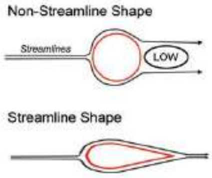
Flight adaptations in birds

(strength and light weight)

1

1. Shape

- Streamlined spindle-shaped body
  - designed to offer minimum resistance to the wind.

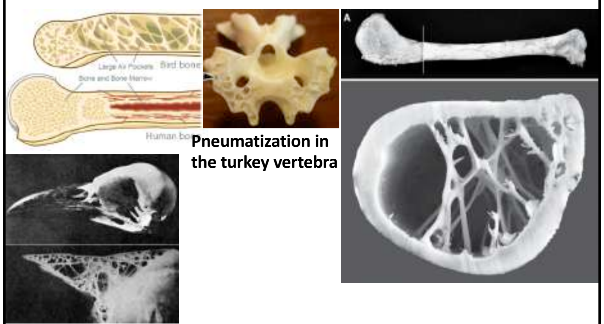


- **Compact body:** dorsally light (but strong) and ventrally heavier★
  - helps in maintaining balance in the air.

2

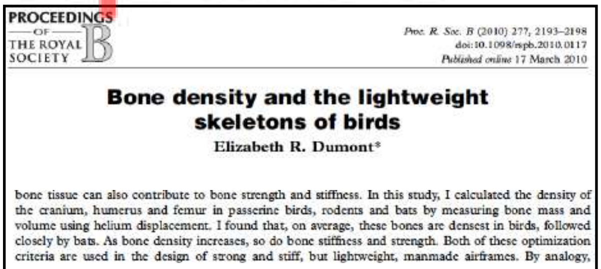
2. Skeletal adaptations

- **Pneumatization:** Most of the bones are pneumatic (hollow) and filled with air sacs instead of bone marrow★.



internal strut-like reinforcement to resist compresion ★

3



PROCEEDINGS OF THE ROYAL SOCIETY B
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doi:10.1098/rspb.2010.0117
Published online 17 March 2010

Bone density and the lightweight skeletons of birds

Elizabeth R. Dumont*

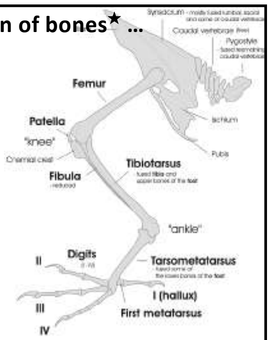
bone tissue can also contribute to bone strength and stiffness. In this study, I calculated the density of the cranium, humerus and femur in passerine birds, rodents and bats by measuring bone mass and volume using helium displacement. I found that, on average, these bones are densest in birds, followed closely by bats. As bone density increases, so do bone stiffness and strength. Both of these optimization criteria are used in the design of strong and stiff, but lightweight, manmade airframes. By analogy,

New data help to dispel the common misconception that bird skeletons are lightweight relative to body mass. Instead, bird and bat skeletons only appear to be slender and delicate—because they are dense, they are also heavy. Being dense, strong and stiff is one more way that birds' and bats' bones are specialized for flight.

4

2. Skeletal adaptations: 1) fusion of bones★ …

1. The fusion of pelvis with **synsacrum** (1-5-2-7) provides
   - firms attachment to the legs to carry the birds weight, and
   - counteracts the effect of shock as the bird alights.
2. The fusion of proximal tarsals with the lower end of tibia to form a ***tibiotarsus***, and that of distal tarsals with the metatrsals to form ***tarsometatarsus*** helps to strengthen the legs for bipedal gait.

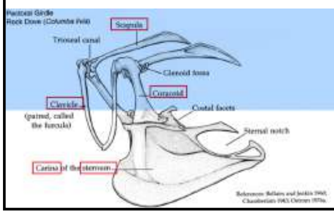


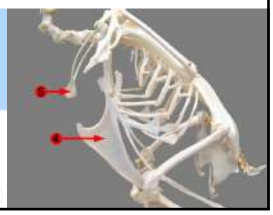
3. Fusing of caudal vertebrae to a single upturned **pygostyl**e which support the tail feathers has assisted stability in the air.

5

2. Skeletal adaptations: 1) fusion of bones★ …

- The furcula (wishbone) is a Y, U or V-shaped central bone in bird's chest; it is formed by the fusion of two clavicles of the pectoral girdles.
- It helps stabilize the chest cavity for flight helping a bird keep its body shape and internal structure intact especially on the upstroke of wings when the bird is under greatest stress.





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A symbol of luck !

The furcula shape is widely available as a pendant, charm, earrings, rings, cufflinks and other types of jewelry as well.

7

2. Skeletal adaptations: 1) fusion of bones★ …

Wrist and hand bones are fused to provide strength to support primary feathers.

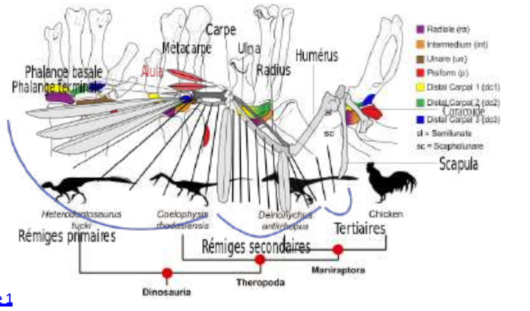


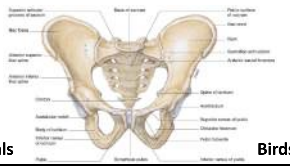
Figure 1

Since early dinosaurs, birds have reduced the number of bones in their wrist, but the origins and identity of those remaining are hard to trace.

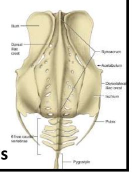
8

2. Skeletal adaptations: 2) Elimination of bones

- The wide pelvic canal★ and the slanting position of the body trunk allow for the caudal displacement of viscera
  - brought the center of gravity over the legs.
  - permitted laying of large eggs with calcareous shells.
- Elimination of a heavy jaw, jaw muscles, and teeth (replaced by a horny bill).
- Skull bones mostly united to form a continuous thin-walled structure encasing the brain and sense organs.



Mammals



Birds

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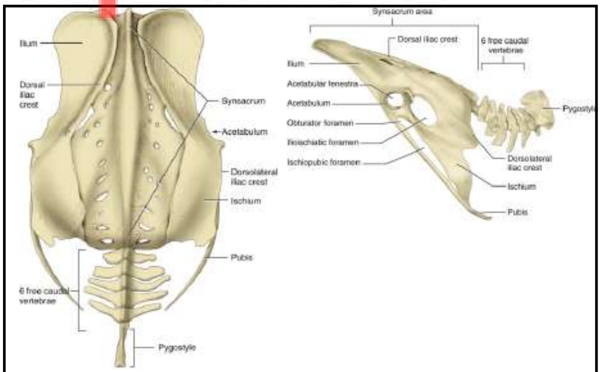

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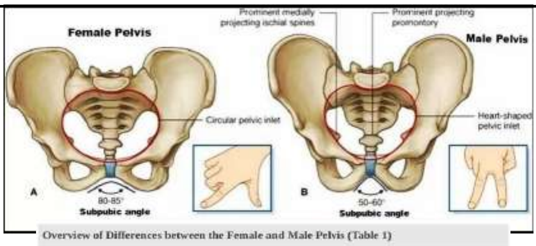


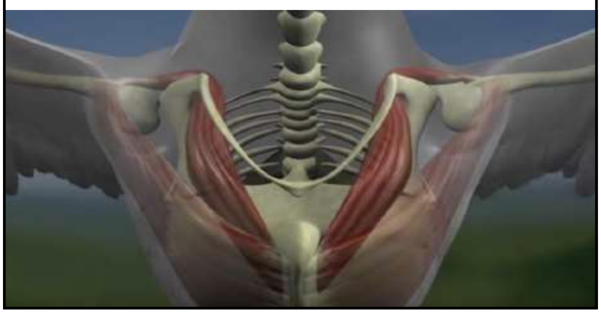
Overview of Differences between the Female and Male Pelvis (Table 1)

	Female pelvis	Male pelvis
Pelvic weight	Bones of the pelvis are lighter and thinner	Bones of the pelvis are thicker and heavier
Pelvic inlet shape	Pelvic inlet has a round or oval shape	Pelvic inlet is heart-shaped
Lesser pelvic cavity shape	Lesser pelvic cavity is shorter and wider	Lesser pelvic cavity is longer and narrower
Subpubic angle	Subpubic angle is greater than 80 degrees	Subpubic angle is less than 70 degrees
Pelvic outlet shape	Pelvic outlet is rounded and larger	Pelvic outlet is smaller

11

2. Skeletal adaptations: 3) New structures

– The greatly expanded sternum bears a large ***mid-ventral ridge or keel*** for the attachment of major flight muscles in flying birds, while it is without a keel in running birds, like ostrich.



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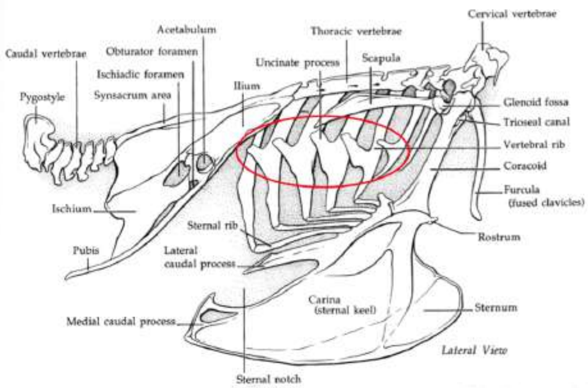
2. Skeletal adaptations: 3) New structures



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The Journal of Experimental Biology 210, 3955-3961
Published by The Company of Biologists 2007
doi:10.1242/jeb.008953

Functional significance of the uncinate processes in birds

Peter G. Tickle[1], A. Roland Ennos[1], Laura E. Lennox[1], Steven F. Perry[2] and Jonathan R. Codd[1,*]

The functional significance of the uncinate processes to the ventilatory mechanics of birds was examined by combining analytical modeling with morphological techniques. A geometric model was derived to determine the function of the uncinate processes and relate their action to morphological differences associated with locomotor specializations. The model demonstrates that uncinates act as levers, which improve the mechanical advantage for the forward rotation of the dorsal ribs and therefore lowering of the sternum during respiration. The length of these processes is functionally important; longer uncinate processes increasing the mechanical advantage of the Mm. appendicocostales muscle during inspiration. Morphological studies of four bird species showed that the uncinate process increased the mechanical advantage by factors of 2–4. Using canonical variate analysis and analysis of variance we then examined the variation in skeletal

14

2. Skeletal adaptations: 3) New structures

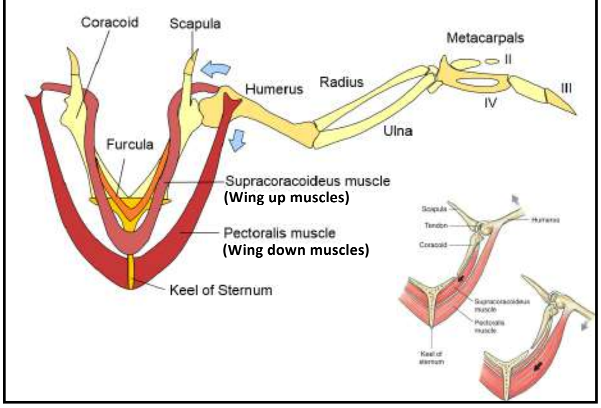
- **Heterocoelous vertebrae** (concave on one axis and convex on the other) especially in the neck.
  - one of the most flexible of vertebral joints allowing *extensive lateral and vertical flexion motion* without stretching the nerve cord too extensively or wringing it about its long axis.

Fig. 4-13 in Podulka et al. 2004

Saddle shaped

15

3. Musculature



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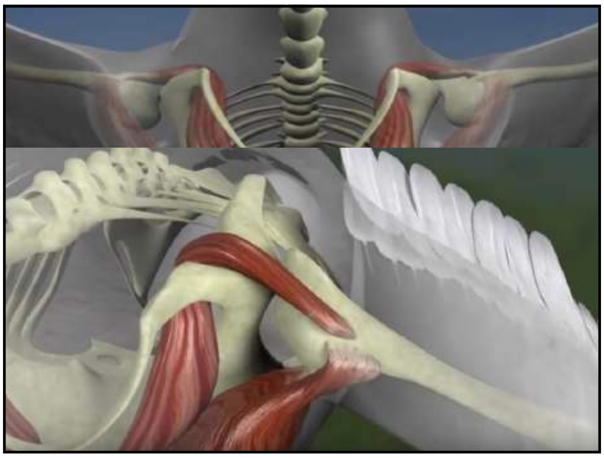

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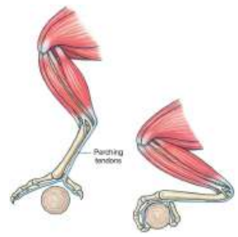
3. Musculature: Perching

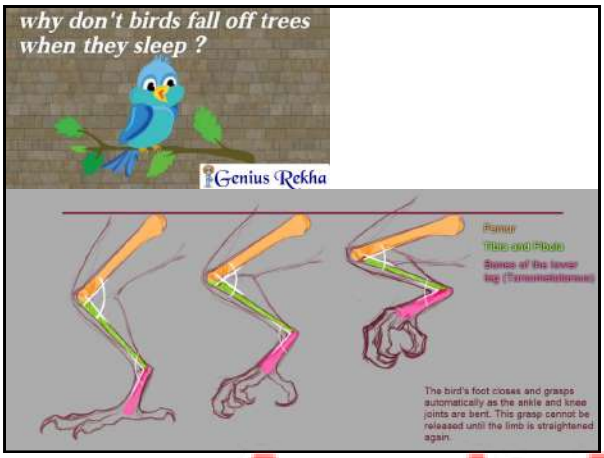
- *Toe-locking mechanism* is an involuntary reflex.
- Prevents a perching bird from falling off a branch while asleep.
- The flexor tendons run behind the heel along the tarsus and are inserted on the lower surface.
- As the bird settles down on the tree, the bending of knee and heel exerts a pull on the flexor tendons which make the toes automatically to flex and to grip the perch with almost no energetic cost.



6 Flexor digitorum longus (front toes) and *2 Flexor hallucis longus (back toe-hallux)*

Bending at the knee and the ankle

18



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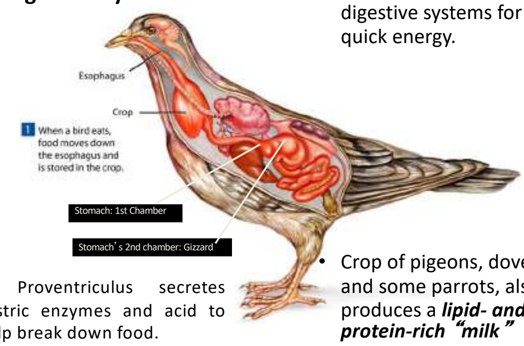
4. Metabolism

- High metabolism and endothermy
  - for quick generation of power and
  - for maintenance of high body temperature [38.0C to 42.0C (100.40F-107.60F)]★.
- The highest flight recorded for a bird was 11,274 m (37,000 ft.) when a Ruppell's griffon vulture collided into a commercial airline over western Africa.
- To help conserve body heat, birds fluff out there feathers to insulation.

20

5. Digestive system

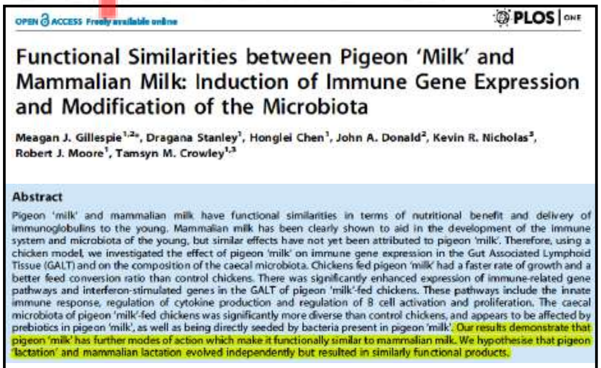
- Rapid and efficient digestive systems for quick energy.



1. Proventriculus secretes gastric enzymes and acid to help break down food.
2. Muscular walls of Gizzard move around contents and ***stones*** help break down food.

- Crop of pigeons, doves, and some parrots, also produces a ***lipid- and protein-rich "milk"*** which is regurgitated during nesting season and feed to young.

21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Functional Similarities between Pigeon 'Milk' and Mammalian Milk: Induction of Immune Gene Expression and Modification of the Microbiota

Meagan J. Gillespie[1,2*], Dragana Stanley[1], Honglei Chen[1], John A. Donald[2], Kevin R. Nicholas[3], Robert J. Moore[1], Tamsyn M. Crowley[1,3]

Abstract

Pigeon 'milk' and mammalian milk have functional similarities in terms of nutritional benefit and delivery of immunoglobulins to the young. Mammalian milk has been clearly shown to aid in the development of the immune system and microbiota of the young, but similar effects have not yet been attributed to pigeon 'milk'. Therefore, using a chicken model, we investigated the effect of pigeon 'milk' on immune gene expression in the Gut Associated Lymphoid Tissue (GALT) and on the composition of the caecal microbiota. Chickens fed pigeon 'milk' had a faster rate of growth and a better feed conversion ratio than control chickens. There was significantly enhanced expression of immune-related gene pathways and interferon-stimulated genes in the GALT of pigeon 'milk'-fed chickens. These pathways include the innate immune response, regulation of cytokine production and regulation of B cell activation and proliferation. The caecal microbiota of pigeon 'milk'-fed chickens was significantly more diverse than control chickens, and appears to be affected by prebiotics in pigeon 'milk', as well as being directly seeded by bacteria present in pigeon 'milk'. Our results demonstrate that pigeon 'milk' has further modes of action which make it functionally similar to mammalian milk. We hypothesise that pigeon 'lactation' and mammalian lactation evolved independently but resulted in similarly functional products.

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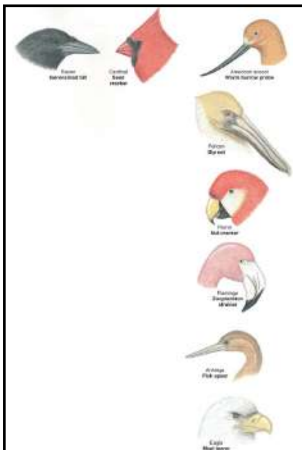


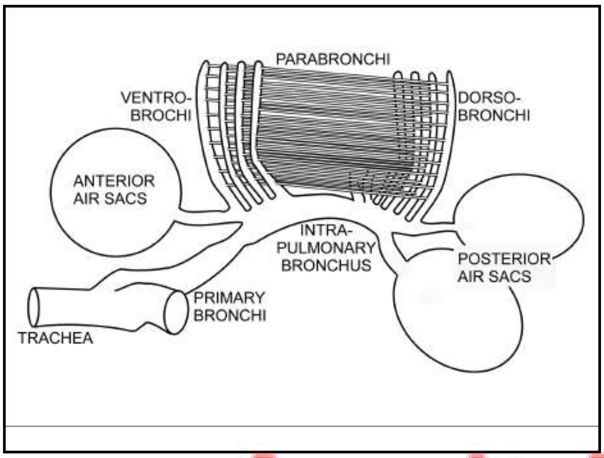
Different bills of birds showing adaptations to different environments

23

6. Respiratory system

- Lungs inelastic★ but proportionately larger and efficient.
  - Finest branches of the bronchi do not terminate in alveoli but tube-like ***parabronchi***.
  - Supplemented by a system of anterior and posterior **distensible air-sacs**, which in turn are connected with the air spaces in the bones to:
    - provide buoyancy.
    - stay cool (during flight when 27x more heat is produced)

24



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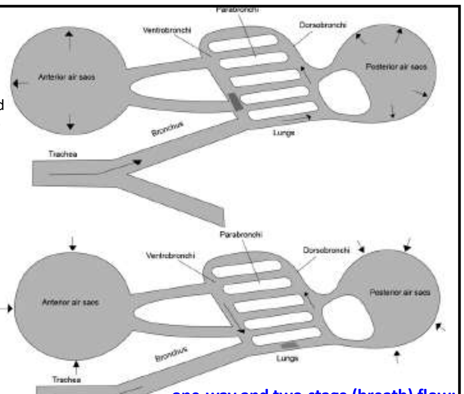
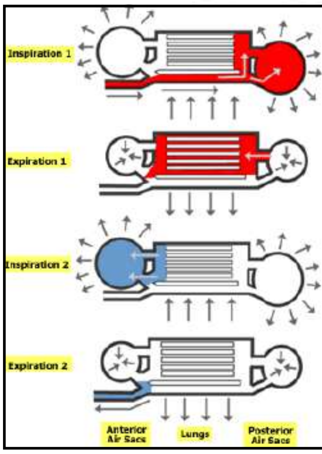
A breath of inhaled air passes first into the posterior air sacs and then, on exhalation, into the lungs. When a second breath is inhaled into the posterior sacs, the air from the first breath moves from shrinking lungs into the anterior air sacs. When the second exhalation occurs, the air from the first breath moves from the anterior air sacs and out of the bird, while the second breath moves into the lungs. The air thus moves in one direction through the lungs.



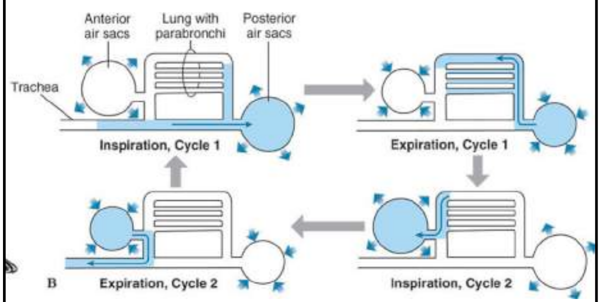
one-way and two-stage (breath) flow: compensation for small sized and inelastic lungs

26



- A breath of inhaled air passes first into the posterior air sacs, bypassing lungs, and then, on exhalation, into the lungs.
- When a second breath is inhaled into the posterior sacs, the air from the first breath moves from shrinking lungs into the anterior air sacs and then, on exhalation, out of the bird.

27



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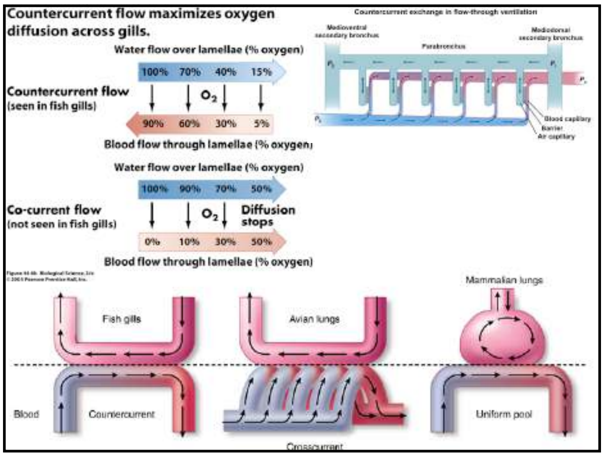

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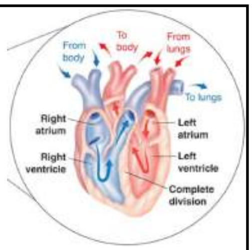
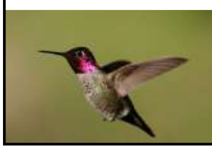
7. Circulatory system

- The four chambered avian heart is relatively large and functions with a double circulation of blood.
- The high proportion of haemoglobin.★
- Rapid heart beat and high blood pressure★ and high blood sugar.



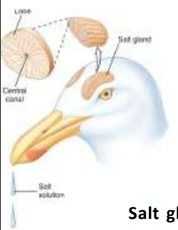


- Turkey heart beats 93 times/ minute
- Chicken heart beats 250 times/ minute
- 600 times a minute

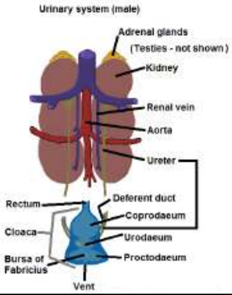
30

8. Excretory system

- The kidneys excrete nitrogenous wastes in the form of semisolid *uric acid*.
- Waste are **voided at once** (because urinary bladder and urethra are absent).



Salt gland of marine birds causing "runny nose"



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The Salt-Secreting Gland of Marine Birds

By Knut Schmidt-Nielsen, Ph.D.

The kidneys of birds and reptiles have a concentrating ability which is considerably less than that of the mammalian kidney, apparently because they contain no typical loops of Henle. Birds, which can excrete a urine which is about twice as concentrated as the plasma, have some looped nephrons, but these are not as highly developed as in mammals. Reptiles have no loops in their kidneys, there is no countercurrent multiplier system, and their urine cannot be concentrated above the plasma concentration. As a consequence, marine birds and reptiles cannot rely on the kidney for osmoregulation, and they appear to have a choice between avoiding the drinking of sea water and acquiring some means for salt excretion more efficient than their kidneys.

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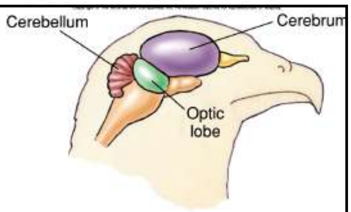
9. Nervous system

Brain:

Proportionally much larger than those of reptiles and comparable, in fact, with those of rodents.



- Cerebral hemispheres enormus- for complex behavioural patters such as navigation, mating and nest building.
- Cerebellum is well developed and convoluted- for coordination of muscular activity and balance.
- Olfactory lobes are greatly reduced but optic lobes are excessively enlarged.

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9. Nervous system

Sense organs (eyes):

- Relatively large and immobile★ eyes gives a wide field of view and/or binocular vision★.
- Sclerotic ring of bony plates protects the eye ball and increases the distance between the lens and retina for sharp distant vision.
- High density of photoreceptor cells retina.

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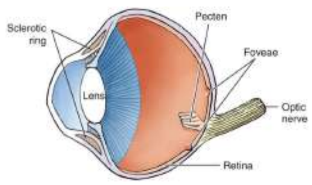
- An indented fovea on retina magnifies the central part of the visual field. Many species (e.g., hummingbirds and albatrosses) have two foveas in each eye.
- Ability to detect polarized light is also common in birds.

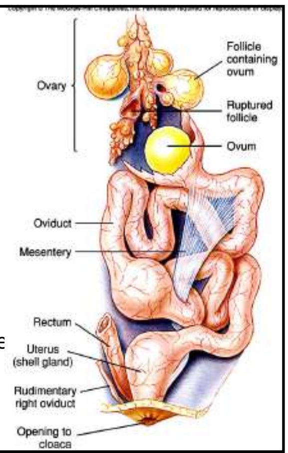


- It is highly vascularized, supplying the bird with nutrients and oxygen for the eye and carrying away waste.
- Cone cells on Foveae- 1.5 million for hawk (0.2 million for human) allows for better vision.

35

10. Reproductive system

- No species give birth to live young★.
- Reproductive organs (testes, ovaries and oviducts) are reduced in size except in the breeding season (up to 300 times).
- With few exceptions like birds of prey★, most females have only one functional (usually left) ovary.
- Female liver is displaced to the right to compensate for weight difference.



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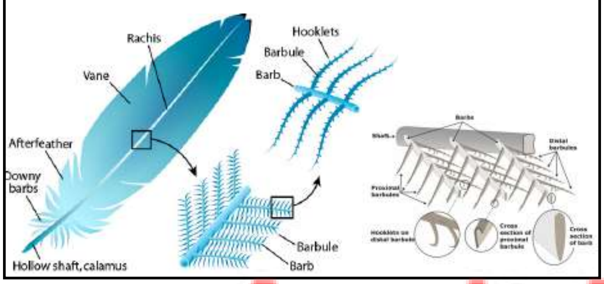
11. Flight: Feathers

- Flight (including buoyancy), insulation, display and camouflage.
- Ground-up vs. trees-down hypothesis.



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- ***Remiges***: On the wings, help in flight.
- ***Rectrices***: On tail, stretch sideways in a fan-like manner so that tail can be used like a rudder for turning and balancing during flight, to suddenly check flight, and as a counterbalance in perching.
- ***Contour feathers:*** Outermost body covering, decrease the body drag by making it streamlined.
- ***Down feathers:*** Under contour, lack rachis and insulate the body.
- ***Filoplume***: Hair like with weak shaft and tufty barbs.

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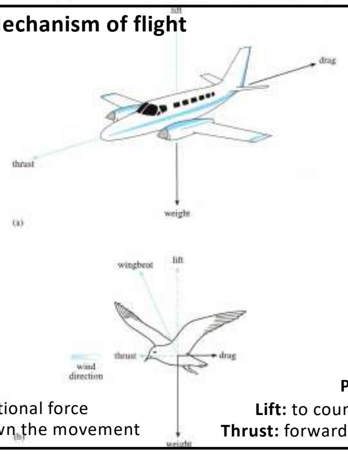
11. Flight: Mechanism of flight



Negative forces
Weight: gravitational force
Drag: slows down the movement

Positive forces
Lift: to counteract weight
Thrust: forward-moving force

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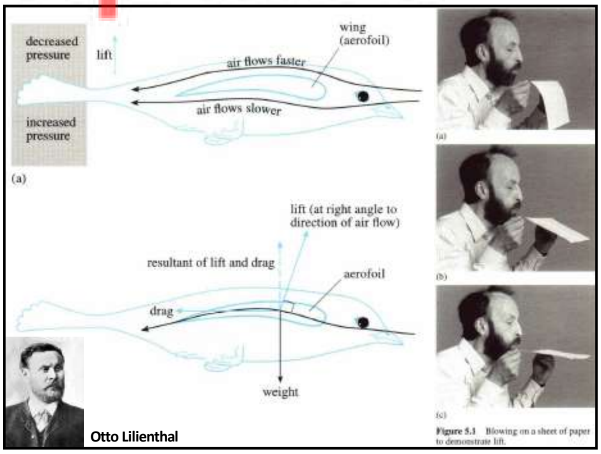

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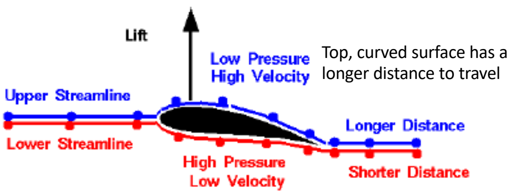

Top, curved surface has a longer distance to travel

Incorrect theory ?

Bird wings are shaped so that the distance from the front to the back over the top of the wing is greater than the distance under the wing. Yet, the same amount of air must flow over both the top of the wing and the bottom. In order for the same amount of air to pass over the longer distance on top, the air on top must move faster than it does over the bottom of the wing. The air over the wing is at a lower pressure. This occurrence is termed the Bernoulli effect. If a bird is moving fast enough, the force from the pressure difference, which is called the lift force, equals or exceeds the weight of the bird and the bird is able to fly.

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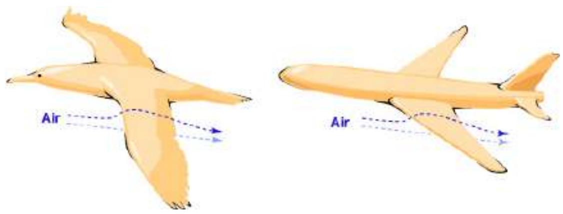
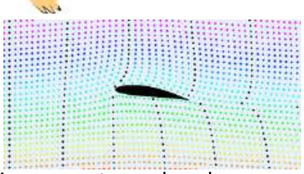
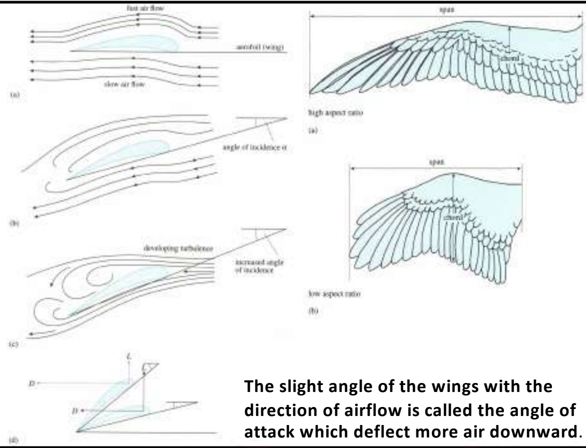
It is the curvature that creates lift, not the distance





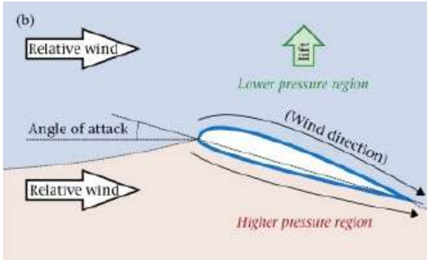
Because the wing geometry and angle ***narrows*** the flow area above the wing and **widens** the flow area below the wing.

42



The slight angle of the wings with the direction of airflow is called the angle of attack which deflect more air downward.

43



Lift is generated in two ways.
(a) Air is deflected downward when there is a positive angle of attack (Newtonian lift).
(b) When air moves faster over the top of the wing than the bottom, the pressure difference is generated (lower on the top of wing) (Bernoulli lift).

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There are four forces that act on a flying machine in flight, whether bird, bat, insect, or airplane: lift, thrust, drag, and gravity. Thrust must equal drag and lift must equal gravity in straight and level flight. When the leading edge of a streamlined wing (airfoil) cleaves the air, it pushes the air both up and down so that the amount of air passing above and below the wing is the same. But if the contours of the wing are unequal, the air pressure against them will be unequal because one airstream must travel faster over one surface of the wing than the other. Because the air molecules travel faster and over a longer distance, there is less pressure (Bernoulli's Law) Thus the wing moves up into the area of lesser pressure (LIFT). But as air passes over the wing, friction is generated; the effect of this friction is to slow the wing and is called DRAG. If the wing is tilted upward (-5 to +15 C; increased angle of attack), the pressure on the upper part of the wing is reduced even further and lift increases; but so does drag. As the angle of attack continues to increase further, it is so steep that air cannot flow smoothly over the top of the wing and lift decreases until a stall (loss of lift) occurs. The more thrust there is, the higher the angle of attack can be without stalling. That's why jets and rockets can go straight up and why their wings are small – because they use the vertical component of thrust rather than lift to gain altitude. To reduce turbulence, wing slots can be used. These slots are on some airplanes as slats or double wings as on biplanes. On a bird, a special small group of feathers attached to the thumb (1st digit), the alula, rests on the anterior wing surface and can be raised so that there is a gap between it and the rest of the wing. At higher angles of attack, the pressure above the alula drops and it is automatically sucked up to make the slot.

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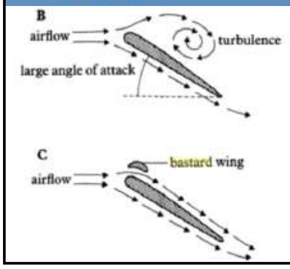

Figure 21.15 The bird wing as an aerofoil. **A** The air flows faster over the upper surface of the wing than the lower surface; this creates a reduced pressure above the wing and an increased pressure below it, thereby providing the bird with lift. The lift force can be increased by holding the wing at a greater angle to the airstream, i.e. by increasing the angle of attack; however, too great an angle of attack may cause turbulence above the wing as shown in **B**. **C** Turbulence is normally prevented by the bastard wing and the end-feathers which serve as slots smoothing the flow of air over the upper surface of the wing.

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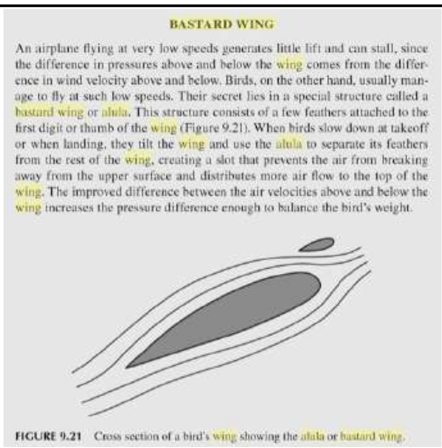

BASTARD WING

An airplane flying at very low speeds generates little lift and can stall, since the difference in pressures above and below the wing comes from the difference in wind velocity above and below. Birds, on the other hand, usually manage to fly at such low speeds. Their secret lies in a special structure called a bastard wing or alula. This structure consists of a few feathers attached to the first digit or thumb of the wing (Figure 9.21). When birds slow down at takeoff or when landing, they tilt the wing and use the alula to separate its feathers from the rest of the wing, creating a slot that prevents the air from breaking away from the upper surface and distributes more air flow to the top of the wing. The improved difference between the air velocities above and below the wing increases the pressure difference enough to balance the bird's weight.

FIGURE 9.21 Cross section of a bird's wing showing the alula or bastard wing.

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