Biology 427 Biomechanics
Lecture 21: Flapping Fundamentals

- Reminder: Homework #6 due Friday 11/18

- Review of airfoils: lift and gliding
- Generating thrust
- Flight gaits
- Deformable wings
- Energy considerations
- The evolution of flight

The Forces of Flight: Lift

Lift from Flow Turning

Glenn Research Center

Lift is a force.

Force = mass X acceleration $F = m\,a$

Force = mass X change in velocity with time $F = \frac{m\,(V_1 - V_0)}{(t_1 - t_0)}$

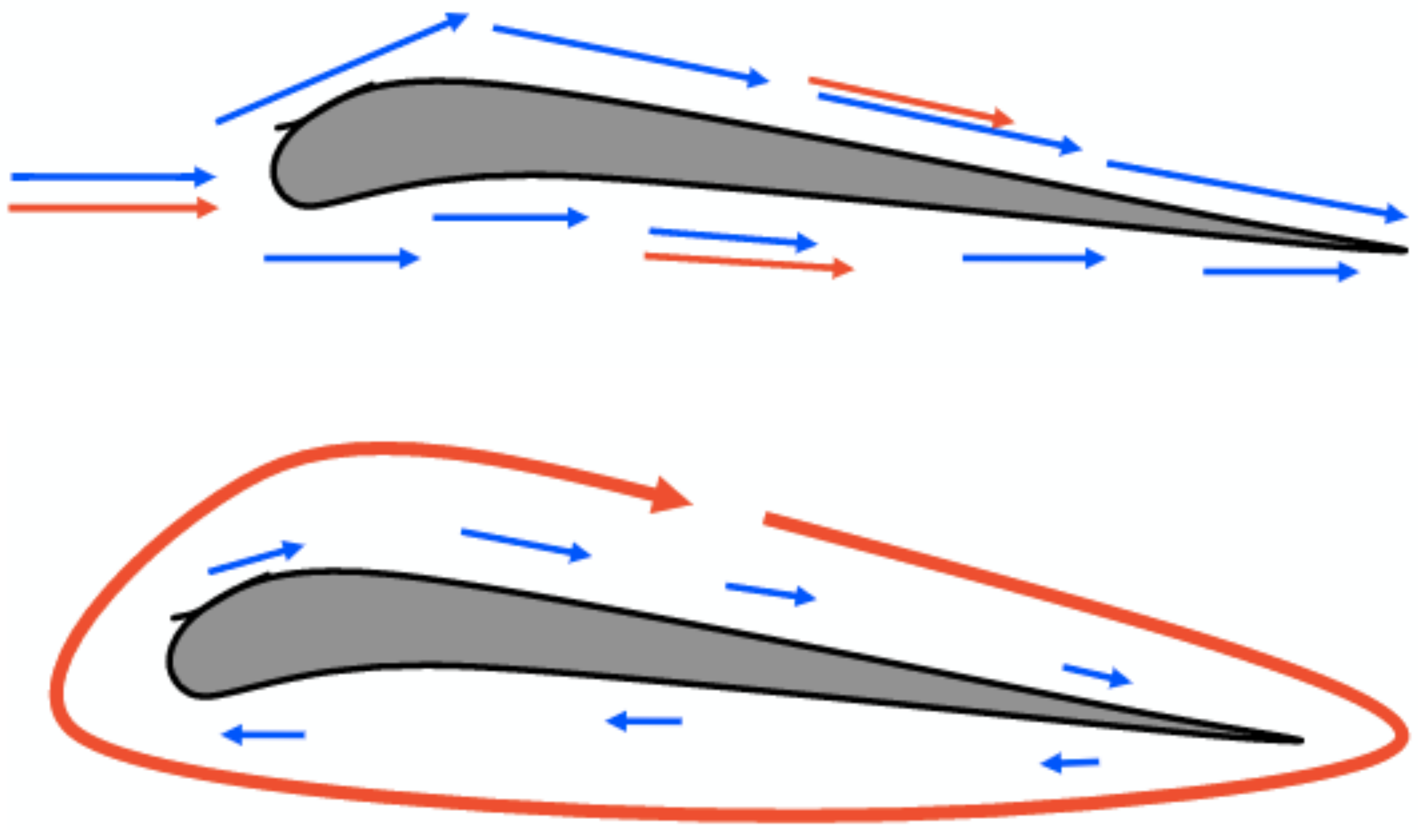
Velocity has both magnitude (speed) and direction.

Changing either the speed or direction of a flow generates a force.

Lift is a force generated by turning a moving fluid.

The Forces of Flight: Lift

Circulation: sum of velocities around the surface

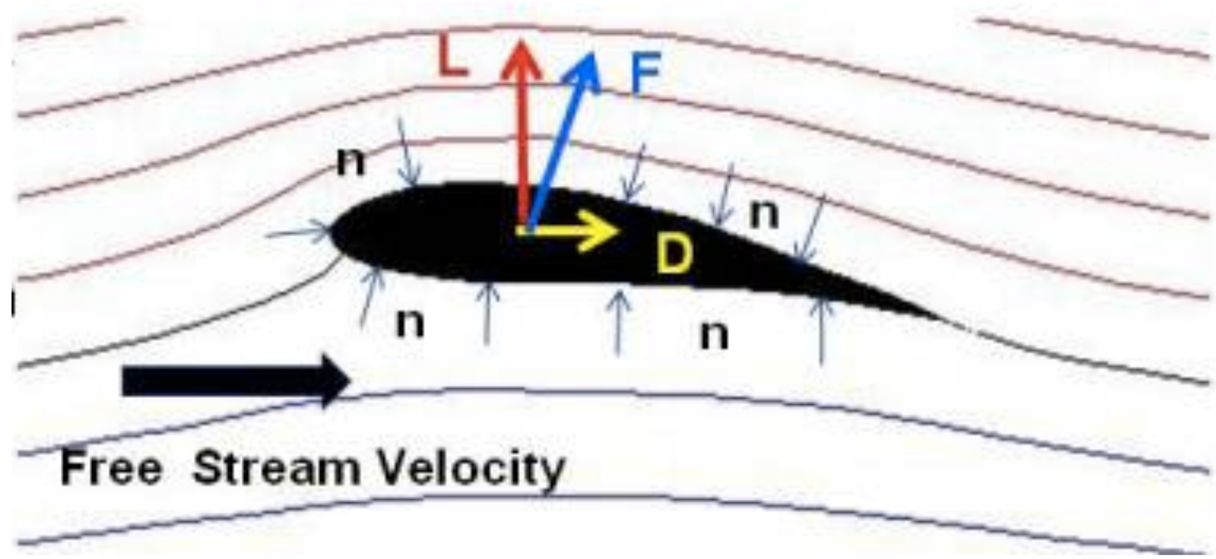


Greater Circulation = Greater Lift

The Forces of Flight: Lift

Bernoulli's Equation relates velocity to pressure.

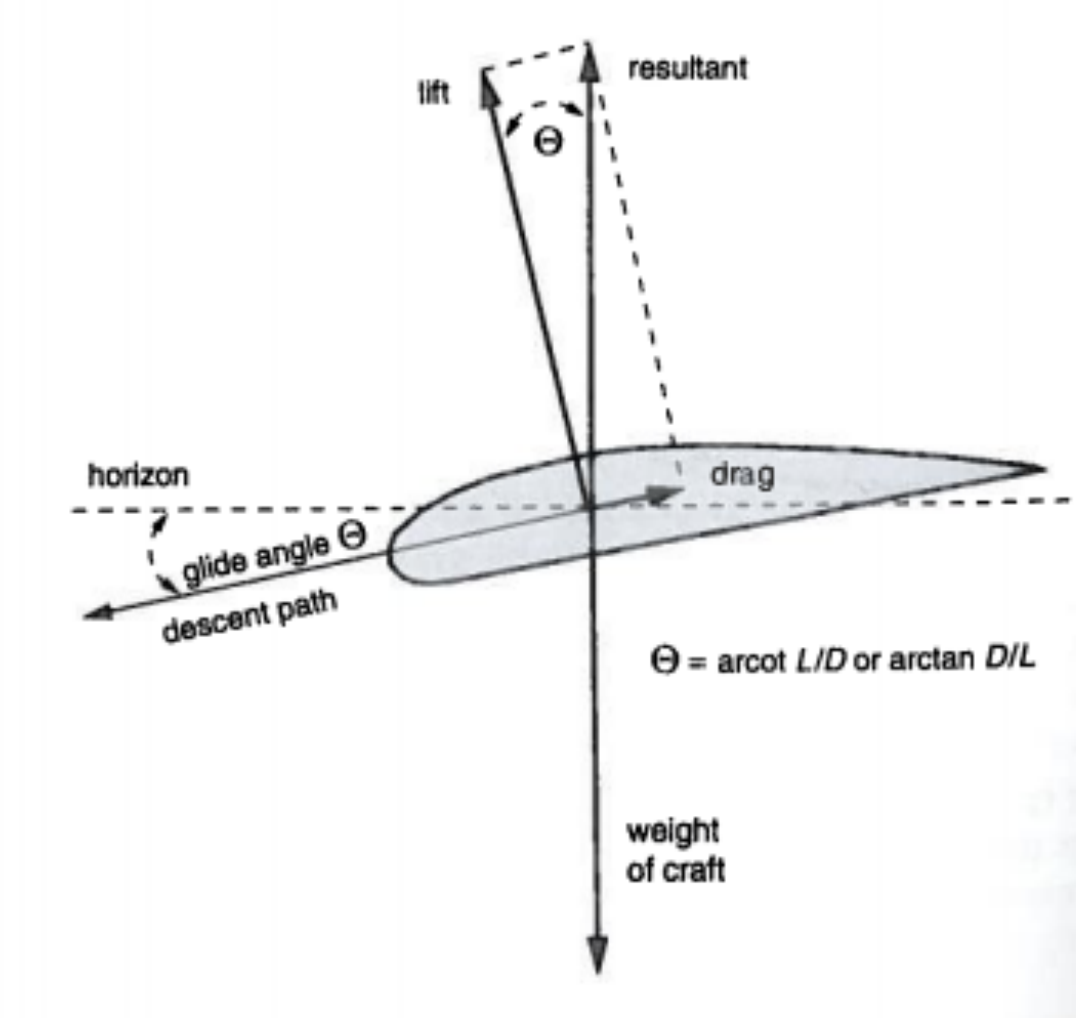
$$(P_2 - P_{1)} /\rho = (u_1^2 - u_2^2)/2$$



Pressure differences around the body create a net force (F).

LIFT -> component perpendicular to direction of motion
DRAG -> component parallel to direction of motion

Review of gliding

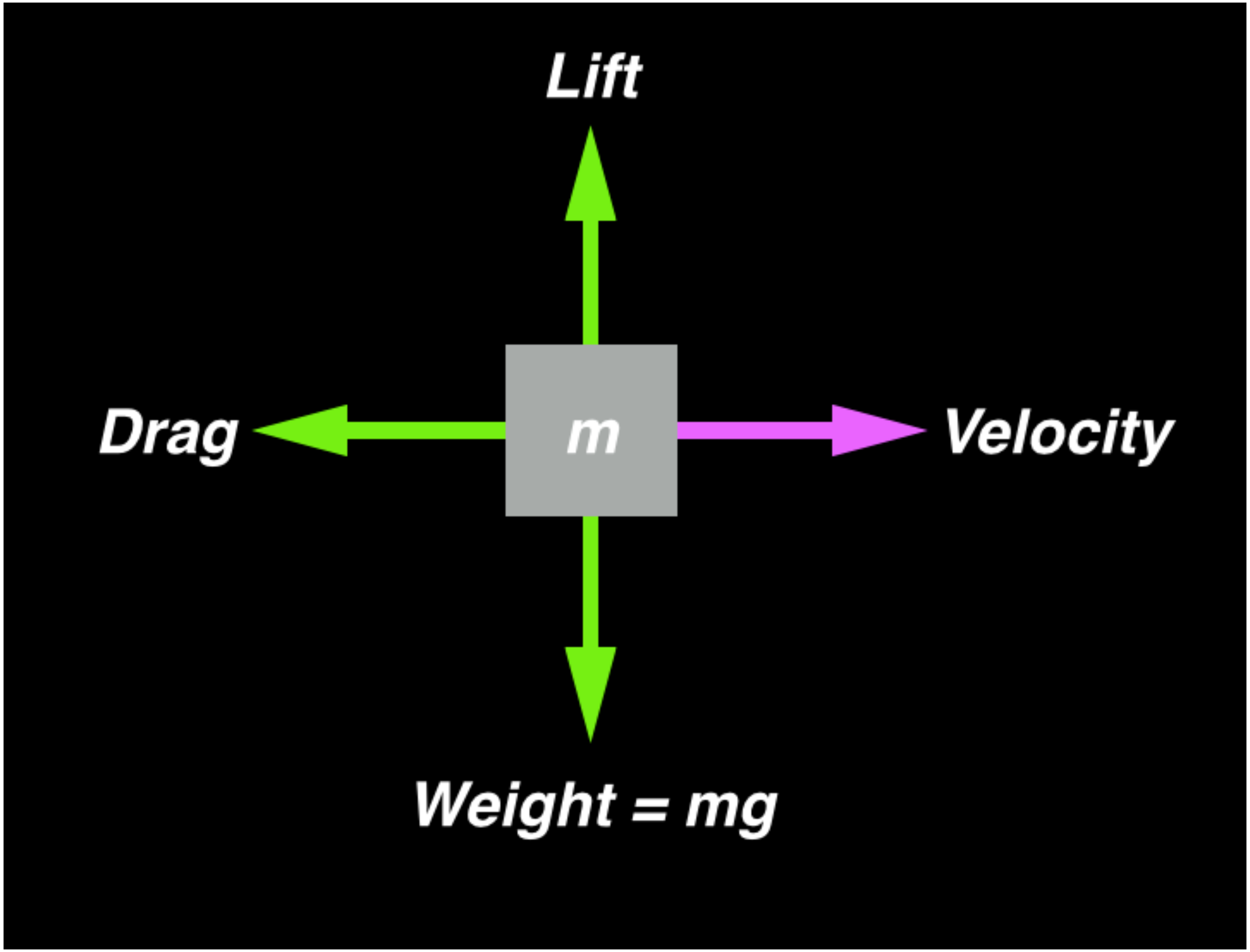


$$Weight = ?$$

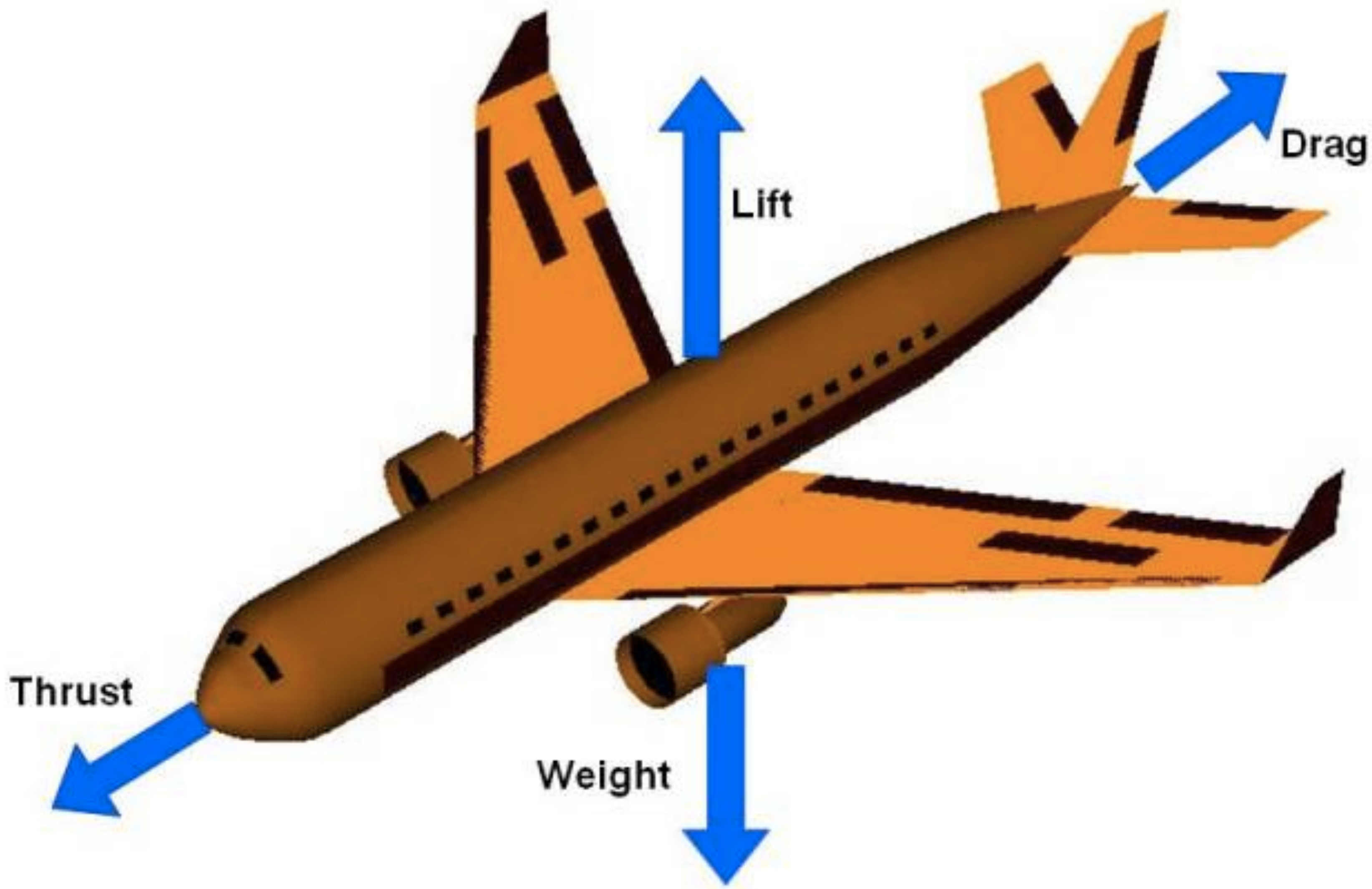
$$Lift = ?$$

$$Drag = ?$$

How does a flier move *forward*?



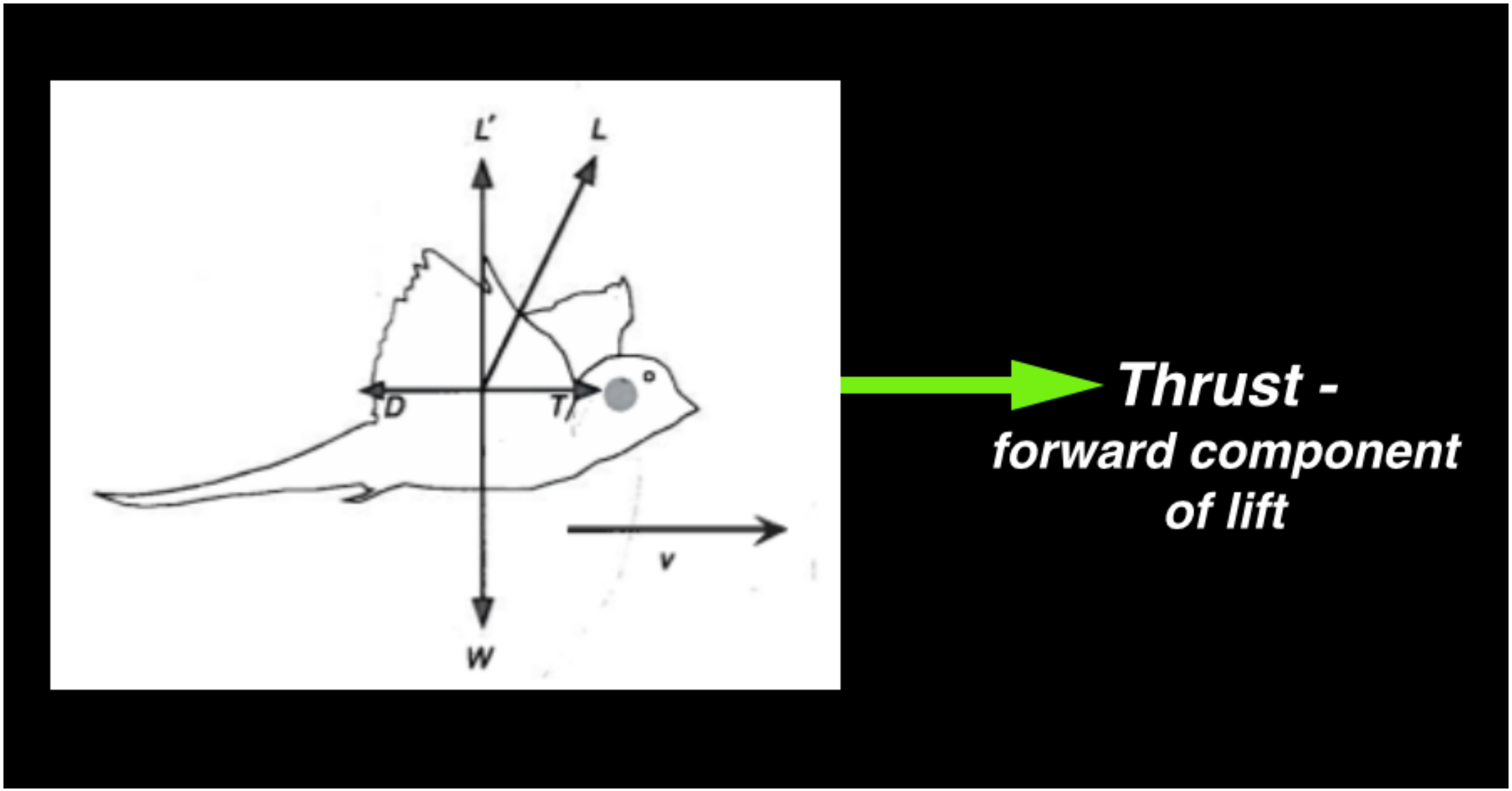
How does a flier move *forward*? THRUST



… but flying animals do not have jet engines.

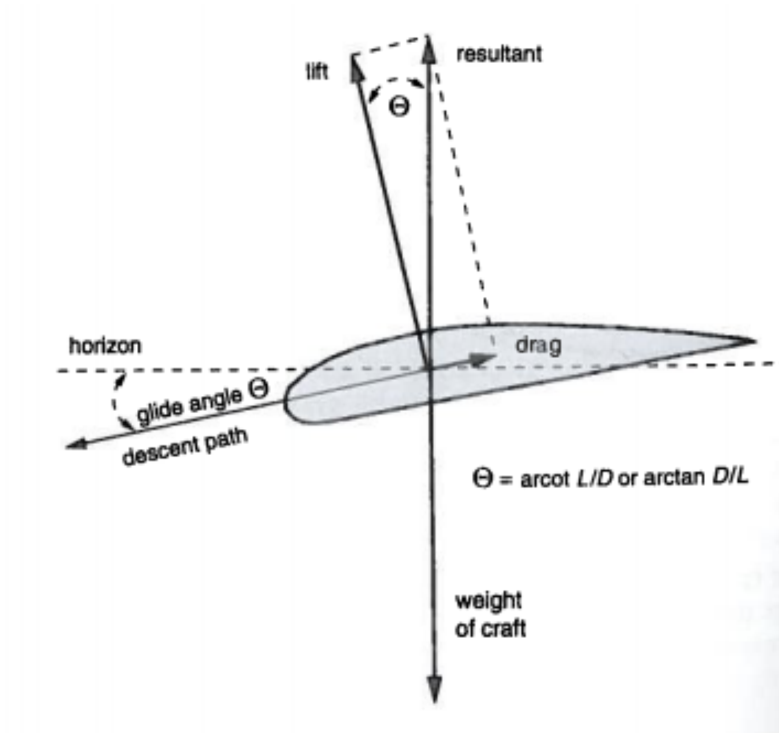
Generating Thrust: Flapping!

Brainstorm: What type of wing motions (“flaps”) can create a forward force?

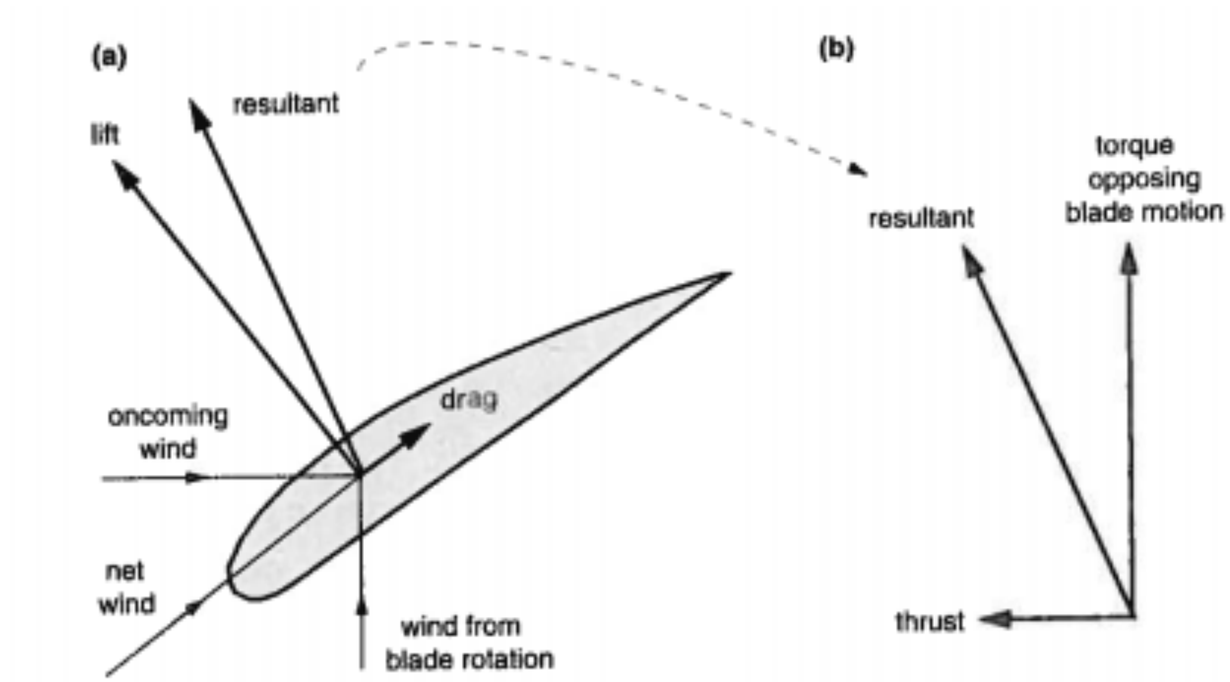


Generating Thrust: Flapping!

Recall gliding:



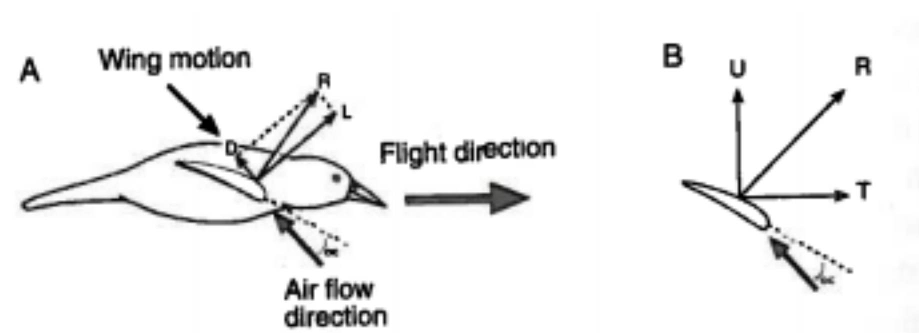
If the “glide angle” is large enough to shift the net aerodynamic force forward, there is a forward force component:



The Helicopter Analogy

To move forward, a helicopter must tilt the plane of rotation of the rotor.

… just like a bird tilts the orientation of its wing.



Flight Gaits: Slow Flight

- Wings move faster to maintain aerodynamic force, compensating for a lower forward velocity.

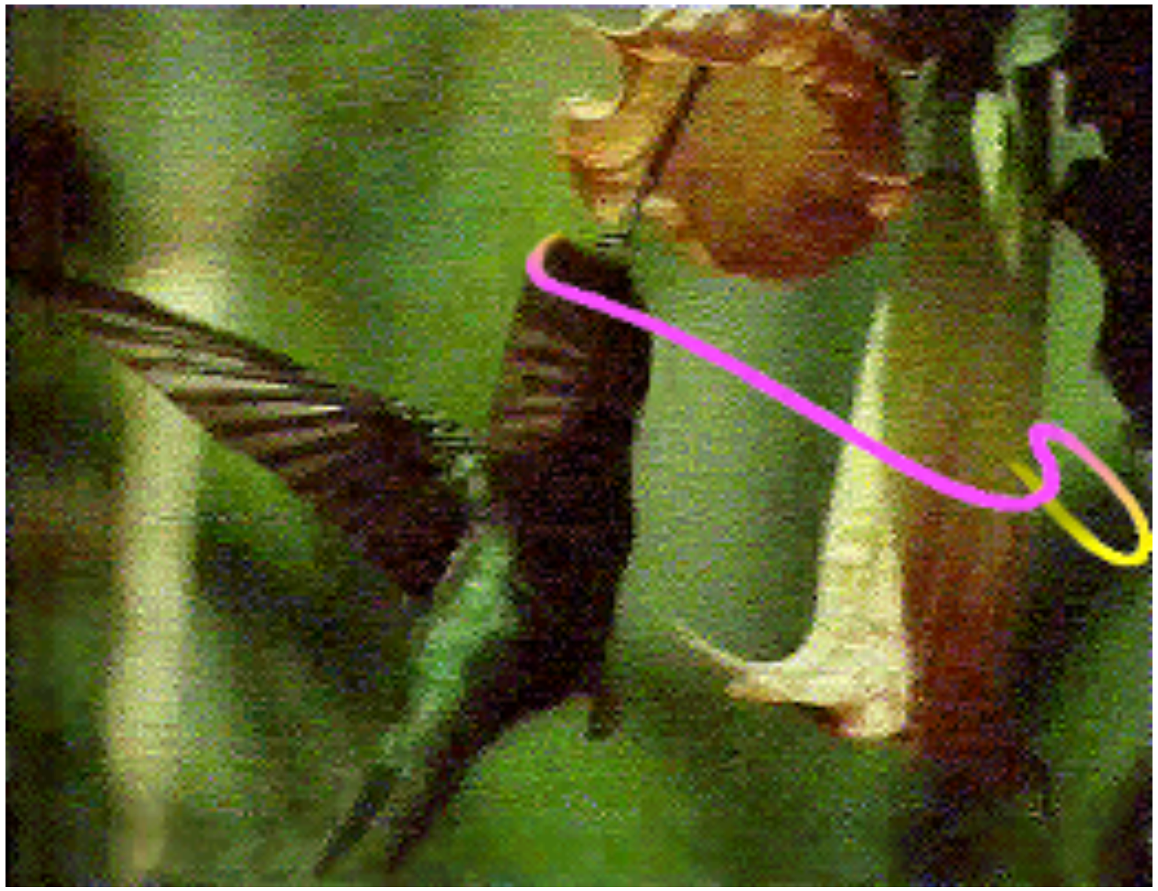
- Distinct vortex rings (circulation shedding)

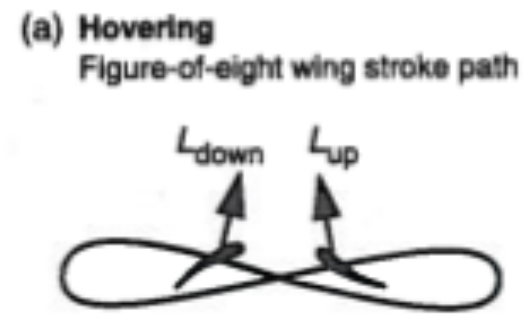
Flight Gaits: Fast Flight

- Wings move slower because of higher forward velocity, but still involves work because drag also increases!

- Continuous vortex shedding

Flight Gaits: Hovering





Net horizontal force in the complete wingstroke must cancel.

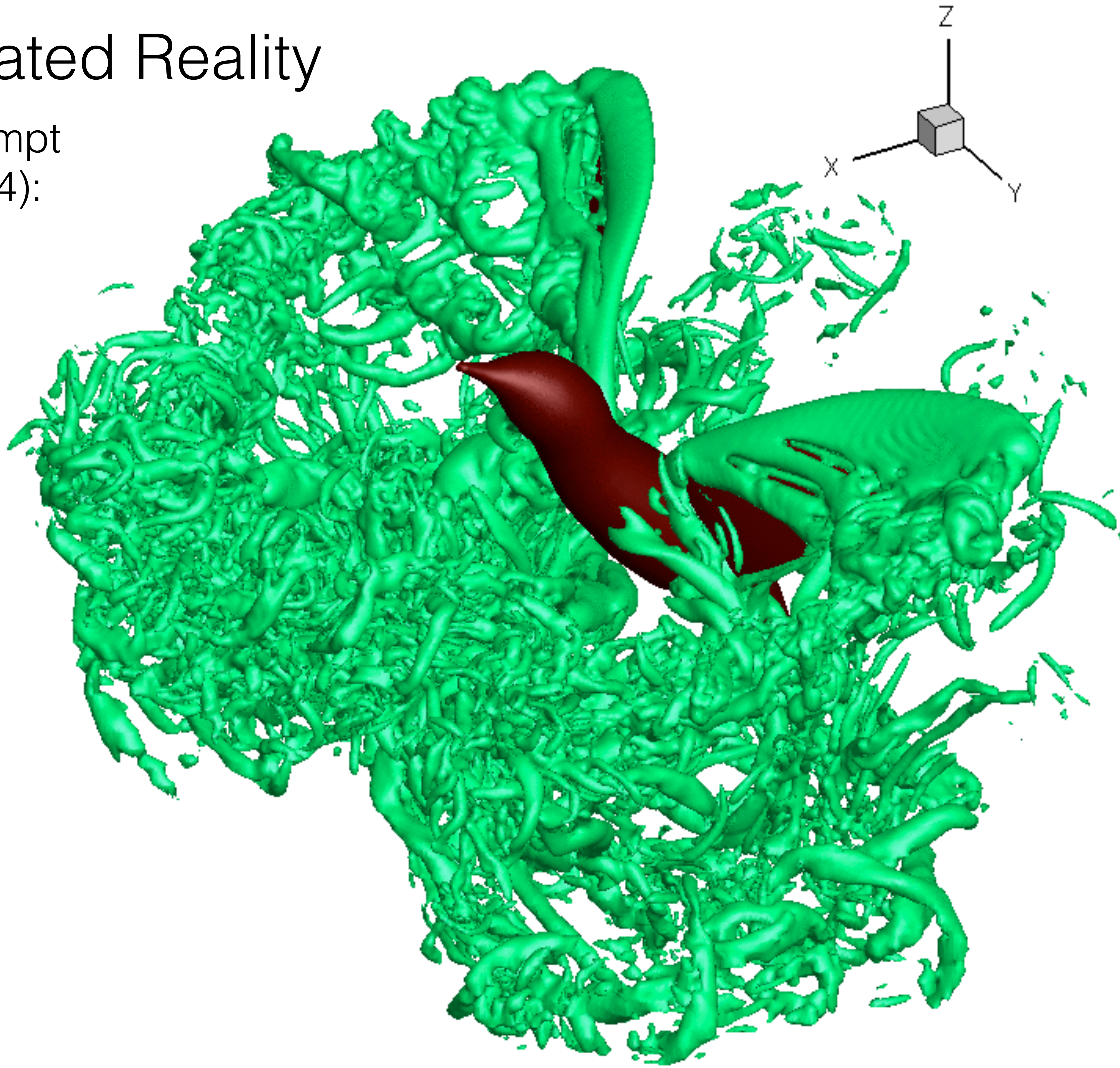
Wings that fly and swim

Also: http://www.arkive.org/puffin/fratercula-arctica/video-08.html

A Complicated Reality

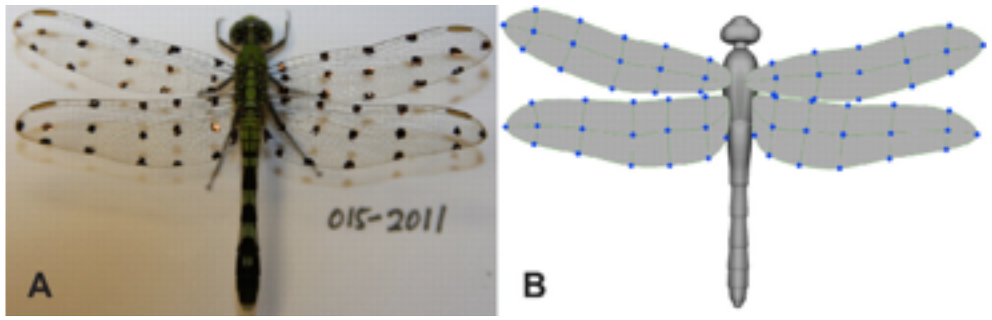
Simulation Attempt (Song et al 2014):

We often approximate flow as steady (constant conditions); in reality, it is *unsteady* (conditions change with time).

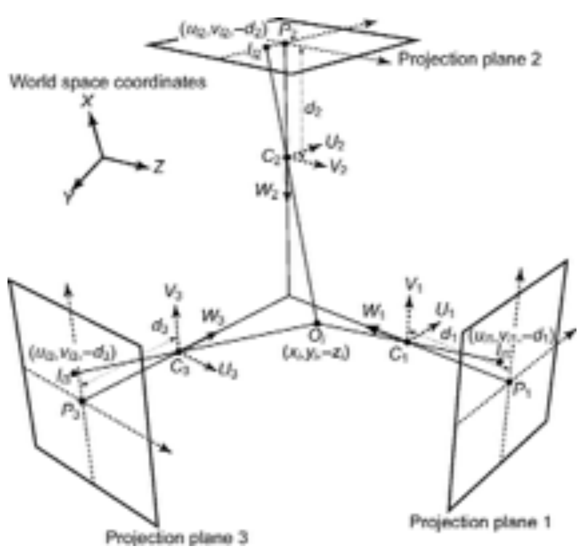


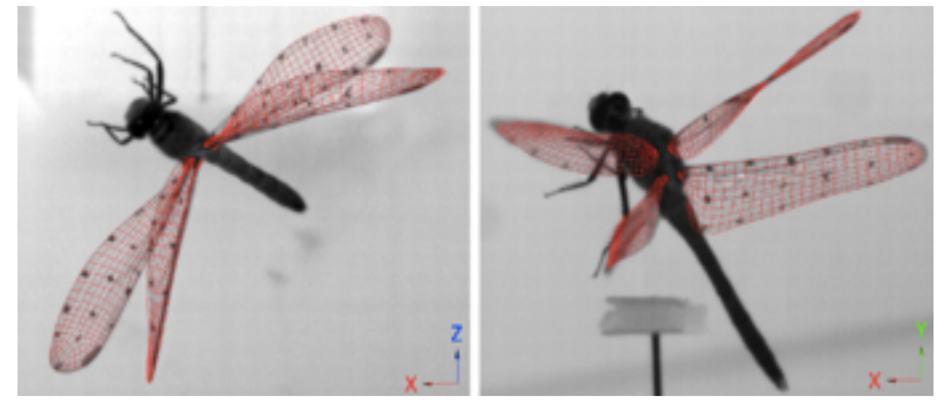
Solids and Fluids: Studying Deformable Wings

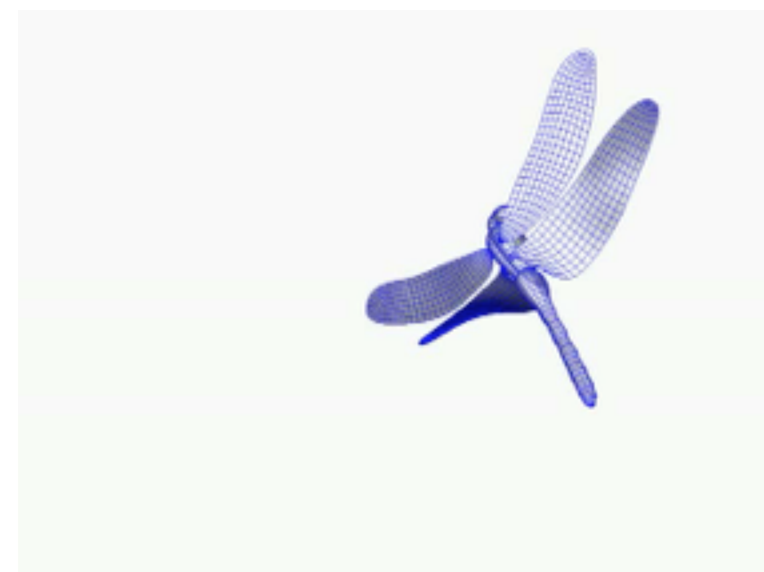
Using high-speed video & photogrammetry to create a model:
(Koehler et al 2012)



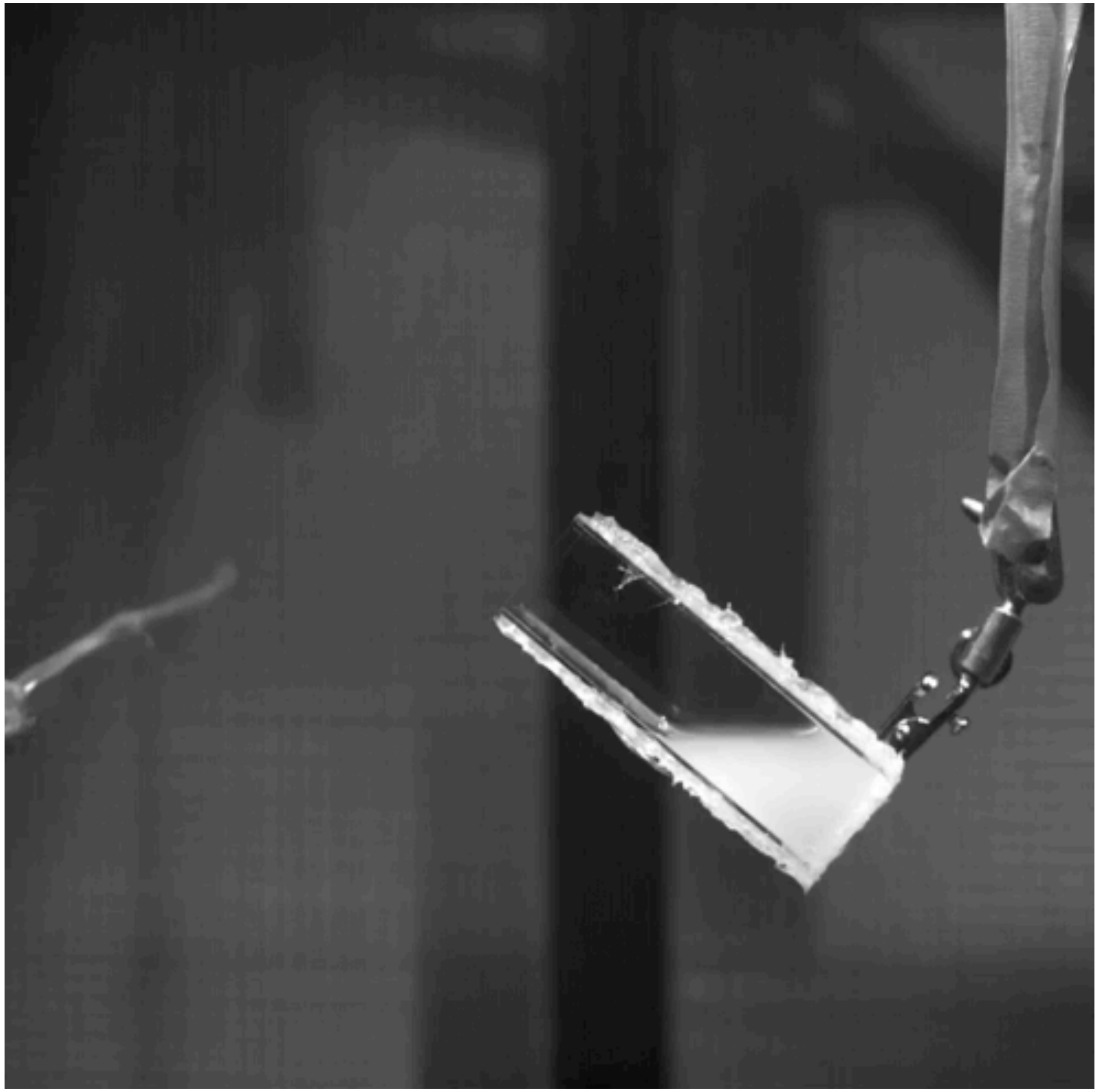
+





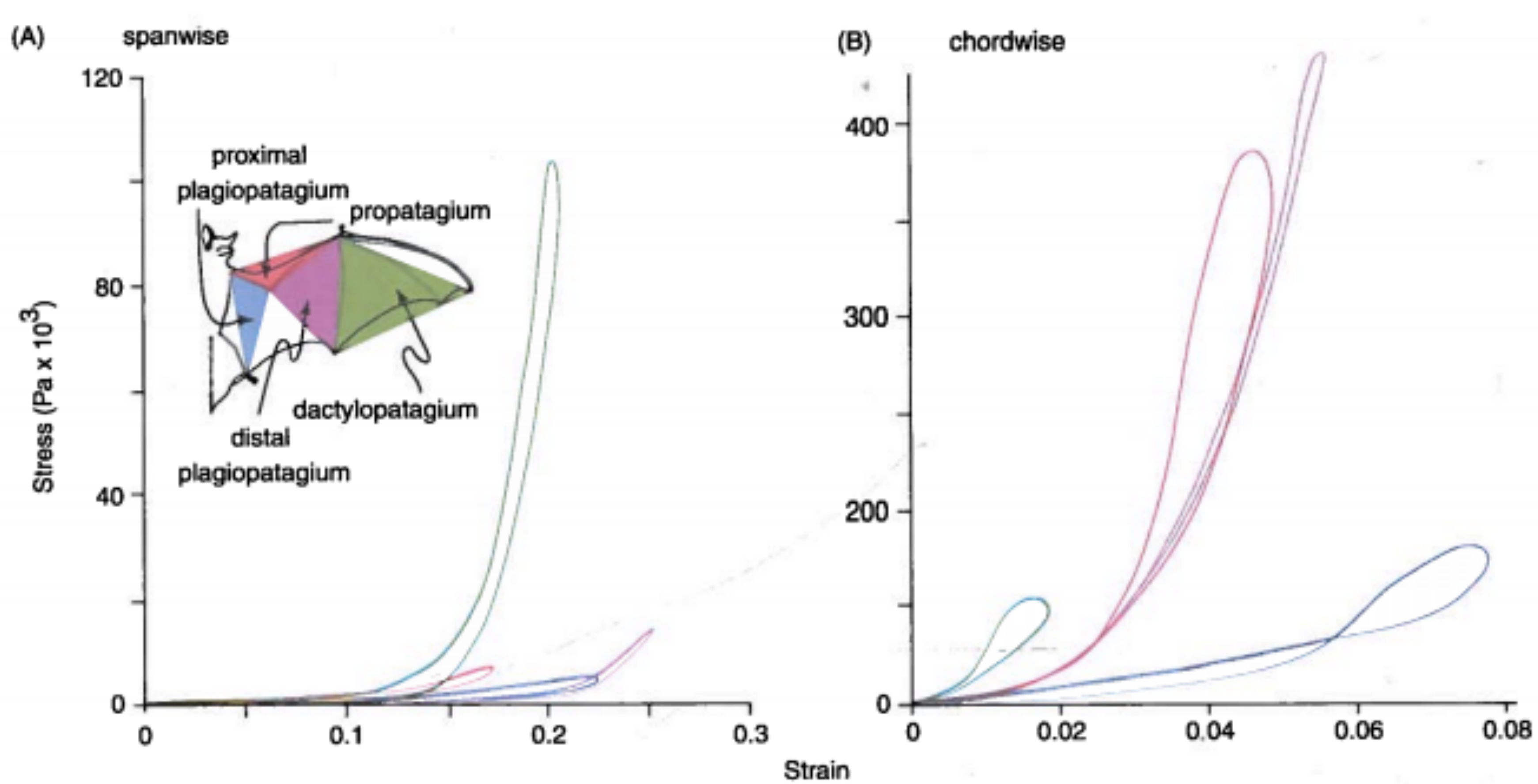


Solids and Fluids: Studying Deformable Wings



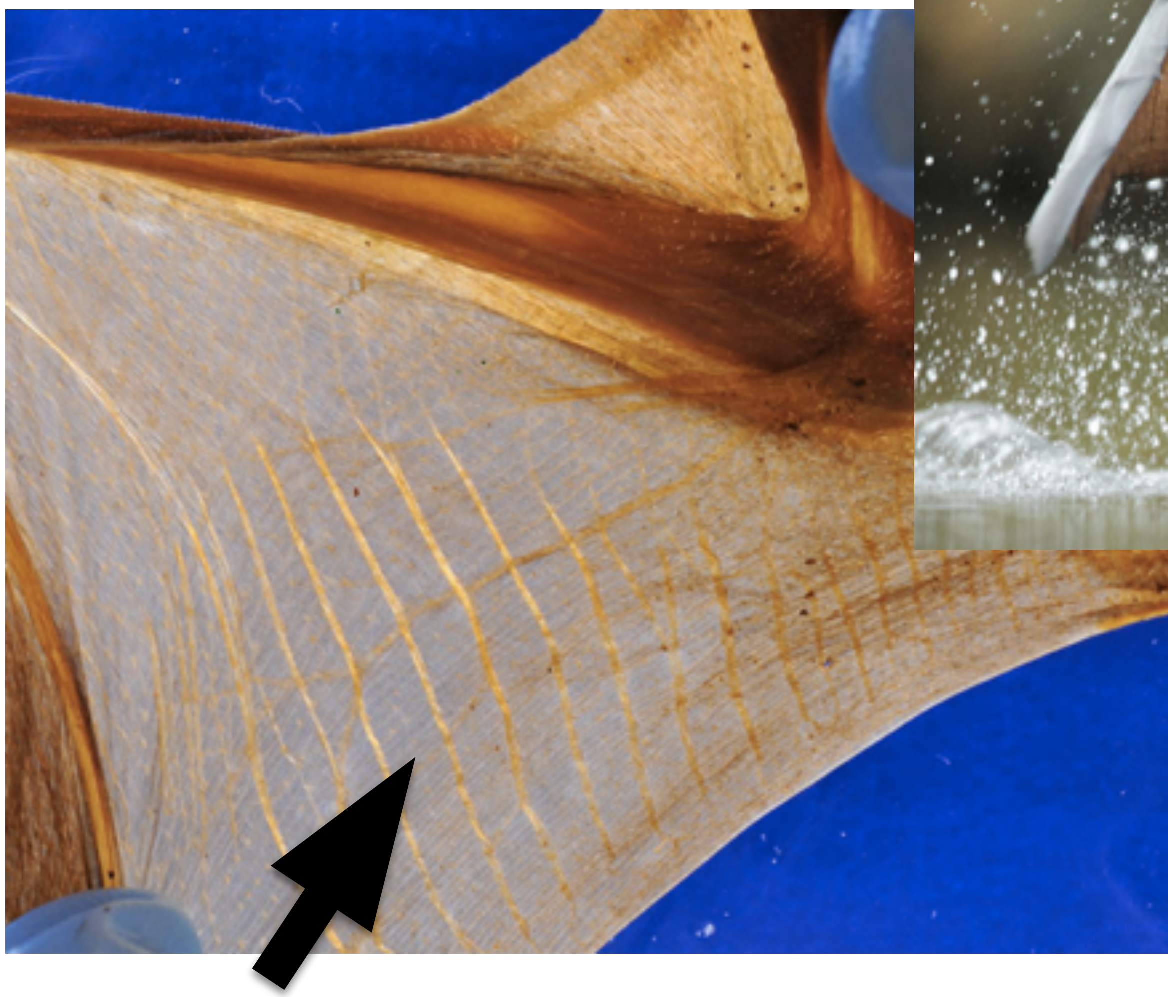
Solids and Fluids: Studying Deformable Wings

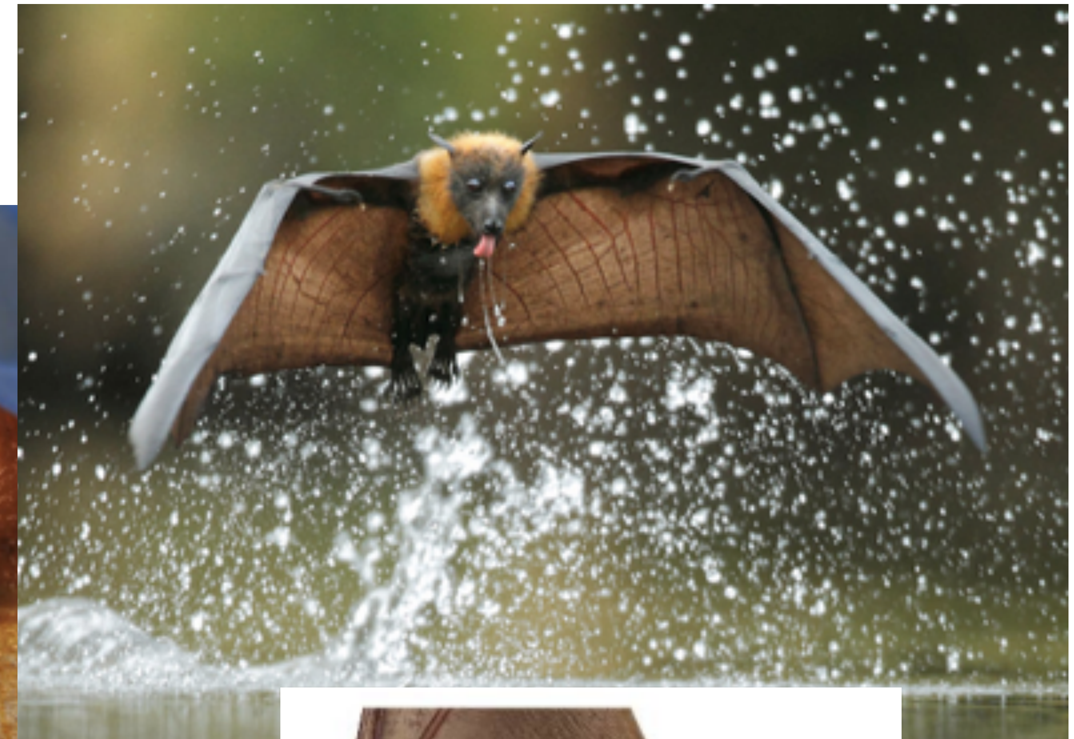
Characterizing material properties:
(Dumont and Swartz 2009)



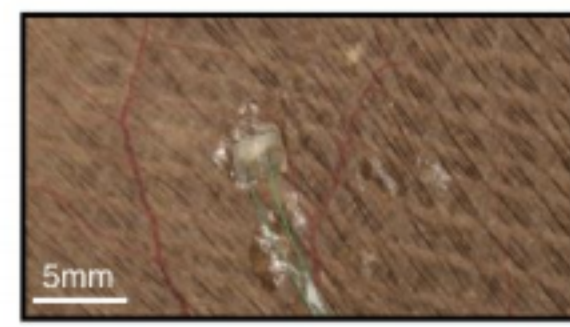
Solids and Fluids: Studying Deformable Wings

Muscles in Membranes
(Swartz Lab)



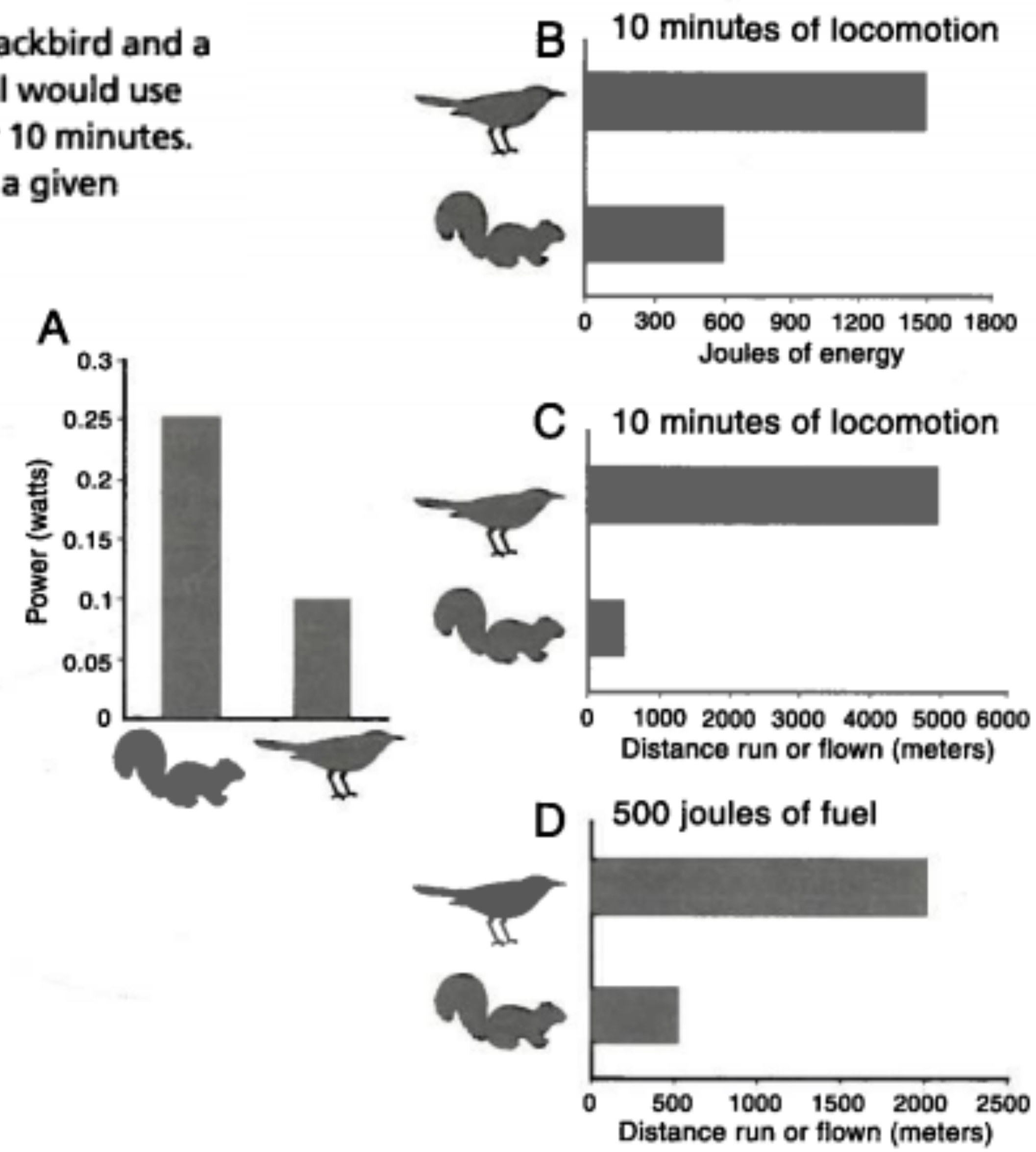


EMG + High-speed video:
(Cheney 2013)



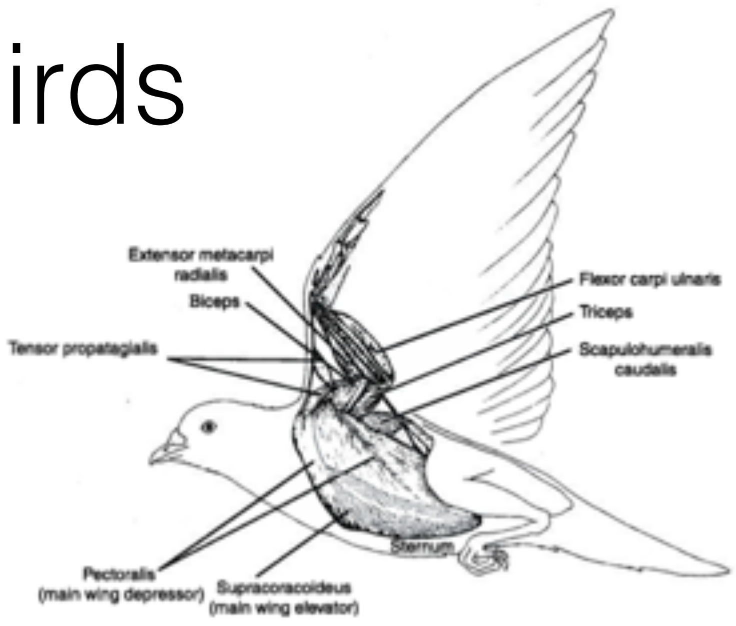
Is Flight Efficient?

Figure 6.5. Comparison of running and flying energetics between a blackbird and a squirrel of the same weight. A. Power used at a speed that each animal would use for long-distance travel. B. Amount of energy they use to run or fly for 10 minutes. C. Distance they run or fly in 10 minutes. D. Distance they run or fly on a given amount of energy, 500 joules in this case. (S.T.)

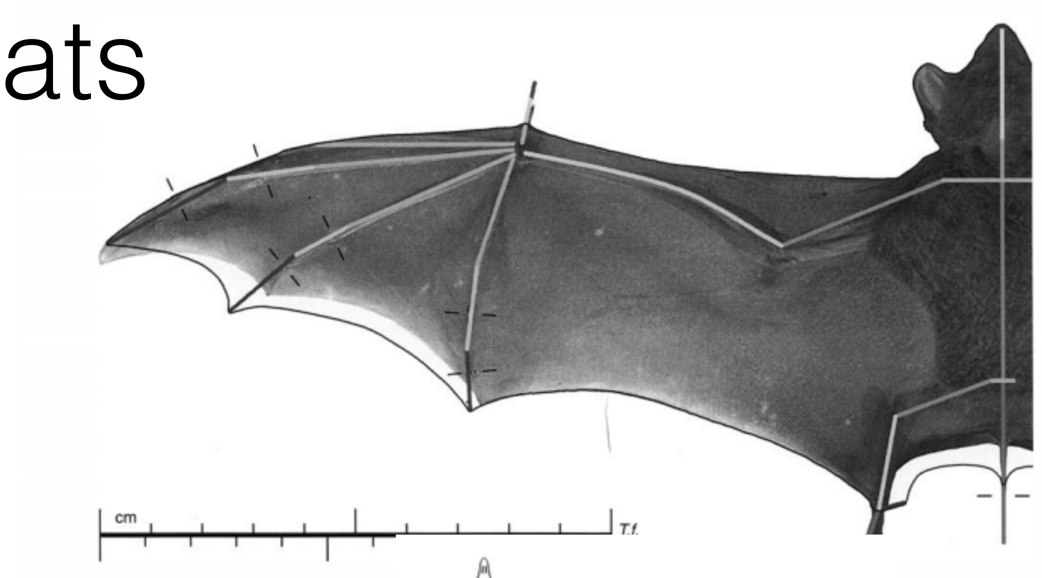


Independent Evolution of Flight in Vertebrates

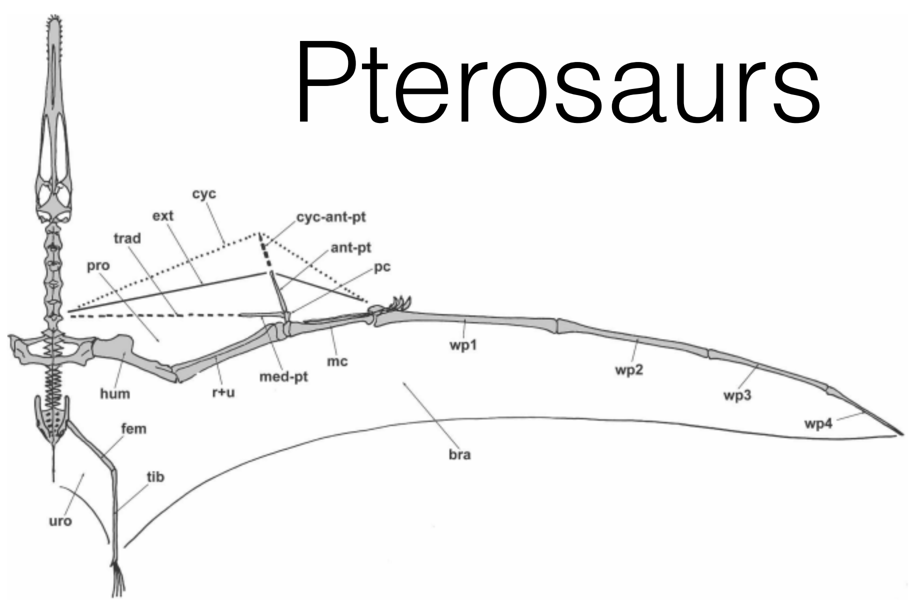
Birds

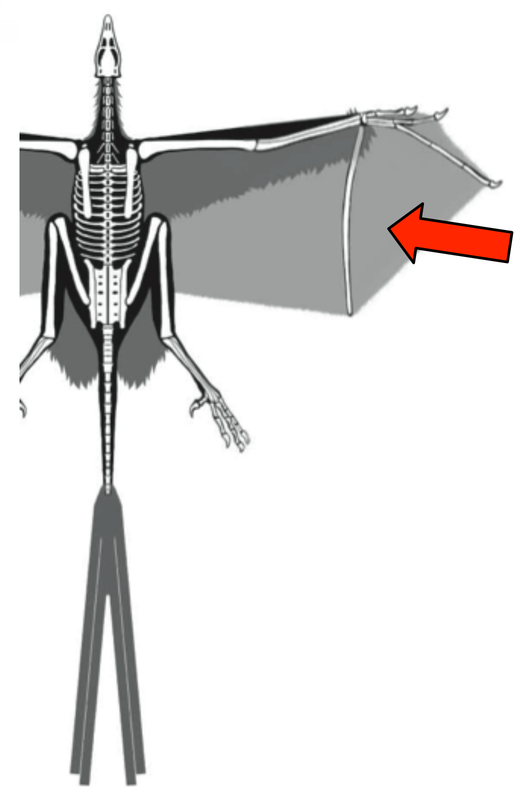


Bats



Pterosaurs





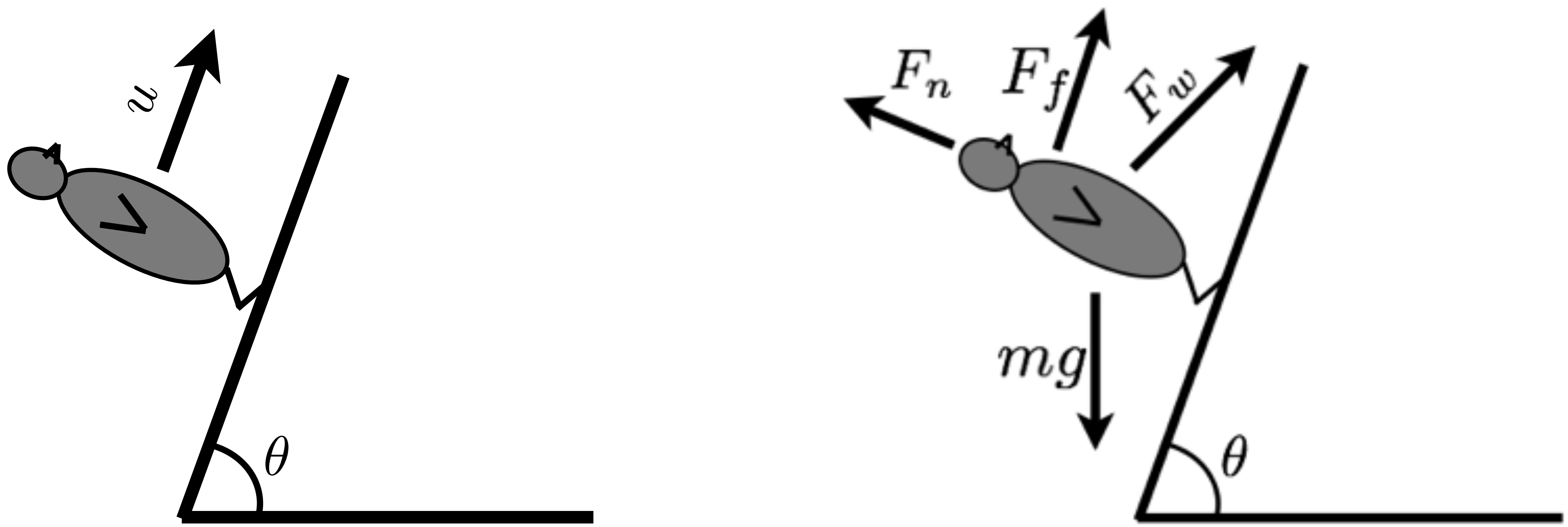
Yi qi Xu et al 2015

Evolution of Flight - Theories

- Top-down (arboreal - began gliding from trees)
- Bottom-up (cursorial - running take-off)
- WAIR (Wing-Assisted Incline Running)

Flapping helps in ascending slopes

- Birds can climb slopes before they can fly



Flapping helps in ascending slopes

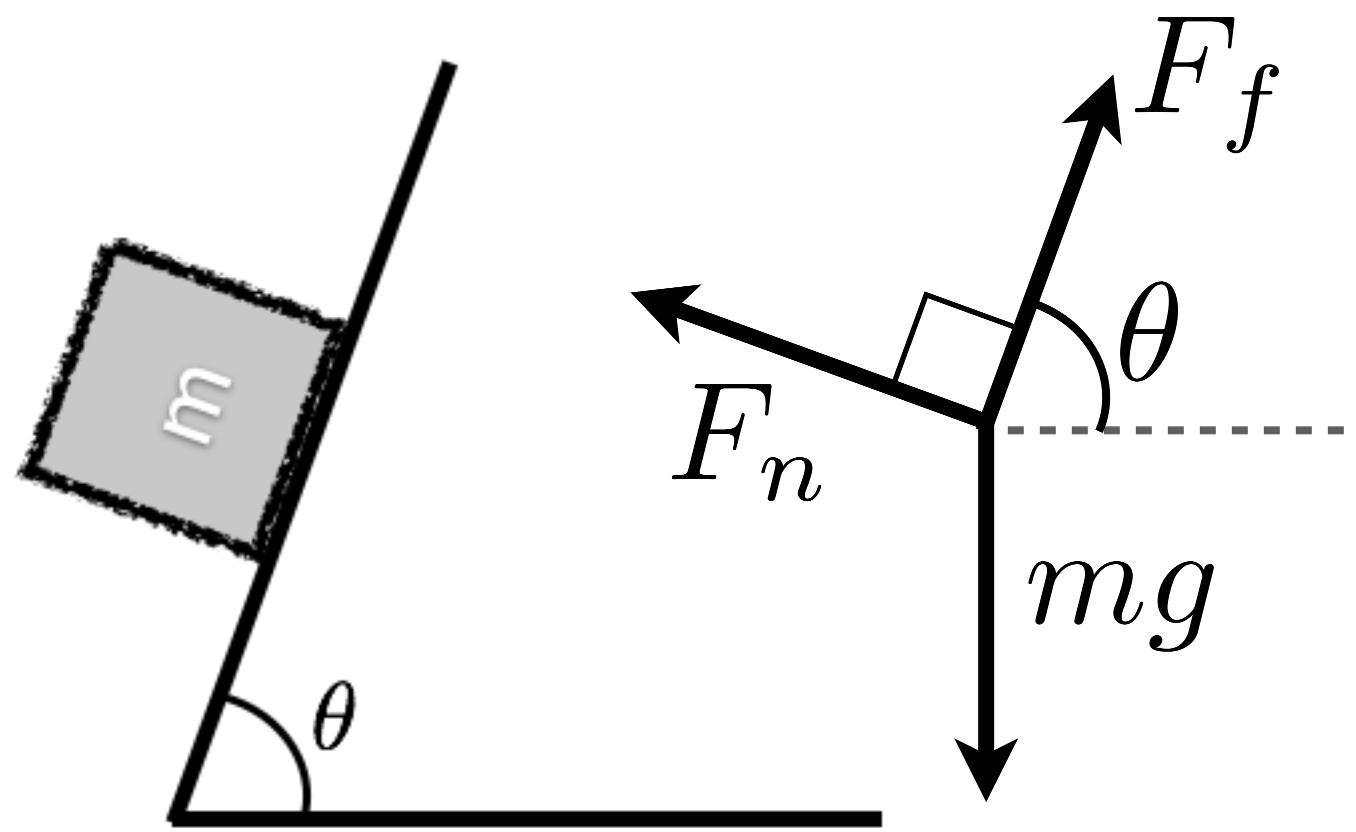
- Think about friction:

Gravitational contribution to normal force is

$$F_n = mg\cos\theta$$

And to sliding is

$$F_s = mg\sin\theta$$

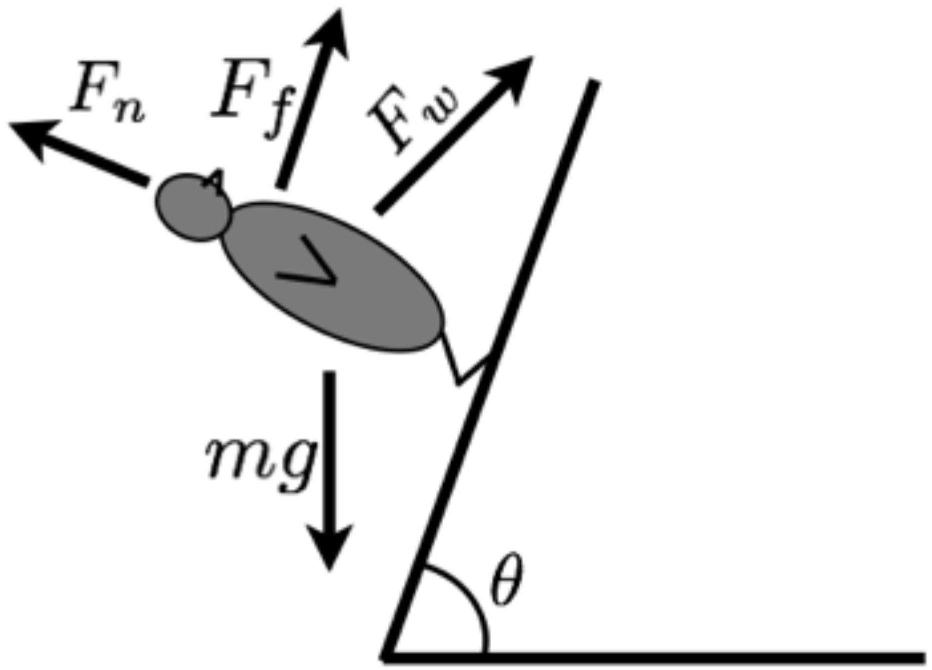


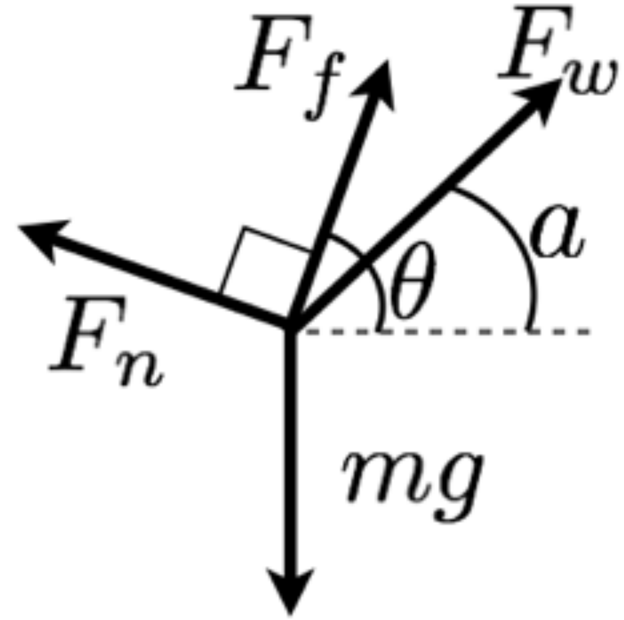
And we stay stuck so long as $F_s \leq F_f$

or

$$mg\sin\theta \leq \eta mg\cos\theta$$

So how does flapping help?





- What is the new normal force? (HINT: How does the flapping force contribute?)
- What is the new frictional force?
- What is the component of the frictional force parallel to the flapping force?

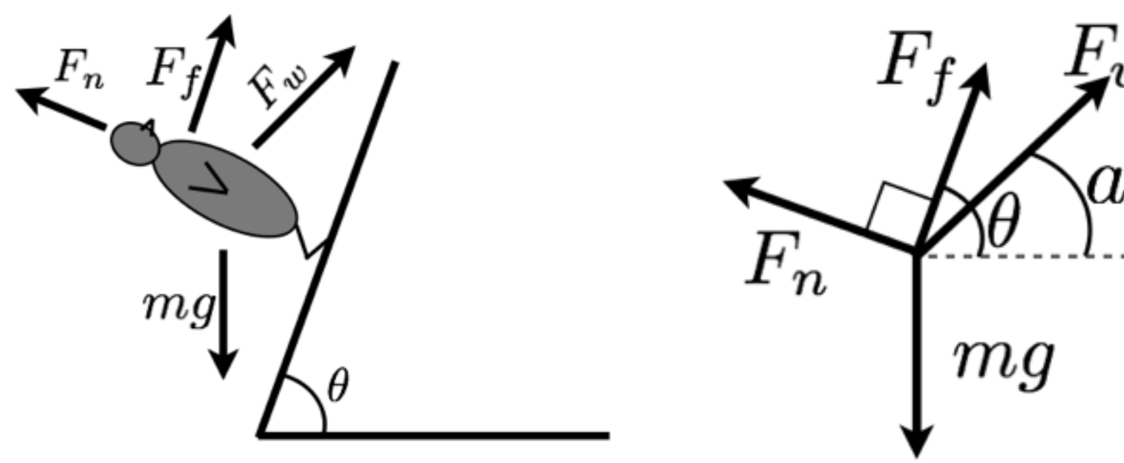
New total normal force is $F_n = mg\cos\theta + F_w\sin(\theta - a)$

So the frictional force is $F_f = \eta(mg\cos\theta + F_w\sin(\theta - a))$

And a component parallel to the frictional force $F_{w||f} = F_w\cos(\theta - a)$

Can 5-day old chukars that can produce a thrust (F_w) of two-thirds their bodyweight climb slopes of 60°? 70°? 80°?

$m = 1\text{kg} \qquad g = 10\text{m/s}^2 \qquad \eta = 0.8 \qquad a = \pi/4 = 45^\circ$



New total normal force is $F_n = mg\cos\theta + F_w \sin(\theta - a)$

So the frictional force is $F_f = \eta(mg\cos\theta + F_w\sin(\theta - a))$

And a component parallel to the frictional force $F_{w||f} = F_w \cos(\theta - a)$