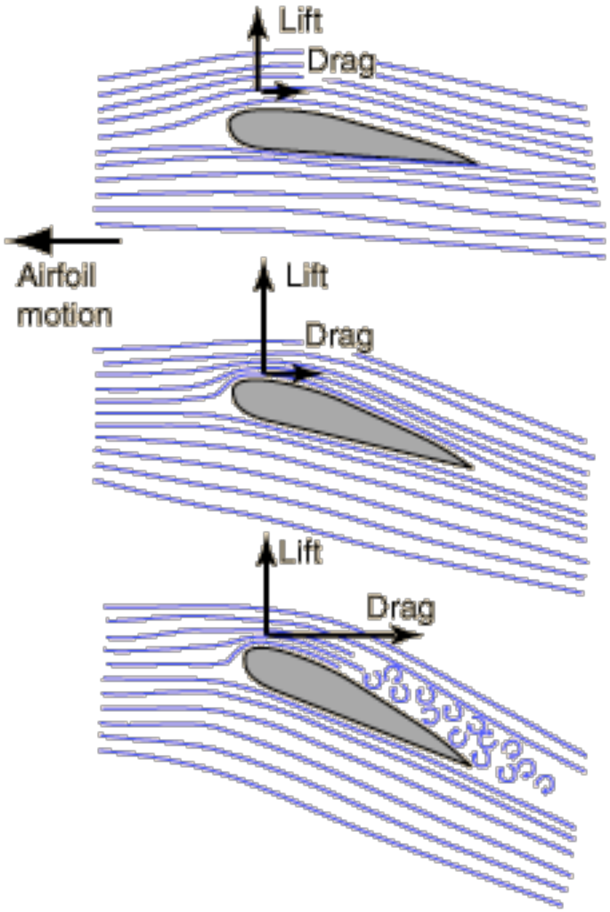


or how to throw a curve ball...

http://hyperphysics.phy-astr.gsu.edu/hbase/pber.html

https://www.youtube.com/watch?v=kWhMYc8JSP8

Bernoulli Effect



Shape of airfoil is important. Top must have “hump” so that air moves faster over the top than the bottom.

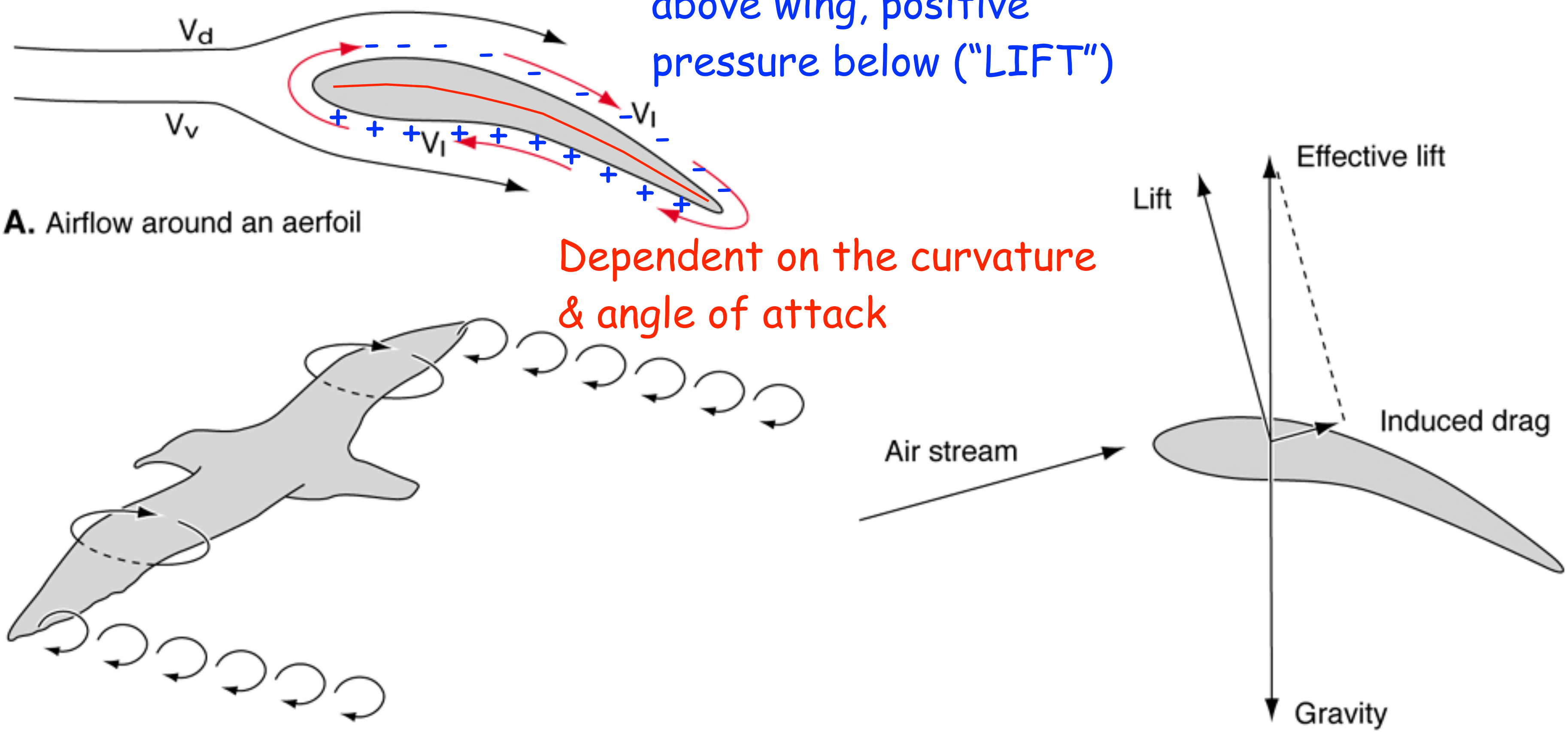
Increasing angle of attack increases lift.

But too great an angle of attack and turbulent flow increases drag too much -> *get stall.*

http://hyperphysics.phy-astr.gsu.edu/hbase/pber.html

Lift: Circulation around the wing

Generates negative pressure above wing, positive pressure below ("LIFT")



A. Airflow around an aerfoil

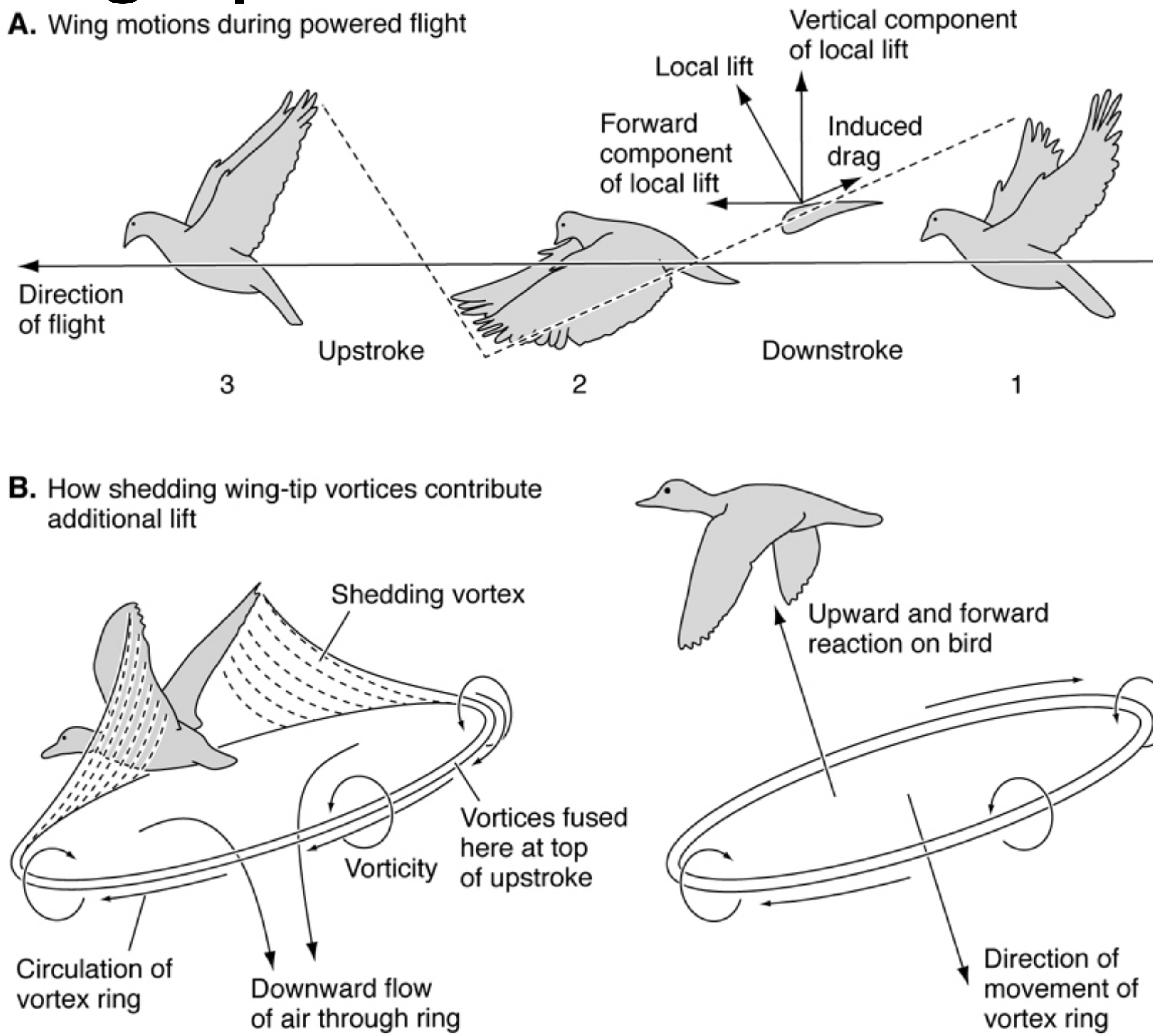
Dependent on the curvature & angle of attack

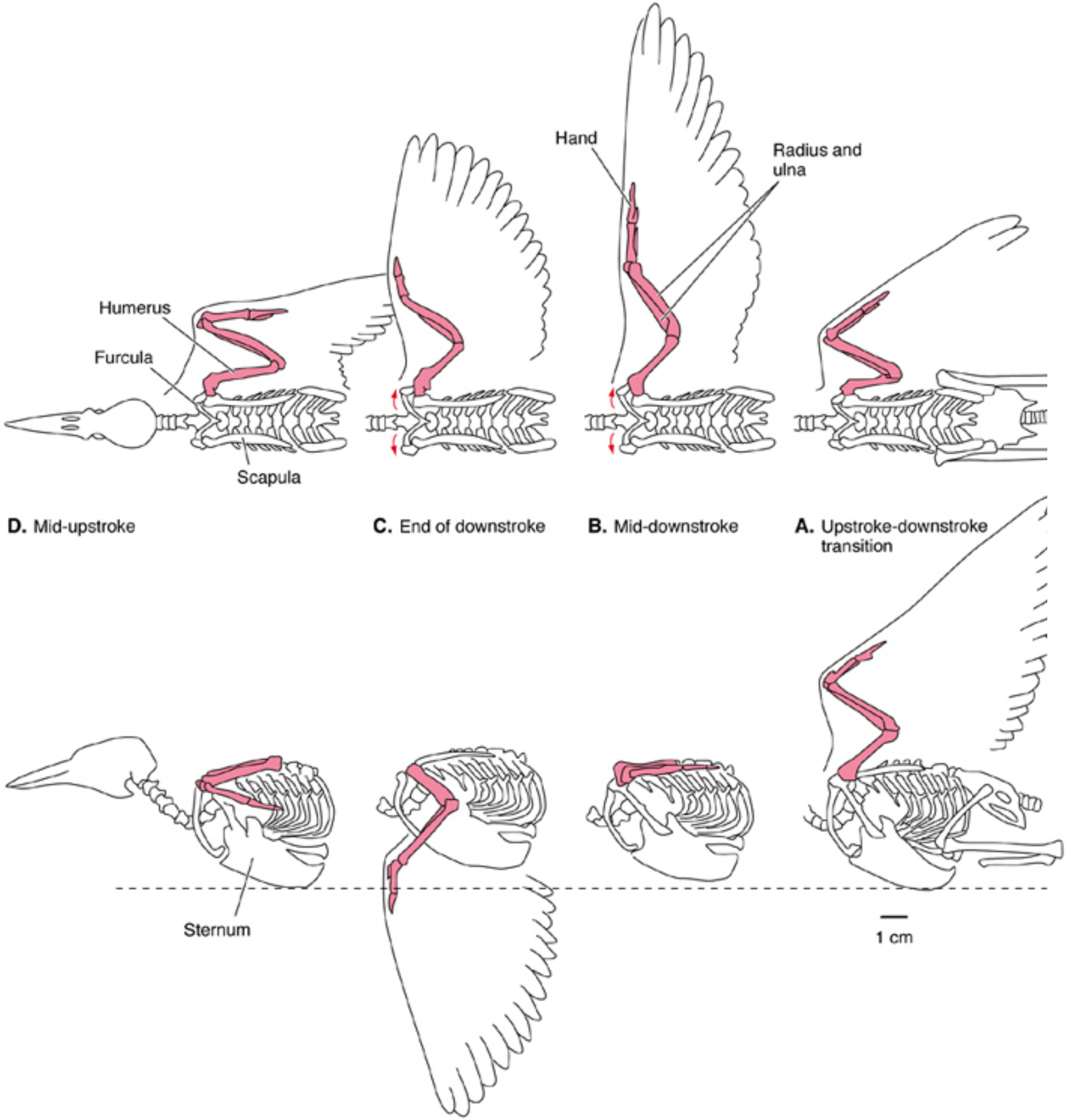
B. Shedding of induced flow as wingtip vortices

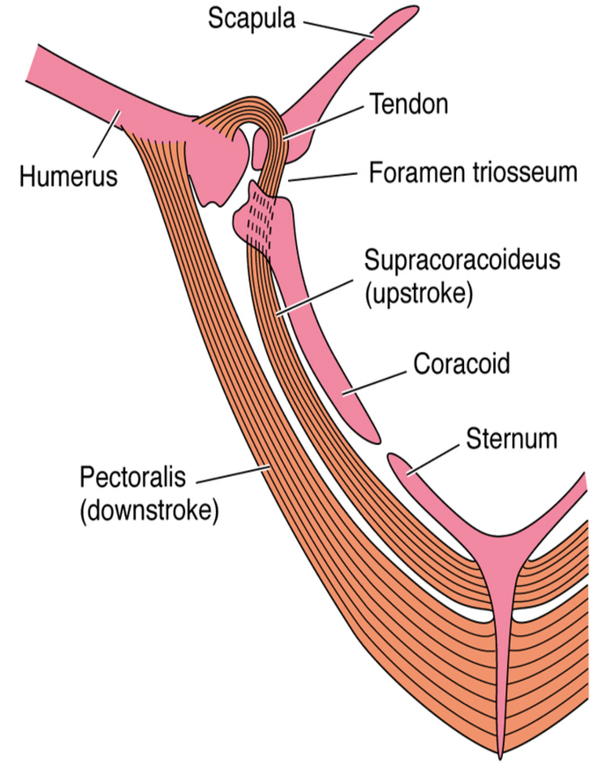
C. Resolving lift vector into effective lift and induced drag

Turbulence is reduced if the circulation is shed "nicely" as wingtip vortices

Shedding wing-tip vortices can add more lift

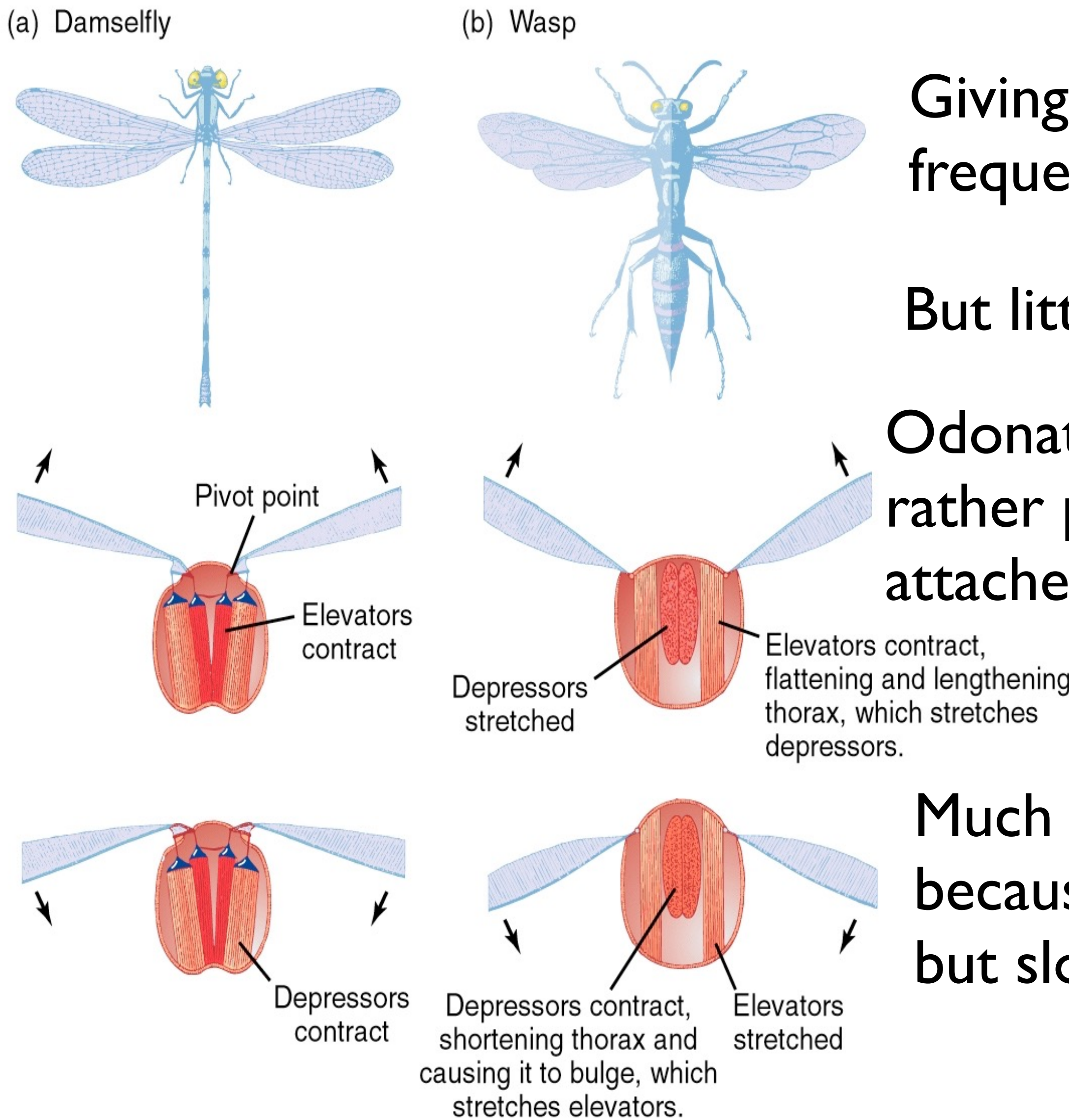



Hand
Radius and ulna
Humerus
Furcula
Scapula
D. Mid-upstroke
C. End of downstroke
B. Mid-downstroke
A. Upstroke-downstroke transition
Sternum
1 cm


Scapula
Tendon
Humerus
Foramen triosseum
Supracoracoideus (upstroke)
Coracoid
Sternum
Pectoralis (downstroke)

Insect Flight

In most insects, flight muscles attached indirectly to wings via thorax.



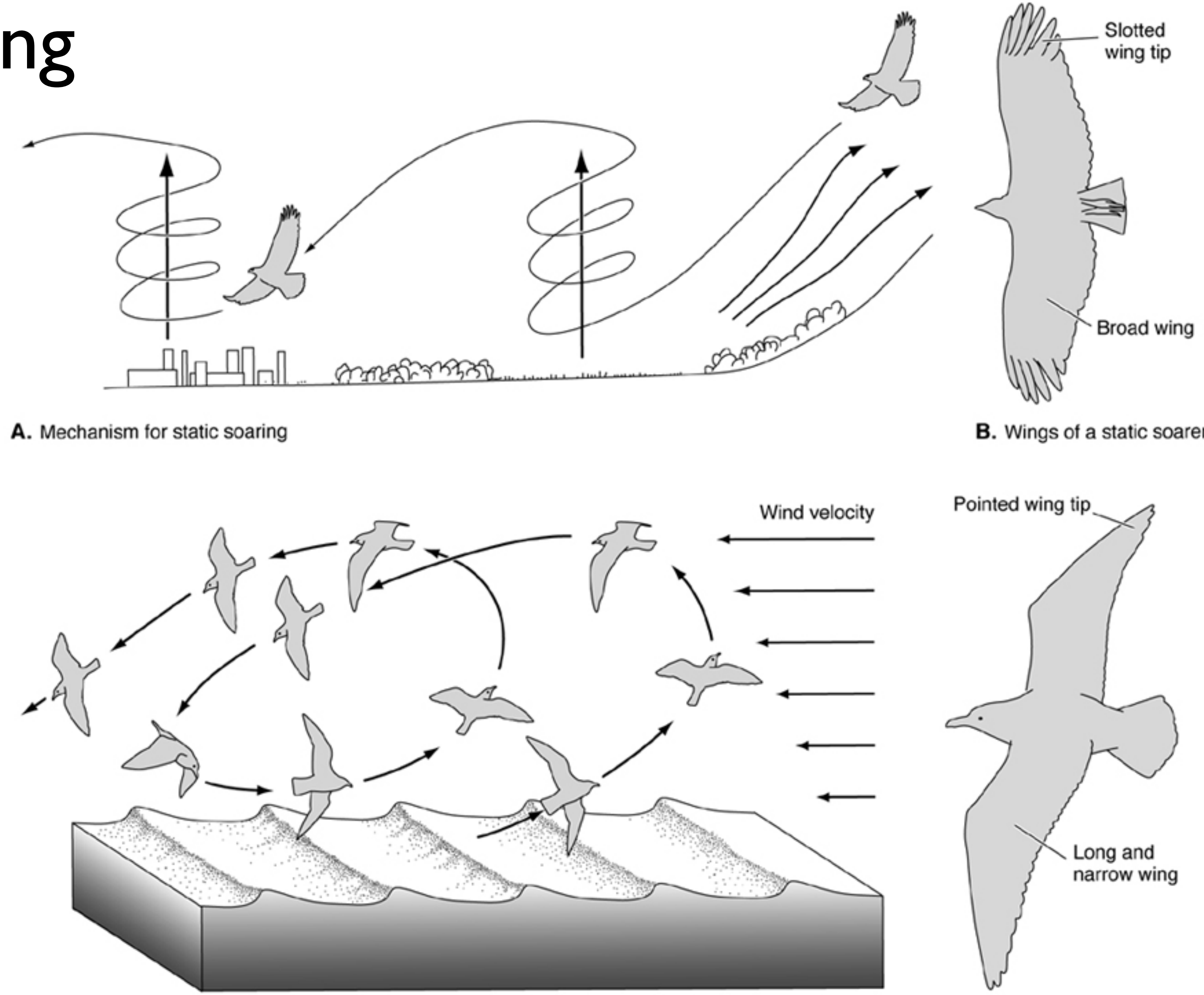
Giving them very high wingbeat frequencies.

But little control other than flapping.

Odonates (dragonflies, damselflies, rather primitive insects), have muscles attached directly to wings

Much better control (important because they are large predators), but slow wingbeats (200/sec)

Soaring



A. Mechanism for static soaring

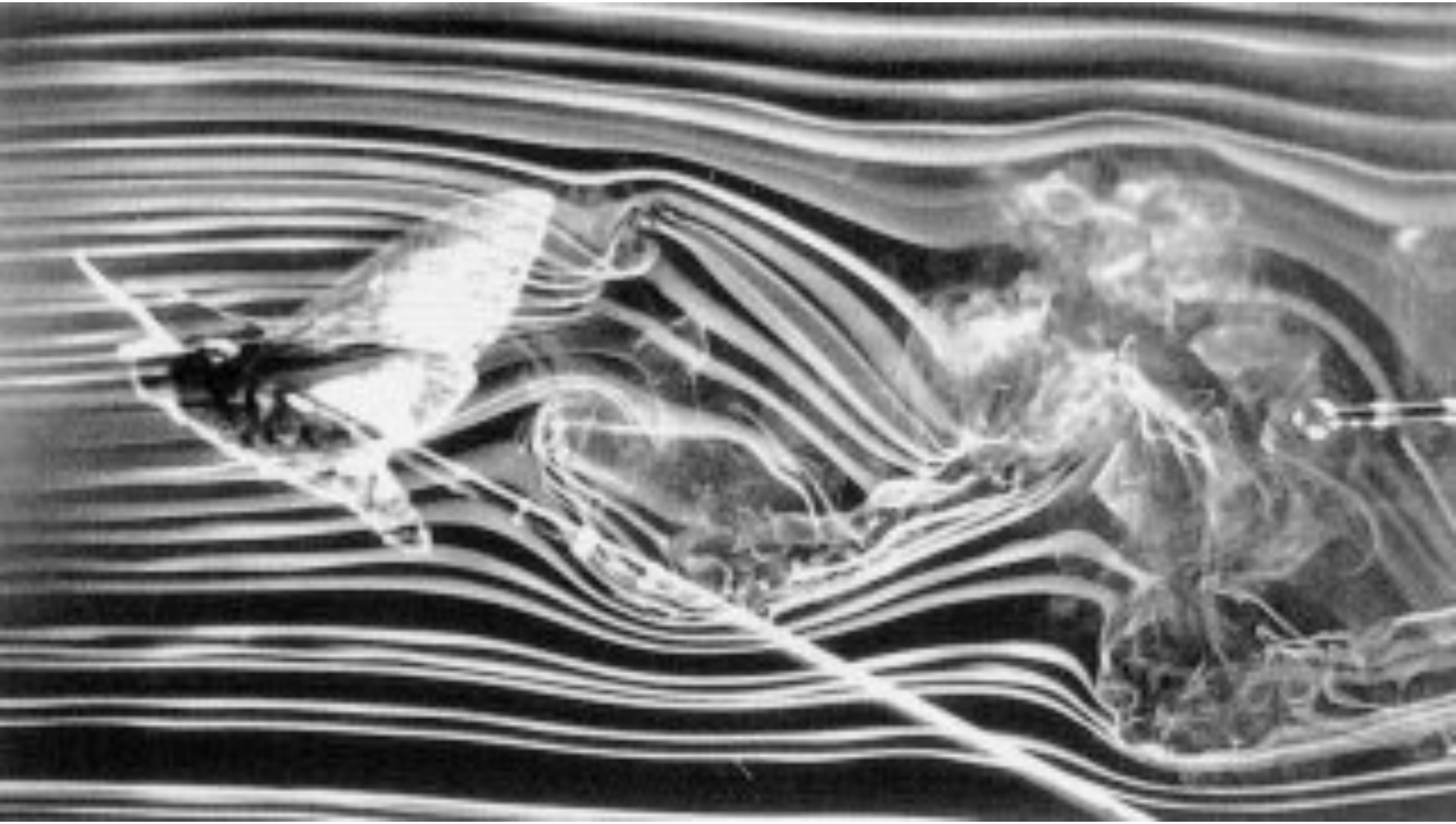
B. Wings of a static soarer

C. Mechanism for dynamic soaring

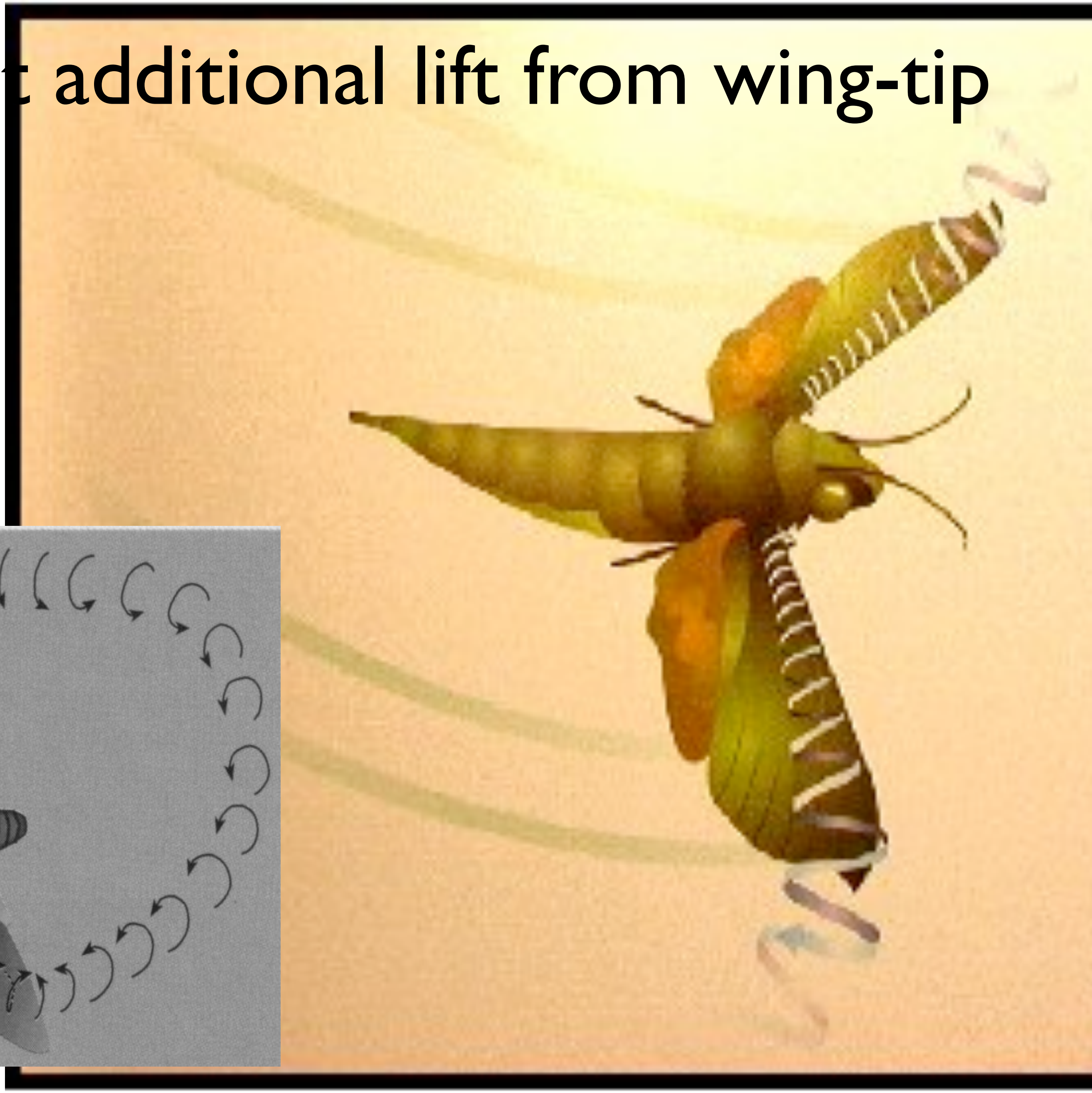
D. Wings of a dynamic soarer

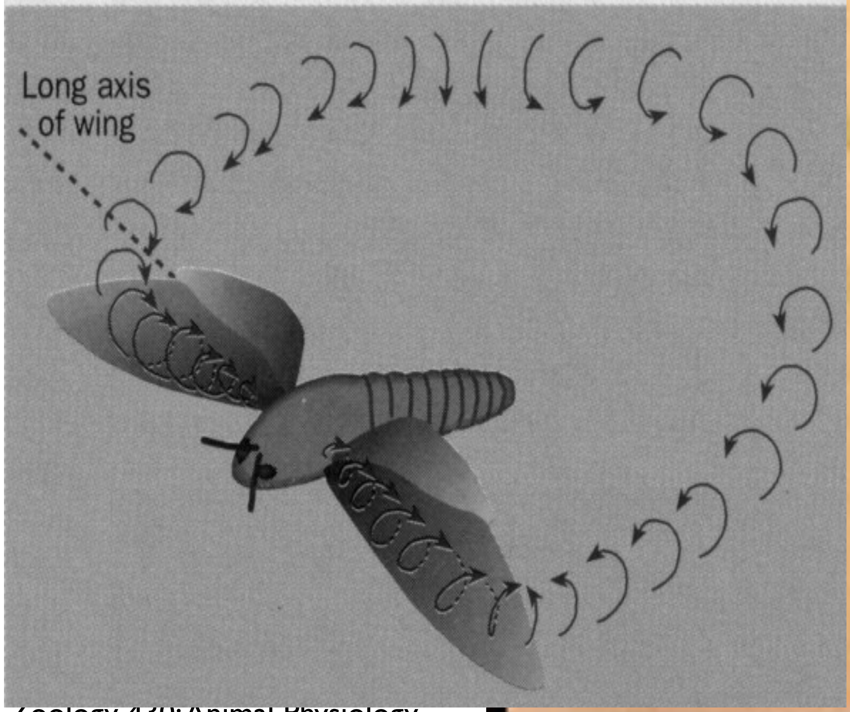
Insects cannot fly according to conventional laws of aerodynamics.

BUT Insect wings are not large enough to get enough conventional lift: Visualize Flow



Insects Get additional lift from wing-tip vortices!





Human Engineers Learn from Animals