

# Styles of Flight, Flight Surface & Flight Muscles of Birds

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**ABSTRACT:** A flying bird in nature is capable of variety of flight manoeuvres such as flapping, hovering, bouncing and gliding. Birds are God gifted Natural Flying Machines. They possess different styles of flight. Some birds have capability of flying long distances even for very long durations. The energy turnover of their flight is considerably small when compared to the different locomotion of animals as well as man-made flying machines. Hence different styles of bird flight, commonly observed, are explained. In bird flight, 'flight System' comprises of flight surface (wing) and flight muscles and are engineered to have adaptation for different styles so that bird can fulfill flight requirement. Hence, flight surface (wing) and flight muscles are described here. This information forms the base and also useful to mathematicians and physicists for the understanding of bird flight adequately.

**KEY WORDS:** Styles of flight, bird flight, flight surface (wing), types of wing, flight muscles.

## I. STYLES OF FLIGHT

The basic requirements for flight are common among the biological fliers. The styles and types of flight are different in different avian orders and these flights have evolved from a common prototype, Birds have an adaptation for different styles of flight. Flight style can be either passive (gliding and soaring) or active (flapping). Less energy is required in passive flight whereas active flight demands more energy. During passive flight the bird makes more use of its structure and the surrounding atmosphere. In conclusion, bird flight is influenced by morphological, anatomical, physiological and environmental factors.

### 1.1. GLIDING FLIGHT

Gliding flight is that bird flight in which lift and drag are components of bird's weight (Fig. 1.). This type of flight is found in large birds and insects such as butterflies, moths, falcons and eagles. During gliding wing beat frequency is rather zero. Wings are held in a fixed configuration. In birds, wing span varies according to gliding speed. During gliding metabolic energy is not spent. This mode of flight is also practiced in forward flight during landing. In gliding, flier may lose velocity and height. For small glide angles lift and weight are equal.



Fig. 1. Gliding flight of a bird

Lift,  $l = W \cos \theta$ ; Drag,  $D = W \sin \theta$ , where  $\theta$  is the gliding angle ie, angle of the flight path to the horizontal

Gliding involves the stretching of the bird's wings in an almost horizontal path, so as to generate greatest lift and least drag. This can be achieved at a certain angle of attack, known as gliding angle. If velocity of gliding bird is constant, it must be in equilibrium under the action of its weight. The equilibrium can be attained if direction of motion is inclined downward relative to the horizontal.

Gliding in still air is also known as *Slope current* flight. During gliding air is assumed to be stationary. In still air, air speed and ground speed are the same. Many birds can be seen gliding for short distances either with wings partially folded or fully stretched. Biological fliers by gliding mainly take the advantage of gravity and some extent wind currents to cover relatively large distances. The gliding birds make use of air currents as the main source of energy to remain air borne by stretching the wings in the horizontal path. During gliding very little metabolic energy is spent.

Good gliders like stork, eagle and kite can descend steeply downward by folding their wings decrease their wing area, increase their wing loading and glide slowly for a long time. Higher is the speed of glide, the wing area and wing span get reduced thus leading to less drag. However, it is notable that wing breadth remains more or less the same in gliding. By flexing the wing, the wing area, aspect ratio and sink rate change. Many birds do undergo some gliding phase for some distance before landing. Parrots and pond herons practice round about landing as a controlled gliding device, which helps in reducing the high velocity before landing. This follows the relation of turning radius as given by  $R = v^2/g[1]$ .

## 1.2. SOARING FLIGHT

Soaring is a kind of bird flight in which flying bird uses convection currents (thermals) to be airborne without having extra power sources, in contrast to airplane in which motor power is required and for birds flapping of wings serve the purpose.

Soaring is one type of gliding (Fig. 2a). Soaring enables a bird to remain airborne for longer periods with relatively little cost of energy. According to Lord Rayleigh [2], the necessary condition for soaring is that the wind velocity must neither be horizontal nor uniform. Therefore, two types of soaring occur – thermal (land) soaring and dynamic (oceanic) soaring.



Fig. 2(a).. Soaring flight of a bird  
(From [ucsdnews.ucsd.edu](http://ucsdnews.ucsd.edu))

Thermal updrafts or thermals are produced when air near the surface of land is warmed and rises in columns. Exposed rocks and forests have a high level capacity and above the surfaces of these, the warming is rapid. The raising air serves source of energy to execute soaring on land. Once thermals are located, the bird flies in a spiral path in the air higher and higher and subsequently glides to another thermal (Fig. 2b).

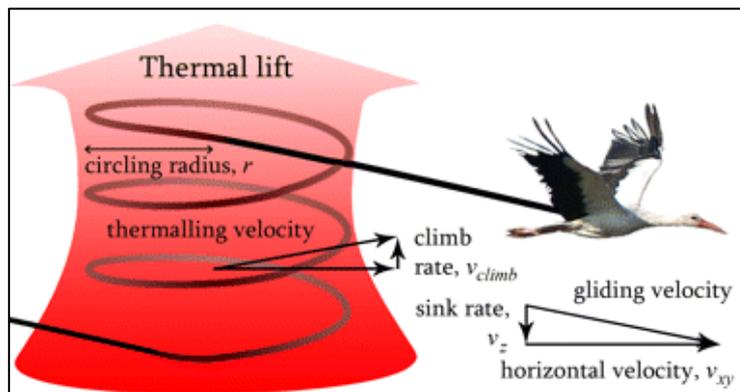


Fig. 2(b). Path of Soaring flight of a bird  
(From Bird flight II, people.eku.edu)

Besides thermals, the bird also makes use of slope updrafts produced when the wind is deflected over an obstacle and front updrafts produced when two different air masses converge. Soaring above the sea, i.e., dynamic soaring, is quite different where the wind is even and a systematic raise in wind velocity does not occur. But the wind velocity is slowed by friction at the surface of water – the closer to the water, the more the wind is slowed down and hence wind speed rises with altitude. The bird can soar higher up in the air due to the increase in lift until it loses momentum, then glides downwards in order to build up speed and rises again into the wind to repeat the entire process. This principle of dynamic soaring was first explained by Idrac [3].

Majority of birds cannot make use of thermals by soaring; instead they continuously flap their wings to generate aerodynamic lift. This is flapping flight. In flapping, the bird's wings move with respect to the air and maintain the wind flow over the wings.

### 1.3. BOUNDING FLIGHT

In bounding flight, the bird makes a flap and then bullet through the air until it is timed for another flap (Fig. 3a). The bird uses bounding flight to save energy. Fig. 3(b). depicts a string of consecutive images in a short duration of time to show the idea of bounding flight. This type of flight executes intermittent flight patterns in which a bird undergoes alternately between flapping (powered) flight and passive flight wherein its wings are folded (Fig. 3b). When a bird adopts this flight, it rises and falls in altitude following a path as shown in Fig. 3(c).

Bounding flight is observed only in small birds. The birds executing bounding flight possess wings of relatively large area and low aspect ratio with rounded tips. Such birds are small passerines, small parrots and small owls; and green wood pecker being the largest bird observed to use this flight style[4-5].



Fig. 3(a). Bounding flight of a bird



Fig. 3(b). Consecutive images strung together to show the idea in a very short duration of time (from moorhen.me.uk)

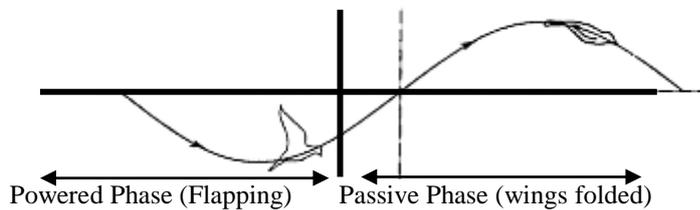


Fig. 3(c). Flight path of Bounding Flight (From semanticscholar.org)

#### 1.4. HOVERING FLIGHT

In this flight, a flier is airborne in dynamic equilibrium, pushing air in downward direction in turn generating reacting force in upward direction by beating its wings so as to balance its weight[6]. In this case weight of the flier is equal to the reacting force (Fig. 4.).

The aerodynamic situation around the oscillating wing is not simple since it involves complicated movements of the wing. During the flapping cycle the wing moves up and down. In many cases, down stroke is the power stroke since it generates much of the lift required for flight. In hovering, the bird extends its wings fully downward so as to generate force to overcome the downward pull of the body.

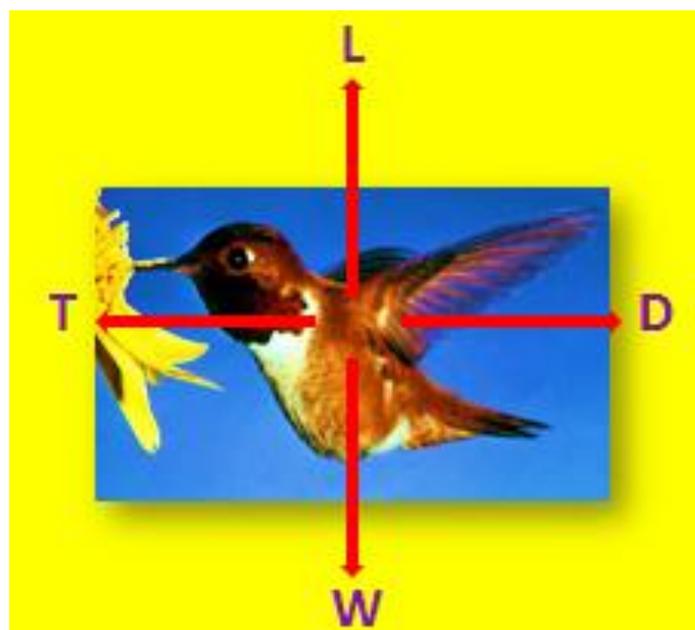


Fig. 4. Hovering flight of a bird  
 $L = W; T = D = 0$

It is the most energy demanding type of areal locomotion in nature. It is also an adaptation for food catching devices, as practiced by kingfishers, humming birds, micro chiropterans (insectivores bats), bumble bee, butterflies etc. In order to maintain constant position, the flier produces rapid wing beats to overcome the lift. In hovering, thrust and drag become equal leading to dynamic equilibrium. The body is held nearly vertical[7]. Many fliers do practice anaerobic hovering momentarily while landing. In contrast, aerobic hovering is a prolonged one.

**1.5. FORWARD HORIZONTAL FLIGHT**

The forward flapping flight of birds is commonly observed in nature. There are two types of flights based on speed of the flight of a flier: (1). Fast forward flight (2). Slow forward flight. A majority of fliers mostly execute fast forward flight. In this flight, flight surface always possesses a component of forward velocity with small amplitude of wingbeat. In the case of slow forward flight, amplitude of wing beat is large and wing tips come to rest at the extremes of the stroke.

In forward flight of a flier, thrust (T) is greater than drag (D), whereas lift (L) balances its body weight (Fig. 5.).



Fig. 5(a). Forward Horizontal Flight of a bird  
L = W; T > D.



Fig. 5(b). Wing positions in Flapping flight  
(From Ruppell 1975, Simkiss 1963)

**II. FLIGHT SURFACE (WING)**

Flight surface (wing) of natural fliers is the most fundamental and aerodynamic requirement to execute flight successfully without which one can not think about their flight attempts. Flight surface as such is not the same in different fliers as far as its shape, structure, structural material and design are considered. Natural fliers have developed successful flight apparatus. There exist some differences in morphology, anatomy, phylogeny and physiology of natural fliers, but each flier has to meet the same aerodynamic requirements of the flight [8-9]. In a bird, feathers constitute a unique flight surface providing heat insulation and streamlined body. The overlapping system, interlocking devices and tapering of feathers resulting in slots improve flight efficiency. Birds possess down feathers and contour feathers.

Down feathers act as heat insulators while the contour feathers are related to flight. They provide large surface area with very little weight. The feathers are made of keratin. The contour feathers are differentiated into primaries and secondaries (Fig. 6.). The primaries generate most of thrust, while the secondaries generate lift.

The bird's wing is able to perform two functions, lifting and propulsion, which in an airplane are separately carried out by fixed wing and the propellers. The inside portion of wing, which remains relatively stationary, produces lift & drag. The outside portion of the wing is more flexible and can be twisted to produce propulsion.

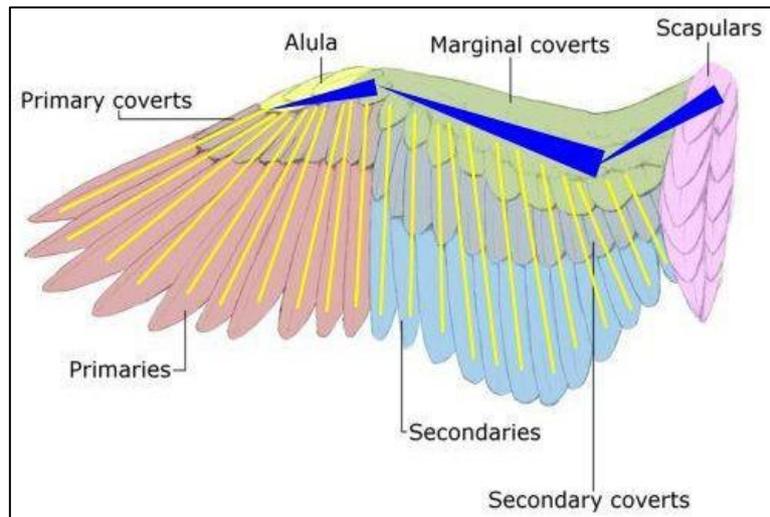


Fig. 6. Structure of Flight surface (wing)

(From dragoart.com)

The aerial density of wing of different natural fliers bears a relation of exponential decrease with increase in wing length [8-9], which meets aerodynamic requirement for flight maneuverability, providing requisite rigidity at joints and flexibility at required places along the wing. High surface density near the wing joint in large birds is due to muscles and joints of different bones. This type of flight surface helps the flier not only to generate required lift and drag, but also in producing propulsion to perform different styles of flight. It is better to compare bird wing with that of airplane. Natural and man-made wings differ significantly in structure; design; mechanism of wing movement and production of forces, but at the end they execute flight.

Flapping flexible winged flight of birds is structurally and functionally different from fixed wing flight in airplanes. Flapping wing generates lift, thrust and induced drag simultaneously. Fixed wing develops only lift and not thrust. In an aircraft, thrust is usually generated by rotating propellers or by engine. Wings are lifting surfaces of birds, which carry mass of the flier in the air. Bird wing consists of bony framework, nerves, muscles, tendons, blood vessels and connective tissues covered by sensory skin with light feathers. The bird wing has complex structure and functions. The thickness, curvature and mass of the wing decrease from base (fulcrum) to the tip. The profile of bird wing differs and hence cross sections are variable. The cross section of a wing is known as airfoil. It has a blunt leading edge and a tapering trailing edge. The upper surface of air foil is always convex and lower surface is always concave [10-11].

## 2.1. TYPES OF BIRD WINGS

Based on the shape, wings are classified into four basic types:

- (1) **Elliptical wings:** These wings are short, broad and elliptical in shape with multiple slots in outer primaries they are of low aspect ratio and high camber. They manoeuvre in forest and woodland. The ideal birds of this type are flycatchers, sparrows, doves, woodpeckers and pheasants. These birds have an adaptation for slow flight in forest.
- (2) **High aspect ratio wings:** These wings have an adaptation for a high speed. These are long slender wings with no wing slots and alula, having flat profile. These include migrating birds such as swifts, humming birds, sandpipers and gulls. This type of wings help in better thrust generation required to fast flight
- (3) **Dynamic soaring wings:** These wings are long, narrow and thin with no slots. Oceanic soaring birds as albatross and frigates possess this type of wings and have an adaptation for high speed, high lift and dynamic soaring.
- (4) **High lift wings:** They have long broad wings, with large wing slots and distinct alula. They develop high lift and low speed. Vultures, hawks, eagles, owls, storks and pelicans belong to this group. Many birds of prey

have slotted high lift wings. The slotted primaries help in slow speed, high lift and less induced drag. Slotted wings help for thermal soaring and low speed. Being descriptive, this kind of classification is rather relative.

### III. FLIGHT MUSCLES

Flight muscles of flying birds are highly specialized muscles with respect to anatomy, biochemistry and physiology in order to meet the requirements of flight. George and Berger [12] described flight muscles. Wings are moved by these muscles. The essential muscles (Fig. 7) are of two types, apart from other accessory flight muscles. The largest superficial muscle is outer *Pectoralis major* which is responsible for down stroke, the power stroke, of the wing. It originates from sternum and clavicle and its insertion is on humerus. The much smaller muscle is inner *Pectoralis minor* (*Supracoracoideus muscle*). It lies below *Pectoralis major*. Its main function is to execute upstroke of the wing.

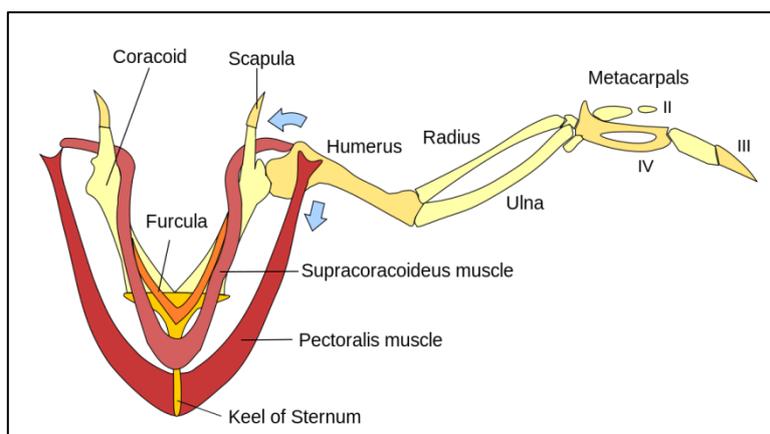


Fig. 7. Major flight muscles – Pectoralis muscle (*Pectoralis major*) and *Supracoracoideus* muscle (*Pectoralis minor*)  
(From nicepng.com)

In good fliers, muscle fibers are red and contain lipid inclusions. The white fibers contain metabolites such as glycogen and less lipid inclusions. The white and red muscle fibers are analogous to fast and slow muscles of mammals respectively, which have adaptation for oxidative and glycolytic metabolism. The red flight muscle fibers help in sustained forward flight and hovering. The *pectoralis minor* and *deltoid* are antagonistic muscles responsible for raising wings. Tensor muscles keep the wings fully stretched. The down stroke of the wing generates lift, thrust and induced drag. The upstroke is a recovery stroke and aerodynamically it is less loaded as compared to down stroke.

Apart from *pectoralis major* and *minor*, there are 48 other muscles within the wing around shoulder joint which are responsible for wing and feather movements [13].

Flight muscles have a large amount of blood vessels and hence have a rich blood supply, which are responsible for supplying oxygen, haemoglobin and other nutrients for high metabolic activity. The red flight muscles have a relatively more rich blood supply and are oxidative as compared to white muscles. They contain more mitochondria and are tuned for less fatigue. The white flight muscles are glycolytic (anaerobic), get fatigued and have a relatively less blood supply and accumulate more lactic acid (more of fatigue toxin). They have high phosphorylase activity, high glycogen, few mitochondria and less lipid. The dark colour of the flight muscle indicates the presence of myoglobin with high capacity for aerobic metabolism in good fliers. Flight muscles contribute about 20% of the body weight. Over 30% of a hummingbird's weight is in its flight muscles. Hummingbirds have large elevator and depressor muscles. Hovering flight is the most power-demanding type of locomotion as compared to horizontal flight. Flight by flapping is also a strenuous activity in nature in contrast to gliding and thermal soaring which are assisted by gravity and hot air rising current. The flight muscles provide the power required for wing motion through metabolism by producing ATP which undergoes hydrolysis and produces energy for flight. Leg muscles in chicken and running birds are red. Flight muscles of pigeons have both red and white fibers [14].

### IV. CONCLUSIONS

Flight surface and flight muscles are essential components of the flight apparatus in birds without which flight cannot be expected. Flying birds are engineered to adapt different flight styles such as hovering, forward flight, bounding, gliding and soaring as the necessity is required. A variety of bird flight is controlled by the design – dorsal contour, slots, shape

and size of the flight surface (wing). Similarly flight muscles are developed to regulate the supply of blood and oxygen. The flight muscle is aerobic nature and very much different to muscle present in animals of terrestrial locomotion.

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