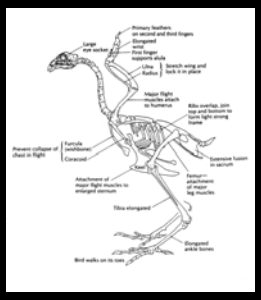
Flight

Skeletal adaptations

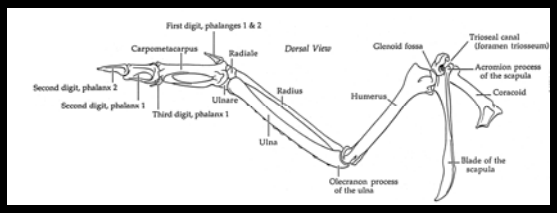
- Light bill and skull
- Keeled sternum
- Uncinate processes
- Pectoral girdle
  - Coracoid
  - Scapula
  - Furcula



Skeletal adaptations

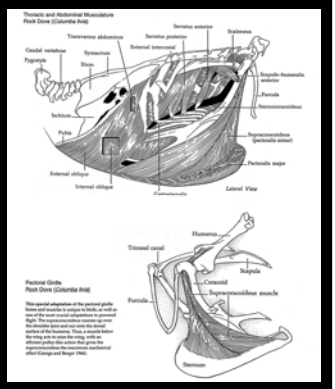
- Bones are pneumatic (air filled and porous)
- Long bones are hollow but very strong, strengthened by internal struts

- Skeletal adaptations of the wing
  - Elaborate joints
  - Fused carpometacarpus (wrist)
  - Fused and modified hand and finger bones
    - Alula (first digit, phalanges 1 & 2)



Flight muscles

- Breast is comprised of two major flight muscles
  - Pectoralalis
    - Connects sternum to bottom of humerus
    - Wing downstroke
  - Supracoracoides
    - Connects sternum to top of humerus
    - Wing upstroke
    - Passes through trioseal canal which works like a pulley to raise the wing
- Birds that are strong flyers have deeply keeled sternum and large breast muscles
- Flightless birds and tree trunk climbers have shallow keels

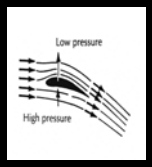


Flight muscle metabolism

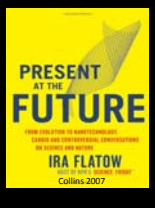
- Two major types
  - Red muscle fibers
    - Important for sustained flight, e.g. hummingbirds
      - Oxidative (aerobic) metabolism, high in myoglobin, mitochondria, enzymes for Kreb's Cycle
  - White muscle fibers
    - Important for short rapid flight, e.g. grouse
      - Anaerobic metabolism, low in myoglobin, mitochondria, lactic acid builds up

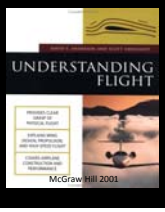
Aerodynamics

- Gliding flight - an airfoil creates differential pressure
  - Bernoulli's principle (minor)
  - Deflection of air downward (Anderson and Eberhardt)
  - Leading edge pushes air up (low pressure), trailing edge pushes wing up (Sir David)
- Powered (flapping) flight creates additional lift and forward movement



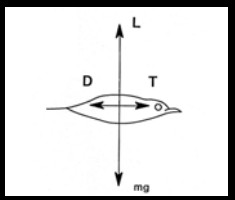
Bernoulli



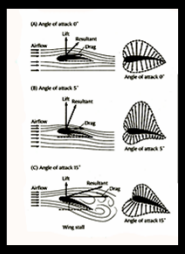


A balance of four distinct forces is needed for horizontal flight

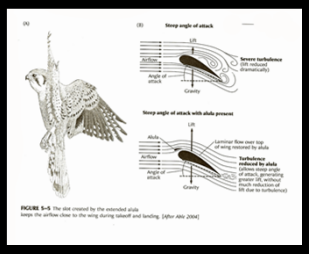
L = lift from airfoil
Mg = weight (gravity)
T = thrust of wings
D = drag (friction)



Aerodynamics



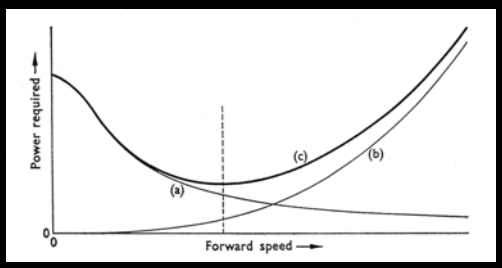
The airfoil



The alula reduces drag

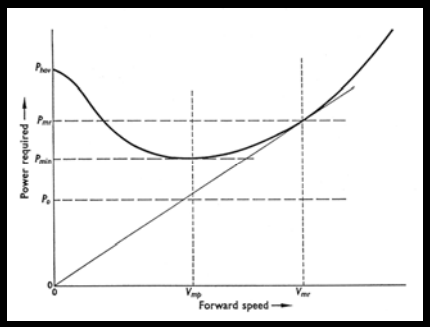
Power curve

a = Induced power
b = Profile power
c = Total Power = a + b



Power curve

Phov = Power required to hover
Vmp = Velocity of minimum power
Vmr = Velocity of maximum range
Po = Power to fly from a stationary position (constant)



Vmr

Power =energy/time
Speed = distance/time

Therefore:

Power/speed = energy/distance

And:

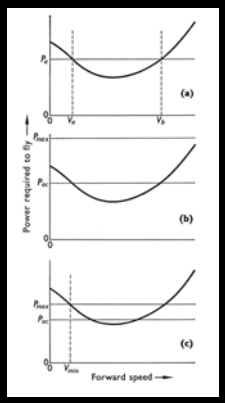
The minimum ratio of energy to distance (Vmr) occurs at the minimum ratio of power to speed. This occurs where the tangent to the power curve passes through the origin.

Vmr > 1.3 Vmp

Power Curves

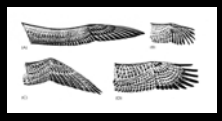
- Pa = Power available
- Pac = Power needed for continuous flight
- Pmax = Maximum power available

C.J. Pennycuick
Animal Flight. 1972
Avian Flight Performance. 1989.



Pmax and Po

Wing size and shape determine, flight speed, agility, and energy consumption. Wing aspect ratio controls performance



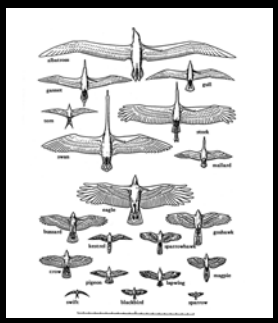



Wing loading (g/cm^2) measures the energetic cost of flight

	Bird Type	Wing Loading	Comment
	Small Songbirds	0.1 – 0.2 g/cm^2	Relatively Large Wings
	Albatrosses	1.7 g/cm^2	Long Slender Wings
	Loons, Auks, Diving Ducks	2.6 g/cm^2	Skitter To Get Airborne

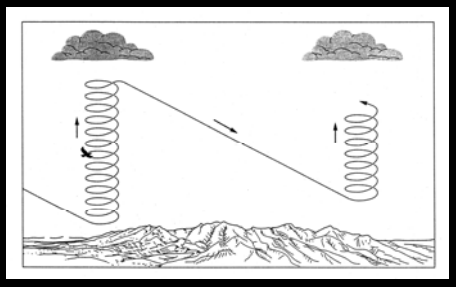
A diversity of wings

- High aspect ratio
  - High lift, low drag
  - Better for gliding and high speed flight
  - Open country, albatross, swallow, falcon
- Low aspect ratio
  - More maneuverable at low speed
  - Forests birds, Goshawk, grouse



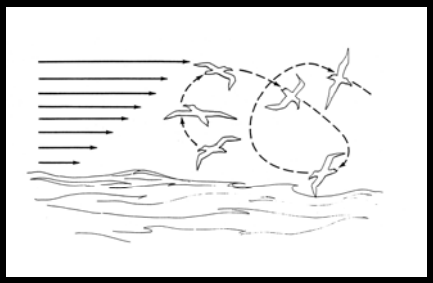
Gliding flight

- Thermal soaring



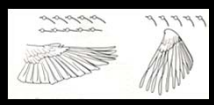
Gliding flight

- Dynamic soaring



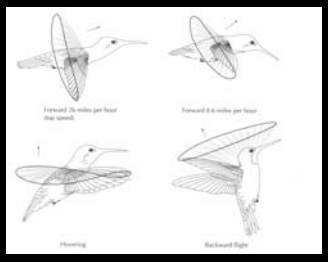
Flapping flight

- Forward momentum provided by primaries
- Each feather acts as airfoil



- Feather structure/arrangement gives high-resistance downstroke and low-resistance upstroke

The extraordinary flight of hummingbirds



Flightless birds

- Predator free environments
- Evolution favors legs
- Wings become flippers



Evolution of wing-propelled divers