BIRDS

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Summary

Birds are warm-blooded terrestrial vertebrates whose front limbs are modified into wings. Most birds can fly and the whole of their shape and internal anatomy is harmoniously developed into a powerful flying machine. The wing surface is provided by feathers serially arranged along the ulnar margin of the fore limbs; additional support for flying and maneuvering is provided by the feather fan replacing the very reduced tail. Birds maintain an almost constant body temperature despite changes in the temperature of the surrounding environment. The needs of their fast metabolic reactions are supplied by exceptionally efficient respiratory, circulatory and digestive systems. The lungs are rigid, lack dead space, and are filled with minute air tubes. Air is pumped through the lungs by a bellows-like action of air sacs found only in birds. All birds lay and incubate eggs from which their young hatch, and they typically have highly developed social and parental behavior. Some 9000 living species of birds are currently acknowledged.

1. Introduction

Birds are feathered, warm-blooded, bipedal, four-limbed vertebrates whose front limbs are modified into wings. In general, birds are active, flying, diurnal creatures that are able to travel rapidly over large distances across the globe. All birds lay and incubate eggs from which their young hatch, and they typically have highly developed social and parental behavior. Birds are among the animals best known to humans. Their large number of species and individuals, widespread occurrence, colorful plumage, daytime activities, loud and often melodious song, and the bizarre courtship displays of some species have long made them familiar and attractive to humans. Above all, humans have been fascinated by the flight of birds and have attempted since antiquity to copy this ability. Success was reached with engine-powered heavier-than-air machines in the early twentieth century, but not until the late 1970s were aircraft light enough to fly with power supplied by human muscles. In 1981 the Gossamer Albatross barely crossed the

English Channel under human power—a herculean feat for a human but an easy task for the countless millions of birds that accomplish it each year.

Birds are studied intensively by ornithologists—students of avian (bird) biology—and they are observed avidly by millions of birdwatchers. Birds and their eggs are major research tools in biological studies. Perhaps even more important, however, birds represent free spirits that provide enjoyment to many people. Feathers—unique to birds—are crucial to avian flight. They provide strong, lightweight flying surfaces on the wings and tail. They also provide an insulating barrier on the body surface, and streamline the outer surface of the body, essential for efficient flight. Although birds are essentially flying machines, it must not be concluded that birds spend all of their time in the air or that all of their activities take place in the air. All birds must return to the ground for nesting. Only a few groups of birds, such as swifts, swallows, man-of-war birds, and some oceanic terns spend most of their time flying. A few species of oceanic terns (noddies) that cannot settle on the water, may spend all of their non-breeding time away from the breeding islands, flying (up to 2 to 3 years for immature birds), including sleeping in flight.

Birds exhibit great variation in color and patterns of plumage, ranging from a single drab color to all hues of the rainbow in striking patterns. Feathers may be modified into brilliantly colored and peculiarly shaped plumes. Birds fill important ecological niches and contribute in many ways to the human economy. Many species eat insects that are harmful to humans and crops, while a few inflict damage, eating grain and fruit crops. Chickens and other poultry provide meat and eggs for food, and waterfowl provide down for bedding and clothing.

In any flying apparatus, weight is critical, and birds have reduced body weight as much as possible. All bones are thin-walled with internal struts for an ultra-light but extremely strong skeleton. All weight is concentrated toward the center of the body, further reducing the need for extra skeletal and muscular strength, and thus for weight. High power output is needed for flight and is produced by rapid chemical reactions in body metabolism made possible by homoiothermy, or warm-bloodedness. Birds, unlike cold-blooded reptiles, maintain an almost constant body temperature despite changes in the temperature of the surrounding environment. The needs of their fast metabolic reactions are supplied by exceptionally efficient respiratory, circulatory and digestive systems.

Birds have evolved from reptiles, from a stock close to the ancestry of dinosaurs. Yet birds are not merely glorified reptiles; almost every aspect of their biology has changed with the acquisition of flight. Birds truly are flying machines. Everything about their structure, function, behavior, and ecology is tied tightly to the ability to fly. Flightless birds are of special interest just because of their inability to fly, although some of them—the penguins—actually fly through the water. Although both birds and mammals have evolved from reptiles, the separation of the two lineages leading to these two groups of warm-blooded vertebrates had already separated by the mid-Carboniferous, 325 MYA. Hence all of the similar attributes of these two groups evolved independently, so that birds are not good analogues to mammals. Birds differ from mammals in numerous significant ways such as possessing enzymes to digest waxes, a pectin in the eyes, color vision with four different color-detecting cone cells in the retina, the ability to see luminescent colors and into the ultraviolet and to see polarized light, and the ability to detect the earth's magnetic field and use it for orientation and navigation, etc.

2. Basic attributes

2.1. Body

Birds vary in size from the smallest hummingbird at 0.08 ounce (2.25 gm) to the largest ostrich at 317 pounds (144 kg). Most species weigh less than 2 pounds (0.9 kg), and the maximum size for living flying birds is just over 22 pounds (10 kg) in swans, turkeys, and bustards. Birds possess two separate systems for locomotion—wings for flying and hind limbs for walking, running, and swimming. Thus they require two different sets of muscles and a strong skeleton to support each, with the result that the trunk of birds is a rigid box. The center of gravity must lie close to the center of the rigid trunk so as to be within the plane of the lift-producing surfaces (the wings) and over the placement of the feet, allowing the bird to stand upright when it locomotes bipedally. In many birds the flight muscles account for 30% to 40% of the total body weight. These muscles are supported by a large keeled sternum, or breastbone, and a stout pectoral, or shoulder, girdle. The muscles of the legs are large and make up 20% to 30% of the body weight in most birds. A fused pelvic girdle and fused sacral vertebrae (synsacrum) form a scaffold for the hind limbs of birds. The trunk skeleton itself is rigid with many bones fused together.

2.2. Feathers

These epidermal outgrowths are unique to birds and are crucial to avian flight. They provide strong, lightweight flying surfaces on the wings and tail. They also provide an insulating barrier on the body surface as well as a streamlining surface for the entire body of the bird which can be readily appreciated by comparing a plucked bird with a fully feathered one. Birds exhibit great variation in color and patterns of plumage, ranging from a single drab color or a camouflaging patters to all hues of the rainbow in striking patterns. Frequently males and females of the same species differ in color and pattern, with the males being generally brighter and more patterned and the females camouflaged. Feathers may be modified into brilliantly colored and peculiarly shaped plumes. For example, the long, paired head plumes of the King of Saxony Bird of Paradise (*Pteridophora alberti*) consist of small enamel-blue vanes on one side of shafts, which are twice the length of the body and are the most bizarre of all bird feathers.

2.3. Power production

High power output is needed for flight. The power, or energy, is produced by rapid chemical reactions in body metabolism. These high rates are made possible by homoiothermy, or warm-bloodedness. Birds, unlike cold-blooded reptiles, maintain an almost constant body temperature despite changes in the temperature of the surrounding environment. The high body temperature of birds—110.5 ^{o}F (43.5 ^{o}C)—makes them metabolic racers. To meet the needs of their fast metabolic reactions, birds have evolved an exceptionally efficient respiratory system and rapid circulatory and digestive systems. The lungs are rigid, lack dead space, and are filled with minute air tubes. Air is pumped through the lungs by a bellows-like action of separate air sacs found only in birds. The heart beat is two to four times higher than in mammals, providing rapid circulation and thus a fast flow of oxygen to body tissues. Digestion is also fast and efficient. Birds eat large amounts of food and utilize a large percentage of its nutritional value.

2.4. Song

Only in the frogs and in some social mammals does the voice even approach the importance it has for birds. A few species—pelicans, storks, and some vultures—have no voice, but the majority of birds produce calls and songs. Most species of birds can be identified by their calls and songs, and some, in fact, can be differentiated in the field only by their songs. Calls, songs, and other noises carry far and can advertise an individual's presence even when it cannot be seen in thick vegetation. In many species songs are an important part of courtship, with males calling and singing to define their territories and attract females during the mating season. The song can vary from a short harsh note to a long elaborate musical sequence. Some species, such as mockingbirds and lyrebirds, are excellent mimics; they copy the songs of many other birds and the sounds of mammals.

Calls and songs are produced in the syrinx, the posterior larynx, located at the junction of the trachea and the two primary bronchi. Sound is produced by the vibration of the membranes in the lateral walls of the syrinx. Proper inflation of the surrounding air sac is essential for sound production. Each side of the syrinx can act independently of the other, and some birds actually produce two sounds at the same time. Deep trumpeting calls in swans and cranes result from resonances developed in their long tracheas. Other birds have resonance chambers formed by inflated cervical (neck) air sacs or an inflated oesophagus.

2.5. Life span

In most, if not all species, most individuals die in their first year, victims of predators, disease, or starvation. After the high mortality of the first year, the death rate drops considerably. In general, small birds live shorter lives than do large birds. For small perching birds the mortality rate in the first year may be up to 80%, with a maximum age of six to eight years. Large birds of prey (eagles, hawks and owls), parrots and albatrosses have a much lower first-year mortality rate and a maximum age of 40 to 50 years. All birds live longer in captivity than in the wild. Small perching species reach 20 to 25 years, and large birds of prey, parrots, cranes, and pelicans 50 to 70 years.

3. Structure and physiology

3.1. Outer shape

Birds are two-footed tetrapods with forelimbs modified into wings. The head is small, with a relatively large brain and large eyes, and the jaws are modified into a horny bill, or beak. The bones of the skull are fused into a solid brain case with the jaw apparatus comprised of a small number of moveable elements. The neck is long and flexible, permitting the bird to reach all parts of its body with its bill. The trunk is short and rigid, dominated by a large bony sternum, stout rib cage, and a large synsacrum plus pelvic arch. The body surface is covered with feathers. The remiges, or wing flight feathers, and the rectrices, or tail flight feathers, are larger and stiffer than the contour feathers of the body. The bases of the flight feathers are covered by overlapping layers of coverts. Wings vary in length and shape from the long narrow wings of albatrosses—with a span of 12 feet (3.65 meters)—and the broad soaring wings of vultures and eagles, to the pointed wings of high-speed swifts, hummingbirds, and falcons, and the rounded wings of forest birds.

The tails of birds typically vary in length and shape from rounded to deeply forked or pointed. Highly elaborate tails are found in some birds in which tail displays are especially important. The tail of a peacock (*Pavo*), for example, is composed of upper tail coverts supported by the retrices. The length of the leg and the structure of the foot depend on the bird's form of locomotion and prey capture. Walking and wading birds have long legs, and swimming birds have webs, either between the toes or along the edges of the toes. Raptors and owls have strong grasping toes with large sharp claws. Perching birds have opposable digits for grasping branches, and climbing birds have strong sharp claws that can dig into bark.

The great variation among bird bills reflects differences in food preferences and methods of feeding. Most groups can be recognized readily by bill structure. Typical bills are spear-like for catching fish, hooked for tearing flesh, thin for picking up insects, flat for catching flies, conical for eating seeds, long for probing in flowers, sieve-like for straining food from water, and chisel-like for digging insects out of trees. Among the most peculiar bills are the flat spoon-shaped bills of the spoonbills, used for capturing small water animals; the elongated knifelike lower jaws of skimmers, used to catch small fish as the birds skim above the water surface; the twisted cross jaws of the crossbills, adapted for digging seeds out of the cones of pines and other conifers; and the asymmetrical bill of the wrybilled plover of New Zealand, which bends sharply to the right halfway to its tip and permits the bird to capture insects beneath stones.

3.2 Integument

3.2.1. Feathers

With the normal exception of the feet, legs, bill, and sometimes the head, the body of birds is covered with feathers, which have evolved from the scales of their reptile ancestors. Body feathers insulate the bird's body against heat loss and provide a streamlined body surface. Wing and tail feathers also provide aerodynamic surfaces for flight. Most, but not all, aquatic birds have waterproof feathers that provide buoyancy by increasing body volume with only a small increase in weight.

The basic structure of a feather is a long shaft bearing two vanes composed of closely packed and interlocked barbs. In addition to typical contour feathers, wing flight feathers, and tail flight feathers, there are several other types of feathers: semiplumes, which have a large downy base; filoplumes, which have a few barbs at the tip of the long shaft; bristles, which have a long shaft with barbs at the base; and down feathers, which have a short shaft from which fluffy barbs arise. Certain specialized down feathers decompose gradually into an exceedingly fine white powder whose function may be to clean or waterproof feathers.

In most birds the contour feathers are arranged in definite feather tracts; only a few groups have feathers distributed uniformly over the body. Muscle fibers connect the bases of neighboring feathers and serve to raise and lower the feathers. The color and pattern of the plumage serve as protective coloration, as recognition marks, and in courtship displays. Frequent preening with the bird's bill is needed to keep the feathers and barbs properly arranged. A secretion from the uropygeal, or preen, gland located at the base of the tail is spread over the surface of the feathers to maintain their structure and in some cases to waterproof them. Water and dust baths and the curious rubbing of ants on the feathers may serve to remove external parasites.

3.2.2. Scales and claws

The legs and feet of birds are covered by scales and scutes identical to the horny scales found in reptiles. Small, rough scales on the undersurface of the toes increase the grip on slippery twigs and prey. Horny claws are found on all toes in birds and on the tips of the fingers in some groups, generally less advanced ones. A few birds have serrated edges on one or more claws of the toes; these are used as a comb during preening.

3.2.3. Bill covering

A heavy, horny continuously growing sheath covers both bony jaws and gives the bill its shape. It is usually a single upper and a single lower sheath, but in some families it is divided into several pieces. The external nares (nose openings) pierce the upper sheath or emerge as paired tubes in shearwaters and their allies. The external nares are completely blocked in gannets and cormorants to prevent the entrance of water when these birds dive into the water. Such birds breathe through their mouths.

3.3. Wings

The wing is a modified tetrapod forelimb to which the flight feathers are attached. All of the original functions of wings have been lost, and they now serve only for flying, balance and (in a few species) for swimming. The first and fifth digits of the hand have been lost, and the bones of the remaining digits have been fused into a single carpometacarpus, to which the bases of the primary flight feathers are anchored (see Figure 1). The primary feathers are the "propellers" that provide forward thrust in flight. A few feathers attach to the free phalanx of the second digit form the alula. When the alula is raised, the slot or gap between it and the wing permits the smooth flow of air at low speeds and prevents aerodynamic stalling. The long series of secondary flight feathers attach to the ulna bone of the lower arm, and in some species a few tertiary flight feathers are attached to the outer end of the upper arm bone, the humerus. Secondaries and tertiaries form the main part of the lifting surface—the equivalent of an airplane's wing.

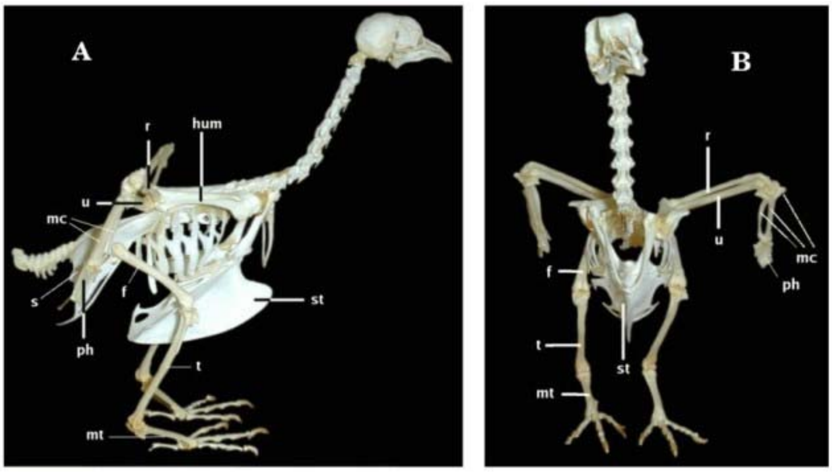

Figure 1. The avian skeleton (pigeon). A: Lateral view. B: Front view. (f: *femur*. hum: *humerus*. mc: *carpometacarpus*. mt: *tarsometatarsus*. ph: *phalanx*. r: *radius*. s: *synsacrum*. st: *sternum*. t: *tibiotarsus*. u: *ulna*.)

The head of the humerus articulates with the shoulder so that it swings up and down during flight and rotates backward when the wings are folded over the back. Two pairs of large flight muscles arise from the keeled bony sternum. The large superficial pectoralis muscle attaches directly onto the ventral surface of the humerus. It pulls the wing downward during the strong power stroke. The wing is pulled upward by the smaller supercoracoideus muscle. The tendon of this deep muscle passes through the junction of the three bones comprising the pectoral girdle and over the shoulder joint to attach to the upper surface of the humerus. In hummingbirds, which have powerful upstroke as well as downstroke, the two muscles are equal in size.

The wings of penguins are modified into a rigid paddle that is powered by the strong flight muscles for "flying" through water. Most flightless land birds have greatly reduced flight muscles and have lost the keel on the sternum.

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Biographical Sketch

Walter J. Bock was born in New York City in 1933. He earned a B.S. from Cornell University in 1955 and a Ph.D. from Harvard University in 1959. He spent two years at the University of Frankfurt in Germany, and taught briefly at the University of Illinois in Urbana-Champaign before assuming an assistant professorship at Columbia University in 1966, where he quickly rose through the ranks.

Walter Bock sees himself primarily as an evolutionary biologist with a focus in basic theory and philosophy. This and his straightforward career, however, stand in stark contrast to his multi-faceted research interests and contributions in ornithology, systematics, functional, ecological and evolutionary morphology, biomechanics, the evolution of higher taxa, the theory of evolution, and the history and philosophy of biology and science. Furthermore, in each research area, his influence has reached a large number of students and associates through his world-wide publications, collaborative efforts, personal associations, and activities in professional organizations. His intellectual biography traces the development and diversification of his thinking, as well as the roles that his empirical research and professional contacts have played in the evolution of his work.